CRITERION 3—

Chapter 4. Large-Scale Patterns of Insect and Disease Activity in the Conterminous United States and Alaska from the National Insect and Disease Detection Survey Database, 2007 and 2008

Kevin M. Potter

Introduction

Analyzing patterns of forest pest infestation is necessary for monitoring the health of forested ecosystems because of the impacts that insects and diseases can have on forest structure, composition, biodiversity, and species distributions (Castello and others 1995). In particular, introduced nonnative insects and diseases can extensively damage the diversity, ecology, and economy of affected areas (Brockerhoff and others 2006, Mack and others 2000). Examining pest occurrences from a landscape-scale perspective is useful, given the regional extent of many infestations and the interaction between landscape characteristics 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 identification of areas at greatest risk and for selection of locations for more intensive analysis.

Methods

Low-altitude aerial survey and ground survey data from 2007 and 2008, compiled nationally by the Forest Health Protection (FHP) Program of the Forest Service, U.S. Department of Agriculture, were used to identify landscape-scale patterns of forest insect and disease activity in the conterminous United States, and to summarize insect and disease activity by ecoregion section in Alaska. Surveys covered 73.3 percent of the forested area in the conterminous United States in 2007 and 68.8 percent in 2008, and 19.2 percent of Alaska's forested area in 2007 and 18.0 percent in 2008 (fig. 4.1).

These surveys identify areas of mortality and defoliation caused by insect and pathogen activity in a given year, 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 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

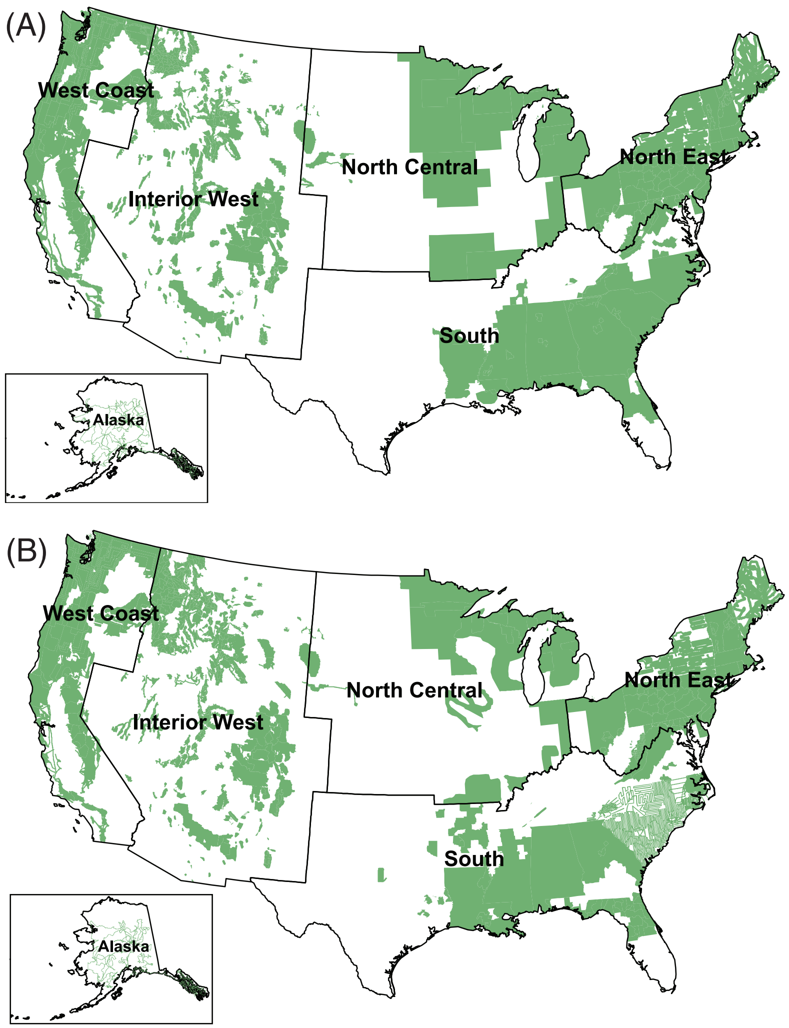

Figure 4.1—The extent of surveys for insect and disease activity conducted in the conterminous United States and Alaska in (A) 2007 and (B) 2008. The lines delineate Forest Health Monitoring regions. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection.)

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 data from 2007 and 2008 were analyzed separately because both the location and extent of the areas surveyed and the classification of forest tree mortality and defoliation agents varied across years.

The 2007 and 2008 mortality and defoliation polygons were used to identify the mortality and 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) imagery by the U.S. 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 for the identification of geographic hot spots of surveyed forest exposed to defoliation-causing and mortality-causing agents.

This Getis-Ord hot spot analysis (Getis and Ord 1992) was employed in ArcMap 9.2 (ESRI 2006). The Environmental Monitoring and Assessment Program (EMAP) 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- or defoliation-causing agents was then calculated. The percent of forest exposed to the identified mortality or defoliation agents was 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 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.

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 (fig. 4.1) 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

FHP survey data identified 60 different mortality-causing agents and complexes on 2 466 924 ha of forest across the conterminous United States in 2007 (an area slightly larger than New Hampshire), and 61 agents and complexes on 3 888 868 ha in 2008 (an area similar in size to that of Maryland and Delaware combined). Mountain pine beetle (*Dendroctonus ponderosae*) was the most widespread mortality agent in both years (1 564 092 ha in 2007 and 2 387 062 ha in 2008) (table 4.1). Other agents affecting more than 100 000 ha were subalpine fir (*Abies lasiocarpa*) mortality, fir engraver (*Scolytus ventralis*), and Douglas-fir beetle (*Dendroctonus pseudotsugae*) in 2007 and bronze birch borer (*Agrilus anxius*), aspen defoliation, fir engraver, and subalpine fir mortality in 2008.

Additionally, the survey identified 62 defoliation agents and complexes affecting 2 516 812 ha of forest across the conterminous United States in 2007, an area slightly larger than Vermont, and 61 defoliation agents and complexes affecting 1 908 566 ha in 2008, an area slightly larger than Connecticut and Rhode Island combined. The most widespread defoliators in both years were western spruce budworm (*Choristoneura occidentalis*) and gypsy

Table 4.1—Mortality agents and complexes affecting more than 5000 ha of forested area in the conterminous 48 States during 2007 and 2008

2007 Mortality agents	Area	2008 Mortality agents	Area
	ha		*ha*
Mountain pine beetle	1 564 092	Mountain pine beetle	2 387 062
Subalpine fir mortality	211 470	Bronze birch borer	381 332
Fir engraver	151 979	Aspen defoliation	228 783
Douglas-fir beetle	105 498	Fir engraver	179 237
Western balsam bark beetle	75 673	Subalpine fir mortality	176 395
Spruce beetle	74 621	Douglas-fir beetle	74 513
Five-needle pine decline	57 127	Beech bark disease	69 927
Bark beetles	43 623	Five-needle pine decline	68 367
Oak decline	26 367	Spruce beetle	51 558
Beech bark disease	24 822	Western balsam bark beetle	50 226
Balsam woolly adelgid	17 436	Western pine beetle	36 074
Ips engraver beetles	13 815	Gypsy moth	34 372
Western pine beetle	10 484	Bark beetles	24 386
Hemlock woolly adelgid	8 872	Forest tent caterpillar	20 648
Decline	8 008	Ips engraver beetles	17 112
Jack pine budworm	7 903	Sudden oak death	13 686
Pinon ips	7 800	Decline	11 989
Armillaria root disease	6 536	Pine engraver	9 734
Forest tent caterpillar	5 501	White pine blister rust	8 488
Eastern larch beetle	5 234	Winter moth	8 056
Port-Orford-Cedar root disease	5 016	Eastern larch beetle	7 625
		Balsam woolly adelgid	6 066

moth (*Lymantria dispar*), followed by aspen defoliation in 2007 and forest tent caterpillar (*Malacosoma disstria*) in 2008 (table 4.2).

Hot spot analyses using both the 2007 and 2008 survey data detected several hot spots of insect and disease mortality associated with mountain pine beetle in the Interior West Region (fig. 4.2) [this is the region defined by the Forest Health Monitoring (FHM) Program of the Forest Service]. In both years, a large and highly clustered hot spot was located in the Northern Parks and Ranges of northern Colorado and southern Wyoming (M331I). In 2008, another large and highly clustered hot spot occurred in three ecoregion sections of western Montana, the Northern Rockies and Bitterroot Valley (M332B), the Belt Mountains (M332D), and the Beaverhead Mountains (M332E). A third, but smaller, hot spot in the Uinta Mountains (M331E) was also associated with mountain pine beetle in 2007 and 2008. A separate hot spot in the Wind River Mountains (M331J), the Overthrust Mountains (M331D), and the Yellowstone Highlands (M331A) was associated with several mortality agents in addition to mountain pine beetle, including five-needle pine decline, spruce beetle (*Dendroctonus rufipennis*), Douglas-fir beetle, and subalpine fir mortality.

The most highly clustered hot spot in the Pacific Coast region occurred both years in the Northern Cascades (M242D), associated most strongly with mortality caused by mountain pine beetle, along with mortality from fir engraver, spruce beetle, Douglas-fir beetle and western

Table 4.2—Defoliation agents and complexes affecting more than 5000 ha of forested area in the conterminous 48 States during 2007 and 2008

2007 Defoliation agents	Area	2008 Defoliation agents	Area
	ha		*ha*
Western spruce budworm	879 469	Western spruce budworm	784 329
Gypsy moth	569 831	Gypsy moth	619 002
Aspen defoliation	220 658	Forest tent caterpillar	152 971
Forest tent caterpillar	214 927	Defoliators	92 078
Defoliators	148 462	Aspen defoliation	59 781
Jack pine budworm	90 807	Larch casebearer	37 953
Needlecast	85 370	Decline	36 328
Decline	58 905	Jack pine budworm	29 915
Spruce budworm	53 356	Spruce budworm	19 129
Fall hardwood defoliator complex	39 302	Needlecast	14 457
Larch casebearer	35 071	Cherry scallop shell moth	10 091
Winter moth	15 302	Leaf spots	6 242
Pinyon needle scale	13 341	Pinyon needle scale	5 495
Fall cankerworm	12 752		
Septoria leaf spot	10 228		
Orange-striped oakworm	8 919		
Tent caterpillar	8 285		
Eastern tent caterpillar	7 537		
Douglas-fir tussock moth	6 353		
Lodgepole needleminer	6 223		
Maple trumpet skeletonizer	5 309		

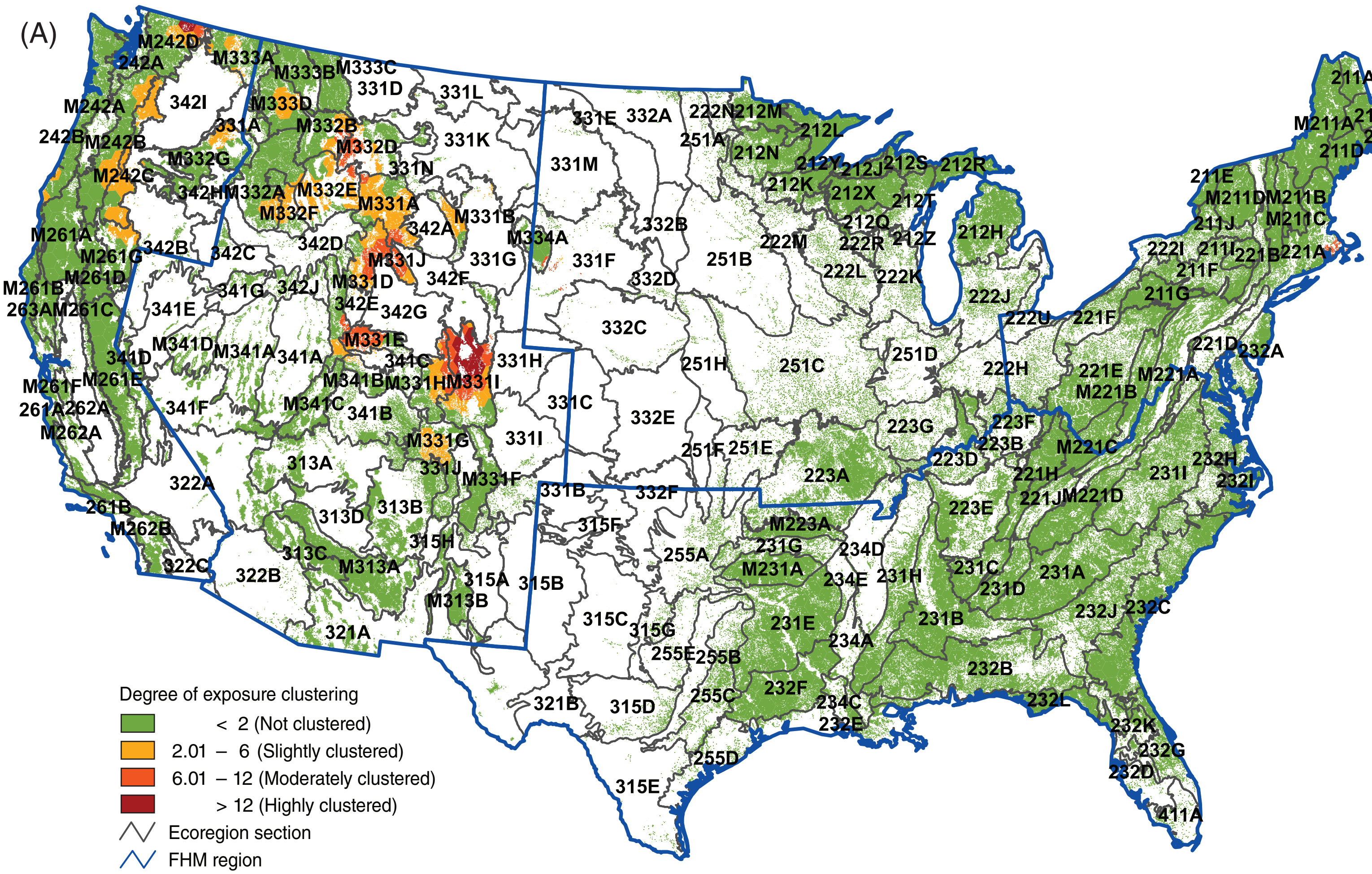

Figure 4.2—Hot spots of exposure to mortality-causing insects and diseases in (A) 2007 and (B) 2008. Values are Getis-Ord G_i scores, with values greater than 2 representing strong and significant clustering of high percentages of forest area exposed to mortality agents. (No areas of significant clustering of low percentages of exposure, less than -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.)* *(continued on next page)*

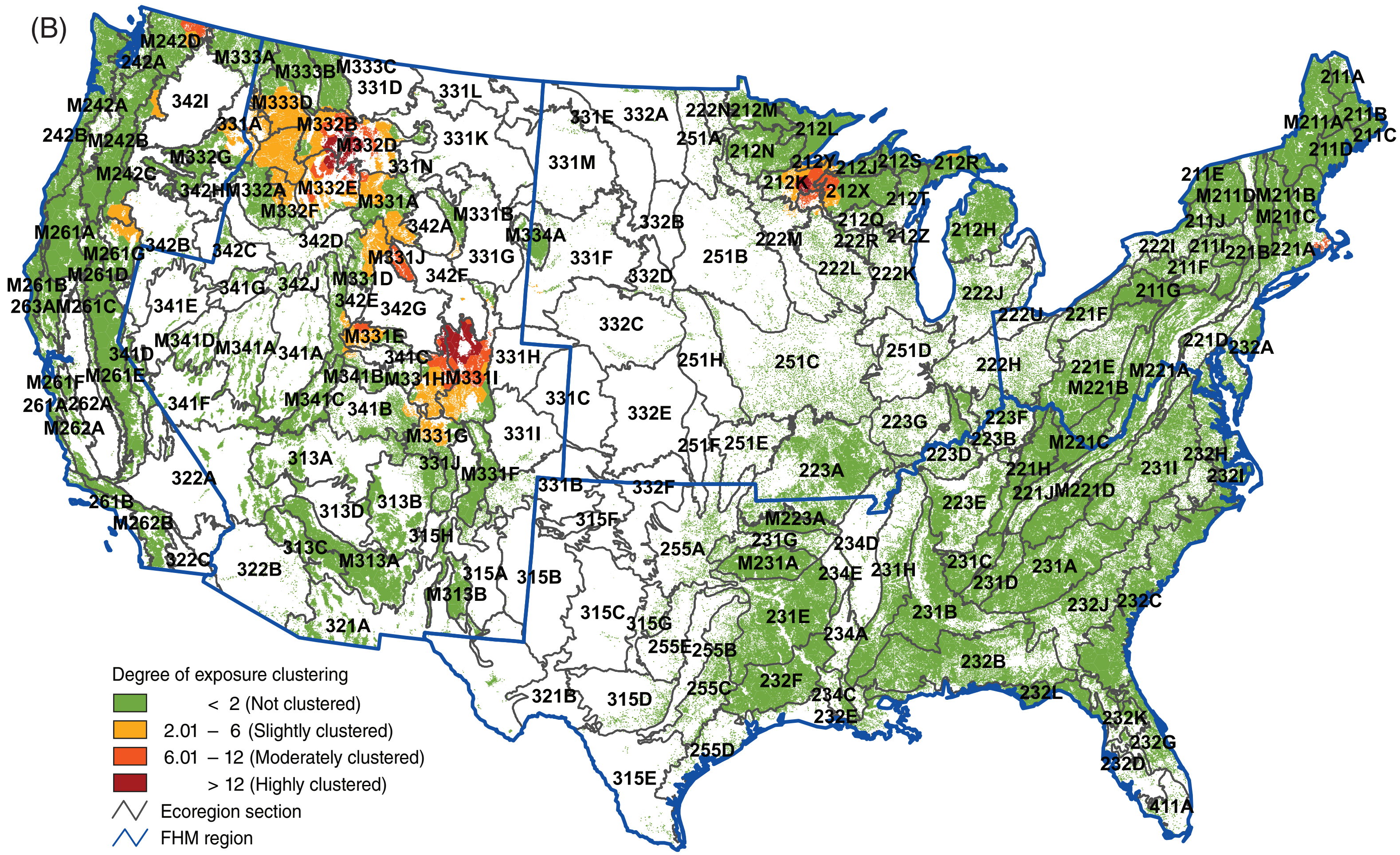

Figure 4.2 (continued)—Hot spots of exposure to mortality-causing insects and diseases in (B) 2008. Values are Getis-Ord G_i scores, with values greater than 2 representing strong and significant clustering of high percentages of forest area exposed to mortality agents. (No areas of significant clustering of low percentages of exposure, less than -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.)*

balsam bark beetle (*Dryocoetes confusus*). In 2007, a set of hot spots along the Eastern Cascades (M242C) and the surrounding ecoregions were caused by mortality associated with a suite of insects that included mountain pine beetle, western pine beetle (*Dendroctonus brevicomis*), fir engraver, western balsam bark beetle, Douglas-fir beetle, and the silver fir beetle (*Pseudohylesinus sericeus*) (fig. 4.2A). Directly to the east, a hot spot of mortality developed in the Blue Mountains (M332G), caused by Douglas-fir beetle, fir engraver, mountain pine beetle, western pine beetle, and balsam woolly adelgid (*Adelges piceae*). Some of the same hot spots remained the following year, although they were generally smaller (fig. 4.2B).

The North Central region experienced a single mortality hot spot in 2007 (fig. 4.2A), associated with mountain pine beetle, in the Black Hills (M334A). In 2008, this region contained a highly clustered hot spot in the Western Superior Uplands (212K), the location of an extensive bronze birch borer outbreak (fig. 4.2B).

In each year, a single hot spot occurred in the North East region, in the Lower New England ecoregion section (221A), where mortality was associated primarily with winter moth (*Operophtera brumata*), gypsy moth (*Lymantria dispar*), and Diplodia canker (*Sphaeropsis sapinea*) both years, in addition to fall cankerworm (*Alsophila pometaria*) and red pine scale (*Matsucoccus resinosae*) in 2007 (fig. 4.2A). No hot spots of mortality exposure developed in the South FHM region either year.

The most extensive hot spot of defoliation activity in both 2007 and 2008 occurred in the North East region (fig. 4.3). In the first year, this was centered in the Northern Glaciated Allegheny Plateau (211F) and the Catskill Mountains (211I) and was caused by forest tent caterpillar and gypsy moth (fig. 4.3A). In the second year, it was centered in the Northern Ridge and Valley (M221A) and was primarily associated with gypsy moth, with a smaller component of forest tent caterpillar (fig. 4.3B). Also in 2008, a smaller defoliation hot spot caused by gypsy moth occurred on the boundary between the North East and South FHM regions, in the Northern Ridge and Valley (M221A), Allegheny Mountains (M221B), and Blue Ridge Mountains (M221D) ecoregion sections.

In 2007, the North Central region experienced a single hot spot in the Black Hills (M334A) and the Western Great Plains (331F) resulting from general defoliators (fig. 4.3A). A year later, a fairly significantly clustered hot spot occurred in the Southern Superior Uplands (212J) and the Southwest Lake Superior Clay Plain (212Y) as a result of defoliation caused by gypsy moth and spruce budworm.

The Interior West contained several hot spots of defoliation exposure in both years (fig. 4.3). Most were caused by western spruce budworm, including the three hot spots centered in the Bitterroot Mountains (M333D), the Belt Mountains (M332D)/Beaverhead Mountains (M332E), and the South-Central Highlands (M331G)/Southern Parks and Rocky Mountain Range (M331F). Additionally, the Grand Canyon ecoregion section (313A) was the location of a hot spot caused by aspen defoliation in both 2007 and 2008, and the North-Central Highlands and Rocky Mountains (M331H)/ Northern Parks and Ranges (M331I) were the location of an aspen defoliation hot spot in 2007.

Finally, two defoliation hot spots in the Pacific Coast region were associated with western spruce budworm. One, centered in the Northern Cascades (M242D) occurred both years, while the other, centered in the Blue Mountains (M332G), was caused by both western spruce budworm and larch casebearer (*Coleophora laricella*) in 2007.

The low density of survey data from Alaska in 2007 and 2008 precluded the use of hot spot analyses for that State. Instead, mortality and defoliation data were summarized by ecoregion section, calculated as the percent of the forest within the surveyed areas affected by agents of mortality or defoliation. In 2007, six mortality-causing agents and complexes were reported for Alaska, affecting 82 428 ha. In 2008, five mortality-causing agents and complexes were reported across 56 007 ha.

In both years, spruce beetle was the most widespread mortality agent, affecting 61 128 ha across many of the forested areas of Alaska in 2007 and 28 126 in 2008. Northern spruce engraver beetle (*Ips perturbatus*) was the second leading mortality agent both years, detected on 13 273 ha in 2007 and 24 130 ha in 2008, mostly in east-central Alaska. Yellow-cedar (*Chamaecyparis nootkatensis*) decline was also a major mortality agent in 2007 (10 605 ha), in the panhandle of the State, but less so in 2008 (3685 ha). The Northern Chugach Range (M135A) had the highest percent of exposure to mortality-causing agents in 2007 in surveyed forest areas (3.49 percent), followed by the nearby Wrangell Mountains (M135B) with 3.24 percent (fig. 4.4A). The Cook Inlet Lowlands (213B) and the Yukon Flats (139A) had slightly more than 1 percent of their surveyed forested area exposed to agents of mortality in 2007. The following year, the Bristol Bay Lowlands (M213A) and the Cook Inlet Lowlands had the greatest exposure to agents of mortality (2.32 percent and 2.21 percent, respectively) (fig. 4.4B).

Alaska forests, meanwhile, were exposed to 10 defoliation agents recorded on 385 369 ha in 2007. In 2008, they were exposed to 12 defoliation agents and complexes on 129 458 ha.

Aspen leafminer had by far the largest extent in both years, observed on 305 698 ha across central Alaska in 2007 and 85 078 ha in 2008. As a result of aspen leafminer (*Phyllocnistis populiella*), four ecoregion sections had relatively high percentages of defoliation exposure in 2007 (fig. 4.5A): the Dawson Range (M139C), with 9.84 percent surveyed forest exposed; the Yukon Bottomlands (131A), with 9.19 percent; the Copper River Basin (135A), with 6.63 percent; and the Kuskokwim Colluvial Plain (131B), with 6.09 percent. The degree of defoliation was much reduced in 2008, with many of the same sections experiencing < 5 percent defoliation within the surveyed areas (fig. 4.5B).

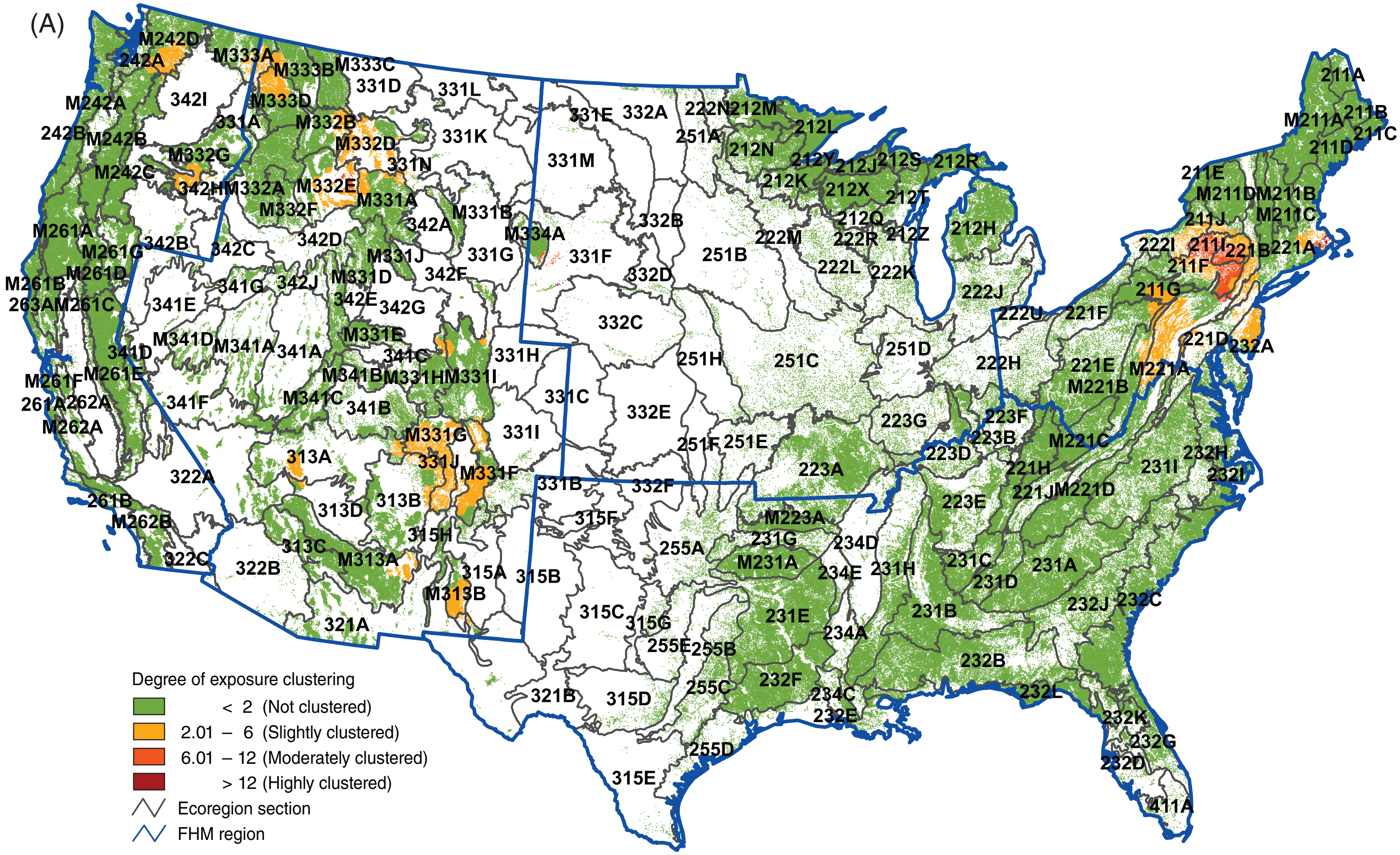

Figure 4.3—Hot spots of exposure to defoliation-causing insects and diseases in (A) 2007 and (B) 2008. Values are Getis-Ord G_i scores, with values greater than 2 representing strong and significant clustering of high percentages of forest area exposed to defoliation agents. (No areas of significant clustering of low percentages of exposure, less than -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.) (continued on next page)*

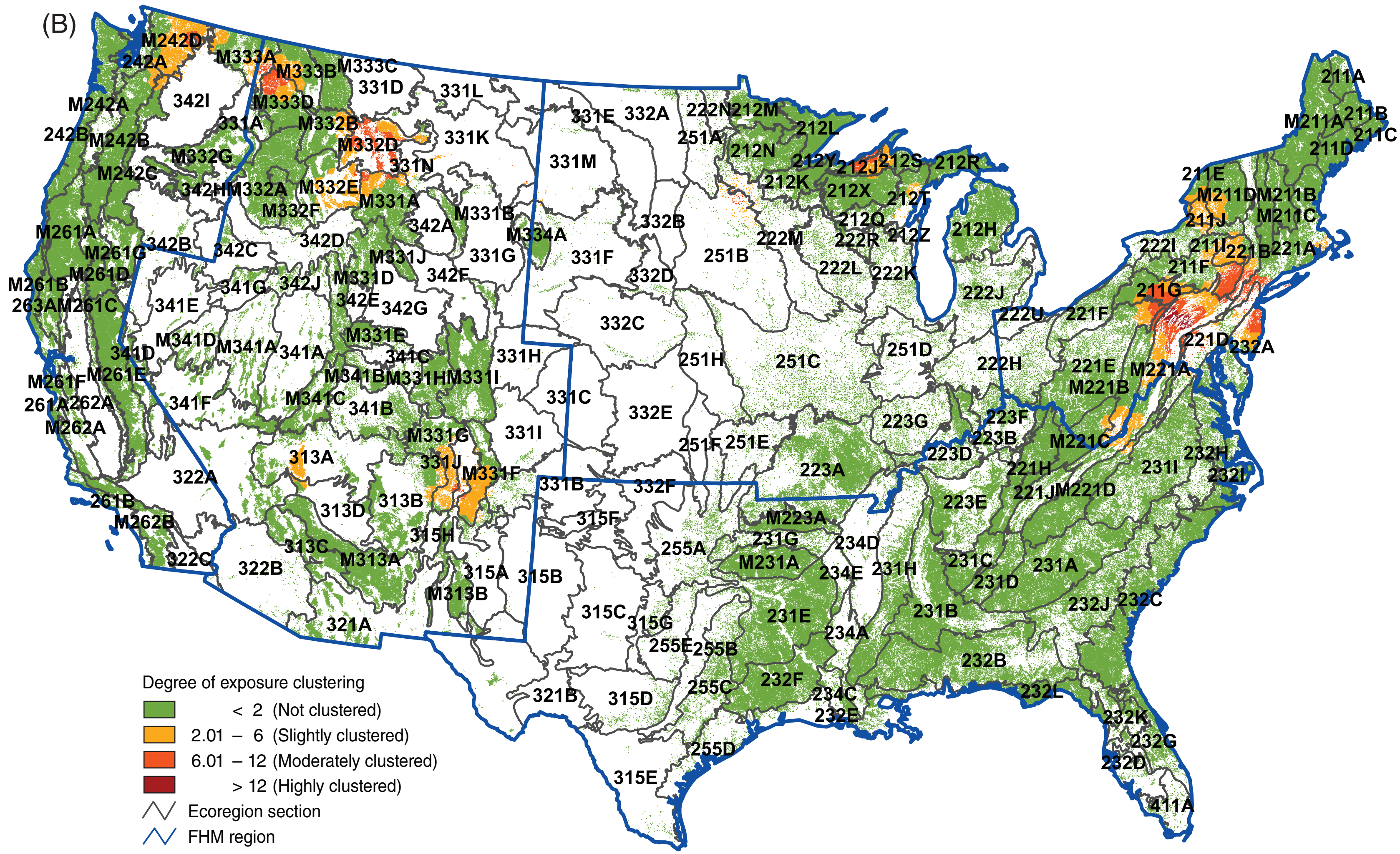

Figure 4.3 (continued)—Hot spots of exposure to defoliation-causing insects and diseases in (B) 2008. Values are Getis-Ord G_i scores, with values greater than 2 representing strong and significant clustering of high percentages of forest area exposed to defoliation agents. (No areas of significant clustering of low percentages of exposure, less than -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.)*

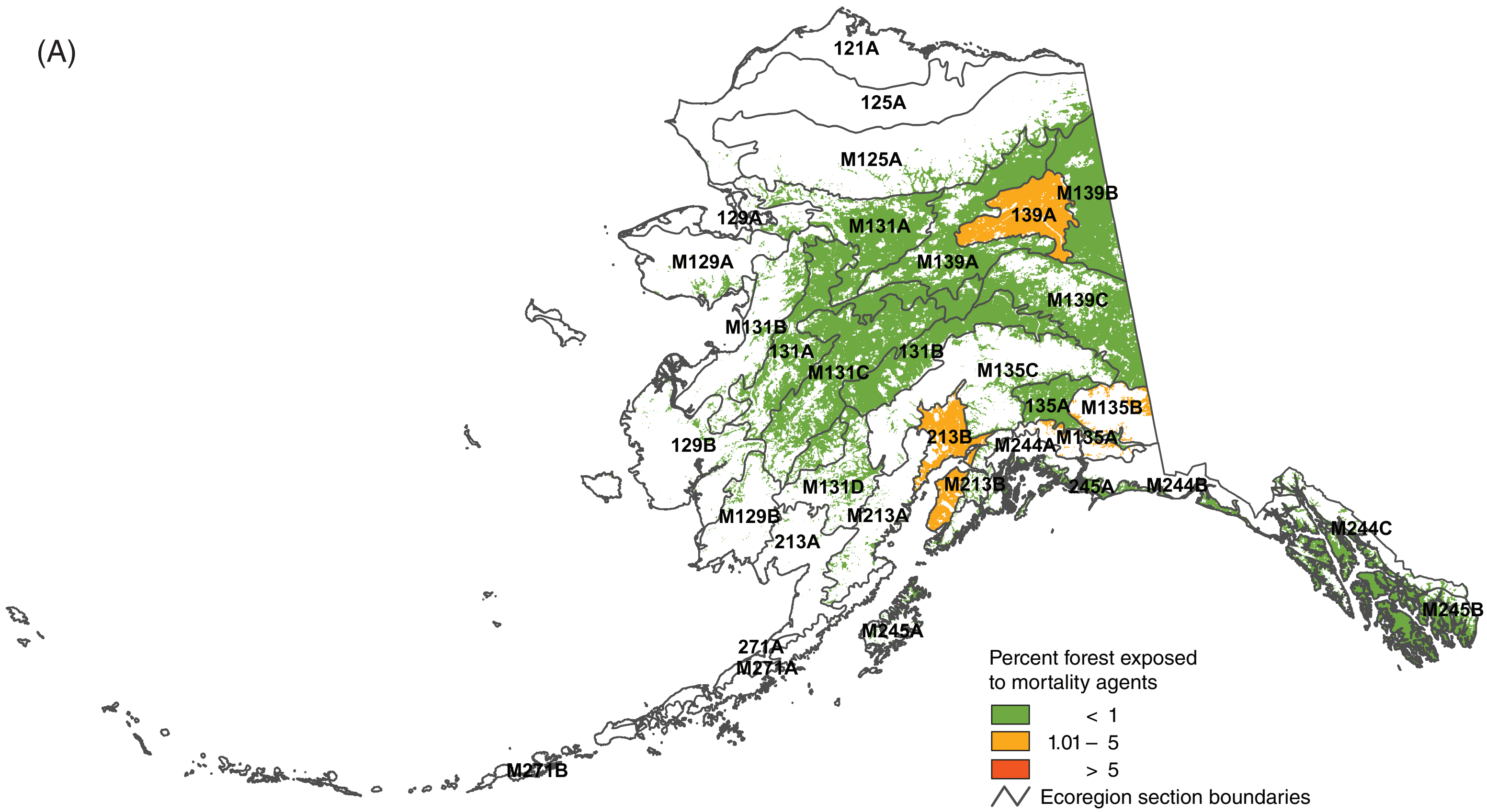

Figure 4.4—Percent of surveyed forest in Alaska ecoregion sections exposed to mortality-causing insects and diseases in (A) 2007 and (B) 2008. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection.) *(continued on next page)*

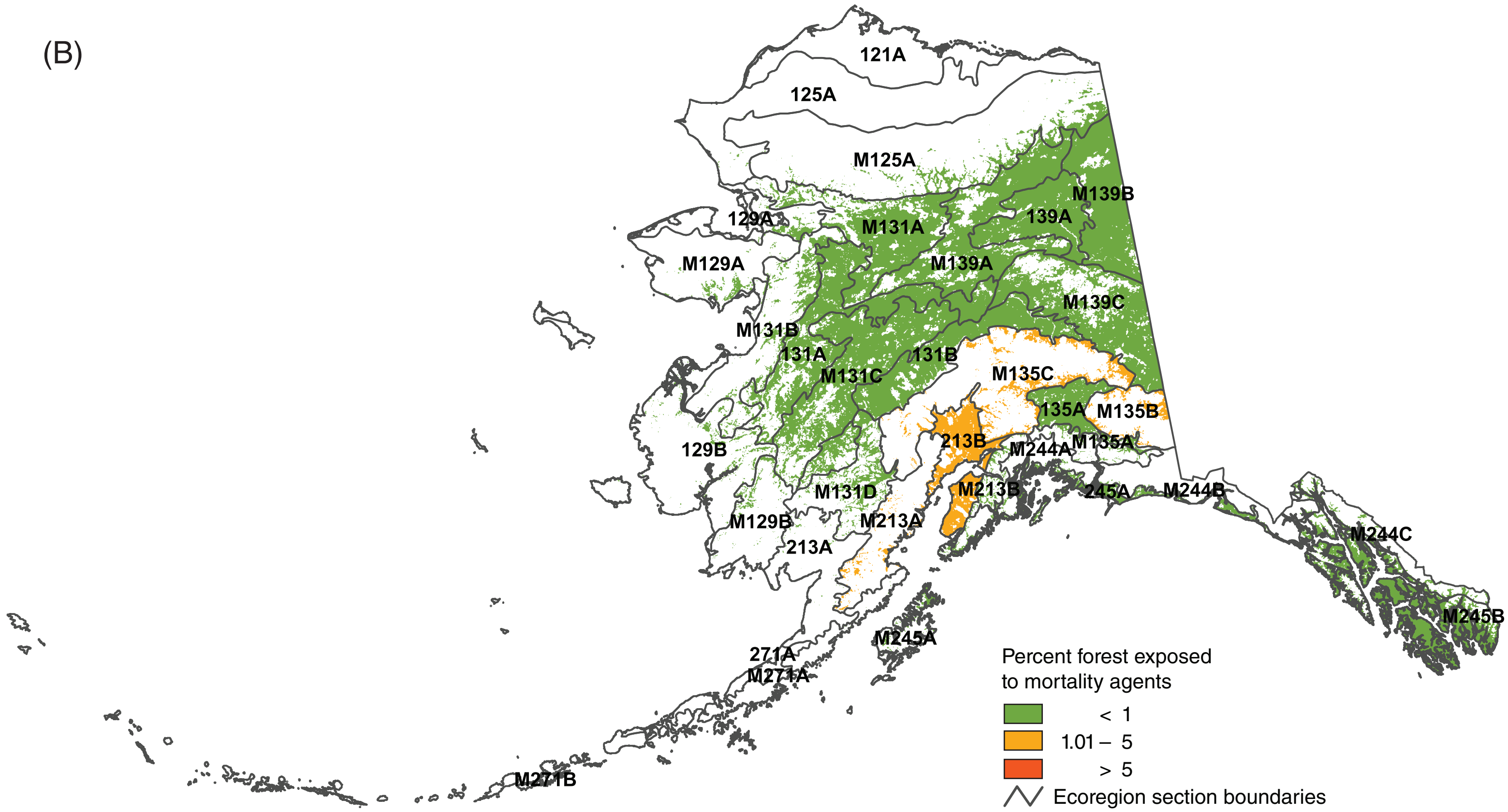

Figure 4.4 (continued)—Percent of surveyed forest in Alaska ecoregion sections exposed to mortality-causing insects and diseases in (B) 2008. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection.)

(A)

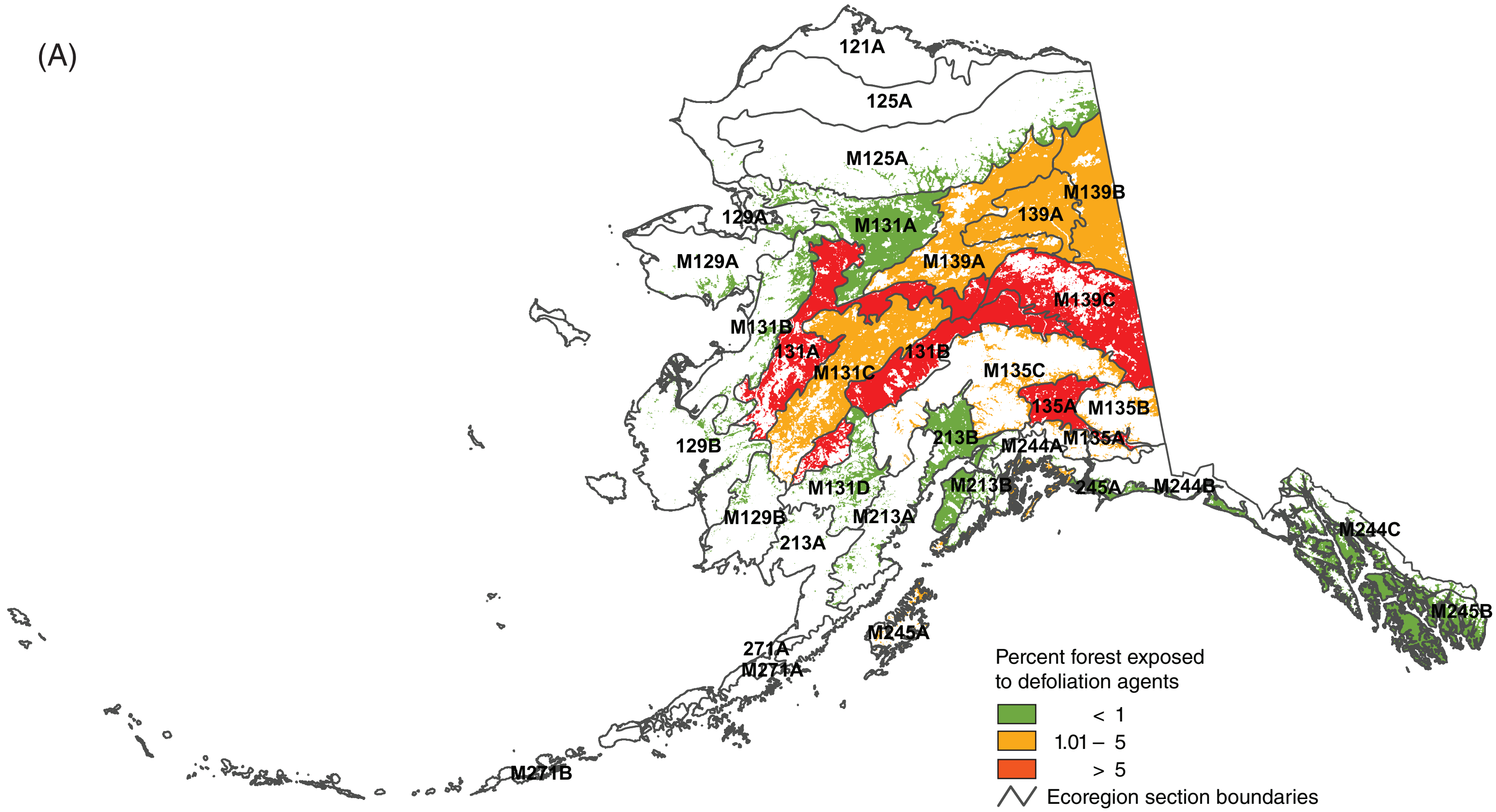

Figure 4.5—Percent of surveyed forest in Alaska ecoregion sections exposed to defoliation-causing insects and diseases in (A) 2007 and (B) 2008. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection.) *(continued on next page)*

(B)

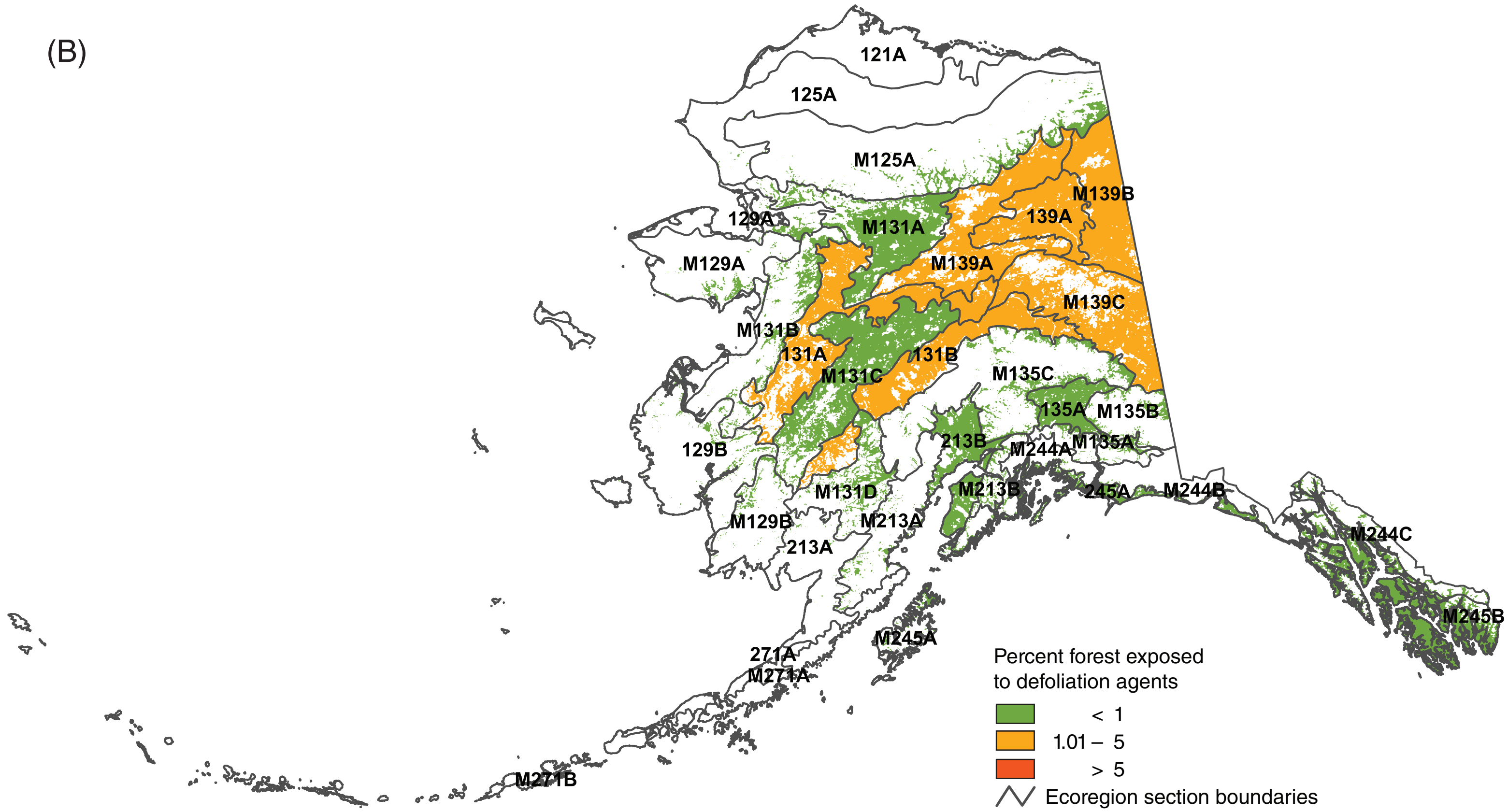

Figure 4.5 (continued)—Percent of surveyed forest in Alaska ecoregion sections exposed to defoliation-causing insects and diseases in (B) 2008. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection.)

Other important defoliators in 2007 were willow leaf blotchminer (*Micrurapteryx salicifoliella*) (37 501 ha), large aspen tortrix (*Choristoneura conflictana*) (16 347 ha), and spruce budworm (15 151 ha). Other than aspen leafminer, the only important defoliator in 2008 was willow leaf blotchminer (31 086 ha).

Continued monitoring of insect and disease outbreaks across the United States will be necessary for determining appropriate follow-up investigation and management activities. As these analyses demonstrate, large-scale assessments of mortality and defoliation exposure, including geographical hot spot detection, offer a potentially useful approach for prioritizing geographic areas where the concentration of monitoring and management activities might be most effective.

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