

## INTRODUCTION

**D**iseases 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 clusters 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 (FHM 2005) consists of information from low-altitude aerial survey and ground survey efforts. This database 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 2012, 2013; Potter and Koch 2012; Potter and Paschke 2013, 2014). In 2012, IDS surveys

# CHAPTER 2.

## Large-Scale Patterns of Insect and Disease Activity in the Conterminous United States and Alaska from the National Insect and Disease Survey, 2012

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covered approximately 142.61 million ha of the forested area in the conterminous United States (approximately 56 percent of the total), and 6.91 million ha of Alaska's forested area (approximately 13.4 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 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 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 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 2012 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 and complexes for Alaska. Because of the insect and disease aerial sketchmapping process, all quantities are "footprint," or approximate, areas for each agent or complex, to delineate 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<sup>®</sup> 9.2 (ESRI 2006) 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 3,382 hexagonal cells, each approximately 2500 km<sup>2</sup> in area, generated in a lattice across the conterminous United States using intensification of the Environmental Monitoring and Assessment Program (EMAP) North American hexagon coordinates (White and others 1992). The 2500-km<sup>2</sup> hexagon size allows for analysis at a medium-scale resolution of approximately

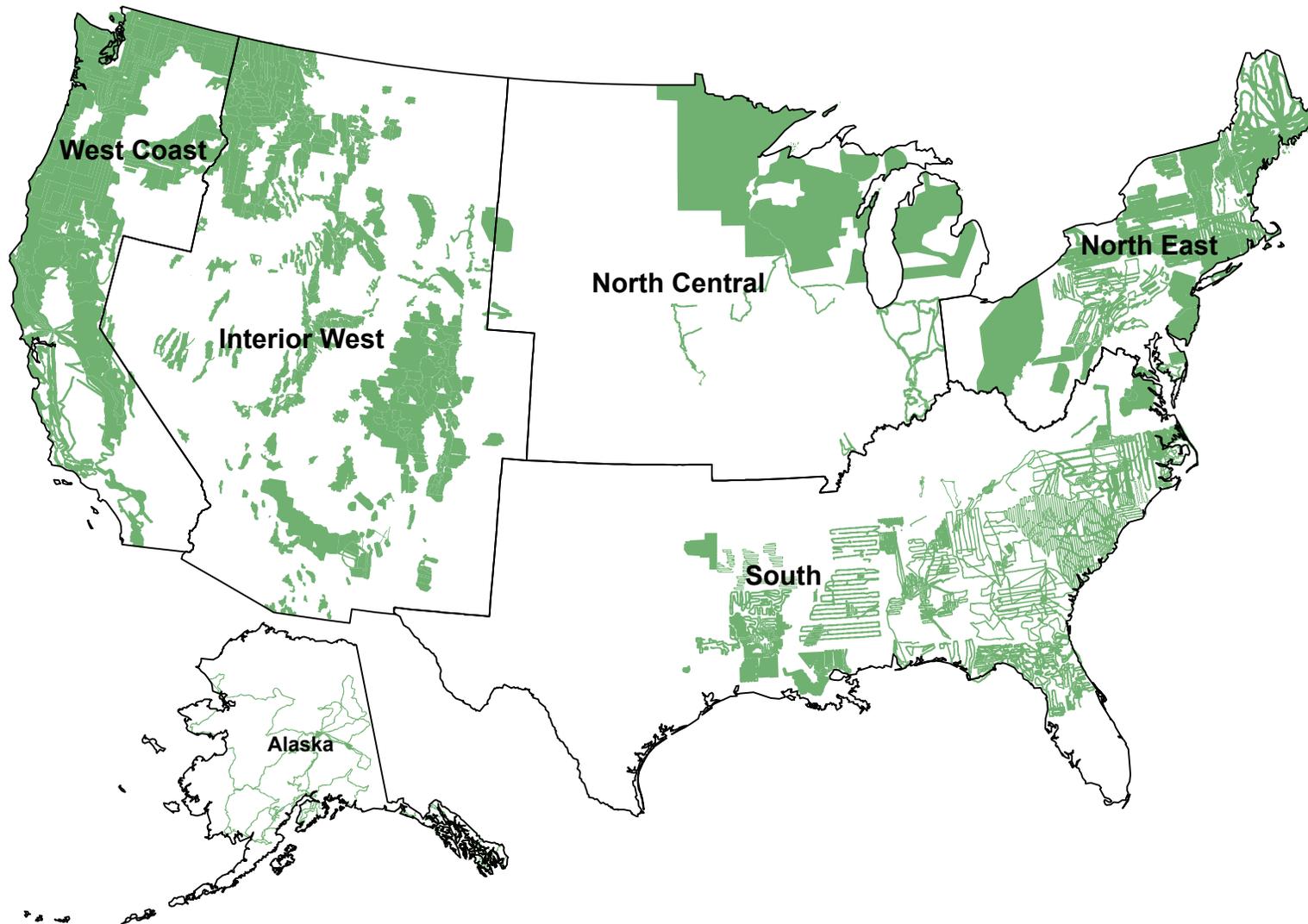


Figure 2.1—The extent of surveys for insect and disease activity conducted in the conterminous United States and Alaska in 2012. The black lines delineate Forest Health Monitoring regions. Note: Alaska is not shown to scale with map of the conterminous United States. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

the same area as a typical county. The variable used in the hot spot analysis was the percent 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 with a forest cover map (1-km<sup>2</sup> 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 IDS-surveyed areas. Finally, the percent of surveyed forest exposed to mortality or defoliation agents and complexes 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 percent of surveyed 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).

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 United States. It is then standardized as a z-score with a mean of 0 and a standard deviation of 1, with values  $> 1.96$  representing significant ( $p < 0.025$ ) local clustering of high values, and values  $< -1.96$  representing significant clustering of low values ( $p < 0.025$ ), since 95 percent of the observations under a normal distribution should be within approximately 2 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 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 6 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 2006).

The low density of survey data from Alaska in 2012 (fig. 2.1) precluded the use of Getis-Ord 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. (As with the mortality and defoliation data, the flown-area polygons were first dissolved to create an overall footprint.) For reference purposes, ecoregion sections (Cleland and others 2007) were also displayed on the geographic hot spot maps of the conterminous 48 United States.

## RESULTS AND DISCUSSION

### Conterminous United States

The IDS survey data identified 82 different mortality-causing agents and complexes on approximately 1.67 million ha across the conterminous United States in 2012, an area slightly smaller than that of Connecticut and Delaware combined. (Three of these mortality-cause categories were “rollups” of multiple agents.) By way of comparison, forests are estimated to cover approximately 304 million ha of the conterminous United States (Smith and others 2009).

Mountain pine beetle (*Dendroctonus ponderosae*) was the most widespread mortality agent, detected on 969 037 ha (table 2.1). This area has declined considerably in recent years, from 3.47 million ha in 2009 (Potter 2013) to 2.77 million ha in 2010 (Potter and Paschke 2013) and to 1.54 million ha in 2011 (Potter and Paschke 2014). Other mortality agents and complexes detected on more than 100 000 ha were spruce beetle (*Dendroctonus rufipennis*), five-needle pine decline, subalpine fir (*Abies lasiocarpa*) mortality complex, and western pine beetle (*Dendroctonus brevicomis*). Mortality from the western bark beetle group, encompassing 23 different agents and complexes in the IDS data (table 2.2), was detected on a total of more than 1.48 million ha in 2012. This represents a large majority of the total area on which mortality was recorded across the conterminous United States.

**Table 2.1—Mortality agents and complexes affecting more than 5000 ha in the conterminous United States during 2012**

Agents/complexes causing mortality, 2012	Area ha
Mountain pine beetle <sup>a</sup>	969 037
Spruce beetle	172 697
Five-needle pine decline <sup>a</sup>	130 050
Subalpine fir mortality complex <sup>a</sup>	114 834
Western pine beetle	101 999
Fir engraver	84 656
Douglas-fir beetle	65 540
<i>Ips</i> engraver beetles	39 397
Spruce budworm	32 131
Emerald ash borer	23 721
Sudden oak death	21 994
Balsam woolly adelgid	13 686
Decline	12 520
Forest tent caterpillar	11 915
Bark beetles	10 156
Pinyon ips	9 253
Eastern larch beetle	7 783
Hemlock decline	6 836
Unknown	6 233
Western balsam bark beetle <sup>b</sup>	5 936
Jeffrey pine beetle	5 089
Other mortality agents (61)	32 037
<b>Total, all mortality agents</b>	<b>1 670 707</b>

Note: All values are “footprint” areas for each agent or complex. The sum of the individual agents is not equal to the total for all agents due to the reporting of multiple agents per polygon.

<sup>a</sup> Rollup of multiple agent codes.

<sup>b</sup> Also included in the subalpine fir mortality rollup.

**Table 2.2—Beetle taxa included in the “western bark beetle” group**

Western bark beetle mortality agents	Genus and species
Cedar and cypress bark beetles	<i>Phloeosinus</i> spp.
Douglas-fir beetle	<i>Dendroctonus pseudotsugae</i>
Douglas-fir engraver	<i>Scolytus unispinosus</i>
Fir engraver	<i>Scolytus ventralis</i>
Five-needle pine decline	NA
Flatheaded borer	<i>Buprestidae</i>
<i>Ips</i> engraver beetles	<i>Ips</i> spp.
Jeffrey pine beetle	<i>Dendroctonus jeffreyi</i>
Mountain pine beetle	<i>Dendroctonus ponderosae</i>
Pine engraver	<i>Ips pini</i>
Pinyon ips	<i>Ips confusus</i>
Pinyon pine mortality	NA
Red turpentine beetle	<i>Dendroctonus valens</i>
Roundheaded pine beetle	<i>Dendroctonus adjunctus</i>
Silver fir beetle	<i>Pseudohylesinus sericeus</i>
Southern pine beetle	<i>Dendroctonus frontalis</i>
Spruce beetle	<i>Dendroctonus rufipennis</i>
Subalpine fir ( <i>Abies lasiocarpa</i> ) mortality complex	NA
True fir ( <i>Abies</i> ) pest complex	NA
Western balsam bark beetle	<i>Dryocoetes confusus</i>
Western cedar bark beetle	<i>Phloeosinus punctatus</i>
Western pine beetle	<i>Dendroctonus brevicomis</i>
Bark beetles (non-specific)	NA

NA= not applicable.

Additionally, the survey identified 81 defoliation agents and complexes affecting approximately 3.64 million ha across the conterminous United States in 2012, an area slightly larger than the combined land area of New Jersey and Hawaii. (Two of these defoliation-cause categories were “rollups” of multiple agents.) The most widespread defoliators were western and eastern spruce budworms (*Choristoneura occidentalis* and *C. fumiferana*), affecting 1.49 million ha (table 2.3). Fall cankerworm (*Alsophila pometaria*), tent caterpillars (*Malacosoma* spp.), pinyon needle scale (*Matsucoccus acalyptus*), and larch needle cast (*Meria laricis*) each 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 2012, approximately 1.11 million ha (table 2.4). A large majority of mortality within that area was associated with mountain pine beetle, although spruce beetle, subalpine fir mortality complex, Douglas-fir beetle (*Dendroctonus pseudotsugae*) and Ips engraver beetles were also important mortality agents and complexes.

The Getis-Ord analysis detected four major hot spots of intense mortality exposure in the Interior West region (fig. 2.2). The most intense was centered on the border between eastern Idaho and western Montana, in ecoregions

**Table 2.3—Defoliation agents and complexes affecting more than 5000 ha in the conterminous United States in 2012**

Agents/complexes causing defoliation, 2012	Area ha
Spruce budworm (eastern and western) <sup>a</sup>	1 494 127
Fall cankerworm	1 086 930
Tent caterpillars <sup>a</sup>	382 788
Pinyon needle scale	200 215
Larch needle cast	106 115
Aspen defoliation	55 534
Pine butterfly	36 864
Pinyon sawfly	33 736
Cherry scallop shell moth	26 842
Anthracnose	22 666
Jack pine budworm	21 866
Pear thrips	21 302
Unknown defoliator	20 294
Douglas-fir tussock moth	19 269
Unknown	17 571
Baldcypress leafroller	16 439
Pine engraver	16 198
Gypsy moth	15 861
Leafroller/seed moth	12 002
Needlecast	11 656
Fall webworm	11 073
Marssonina blight	9 941
Larch casebearer	8 763
Winter moth	7 937
Balsam fir sawfly	7 407
Other defoliation agents (56)	50 012
<b>Total, all defoliation agents</b>	<b>3 638 748</b>

Note: All values are “footprint” areas for each agent or complex. The sum of the individual agents is not equal to the total for all agents due to the reporting of multiple agents per polygon.

<sup>a</sup> Rollup of multiple agent codes.

**Table 2.4—The top five mortality agents or complexes for each Forest Health Monitoring region in 2012**

Mortality agents and complexes, 2012	Area <i>ha</i>	Mortality agents and complexes, 2012	Area <i>ha</i>
<b>Interior West</b>		<b>South</b>	
Mountain pine beetle <sup>a</sup>	727 683	Bark beetles	7 865
Spruce beetle	147 645	Unknown	1 208
Subalpine fir mortality complex <sup>a</sup>	112 021	Southern pine beetle	846
Douglas-fir beetle	47 104	<i>Ips</i> engraver beetles	23
<i>Ips</i> engraver beetles	39 177	Black turpentine beetles	0
Other mortality agents and complexes (23)	93 515	<b>Total, all mortality agents and complexes</b>	<b>9 942</b>
<b>Total, all mortality agents and complexes</b>	<b>1 110 409</b>	<b>West Coast</b>	
<b>North Central</b>		Mountain pine beetle <sup>a</sup>	229 259
Spruce budworm	32 278	Western pine beetle	75 926
Emerald ash borer	23 404	Fir engraver	72 033
Eastern larch beetle	17 428	Spruce beetle	25 019
Mountain pine beetle <sup>a</sup>	12 095	Sudden oak death	21 994
Decline	3 405	Other biotic mortality agents and complexes (25)	52 980
Other mortality agents and complexes (20)	9 011	<b>Total, all mortality agents and complexes</b>	<b>409 751</b>
<b>Total, all mortality agents and complexes</b>	<b>97 609</b>	<b>Alaska</b>	
<b>North East</b>		Yellow-cedar decline	7 044
Forest tent caterpillar	15 335	Spruce beetle	6 726
Beech bark disease	4 806	Northern spruce engraver	4 652
Emerald ash borer	3 907	<b>Total, all mortality agents and complexes</b>	<b>18 422</b>
Decline	2 874	<b>Note:</b> 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.	
Unknown	2 745	<sup>a</sup> Rollup of multiple agent codes.	
Other biotic mortality agents and complexes (41)	14 739		
<b>Total, all mortality agents and complexes</b>	<b>42 995</b>		

M322B–Northern Rockies and Bitterroot Valley, M332A–Idaho Batholith, and M332E–Beaverhead Mountains. Mortality in this area was attributed almost entirely to mountain pine beetle in lodgepole pine (*Pinus contorta*) forests, although Douglas-fir beetle also caused mortality in Douglas-fir (*Pseudotsuga menziesii*) stands. The hot spot extended beyond those ecoregions into several others, including M332D–Belt Mountains, M332F–Challis Volcanics, M333D–Bitterroot Mountains, M333C–Northern Rockies, and 331K–North Central Highlands.

Two hot spots of intense mortality were detected in north-central Colorado and south-central Wyoming where mountain pine beetle and subalpine fir mortality complex caused extensive mortality in two ecoregion sections, M331I–Northern Parks and Ranges and M331H–North-Central Highlands and Rocky Mountains. The clustering of mortality exposure extended into northeast Utah (M331E–Uinta Mountains). In the south-central part of Colorado, spruce beetle, subalpine fir mortality complex, fir engraver (*Scolytus ventralis*), and Douglas-fir beetle were associated with a cluster of mortality in M331G–Southern Central Highlands, M331F–Southern Parks and Rocky Mountain Range, 313B–Navajo Canyonlands, and 341B–Northern Canyonlands.

In west-central Wyoming, mountain pine beetle, five-needle pine decline, spruce beetle, and subalpine fir mortality complex were associated with a hot spot of intense mortality centered on the M331J–Wind River Mountains

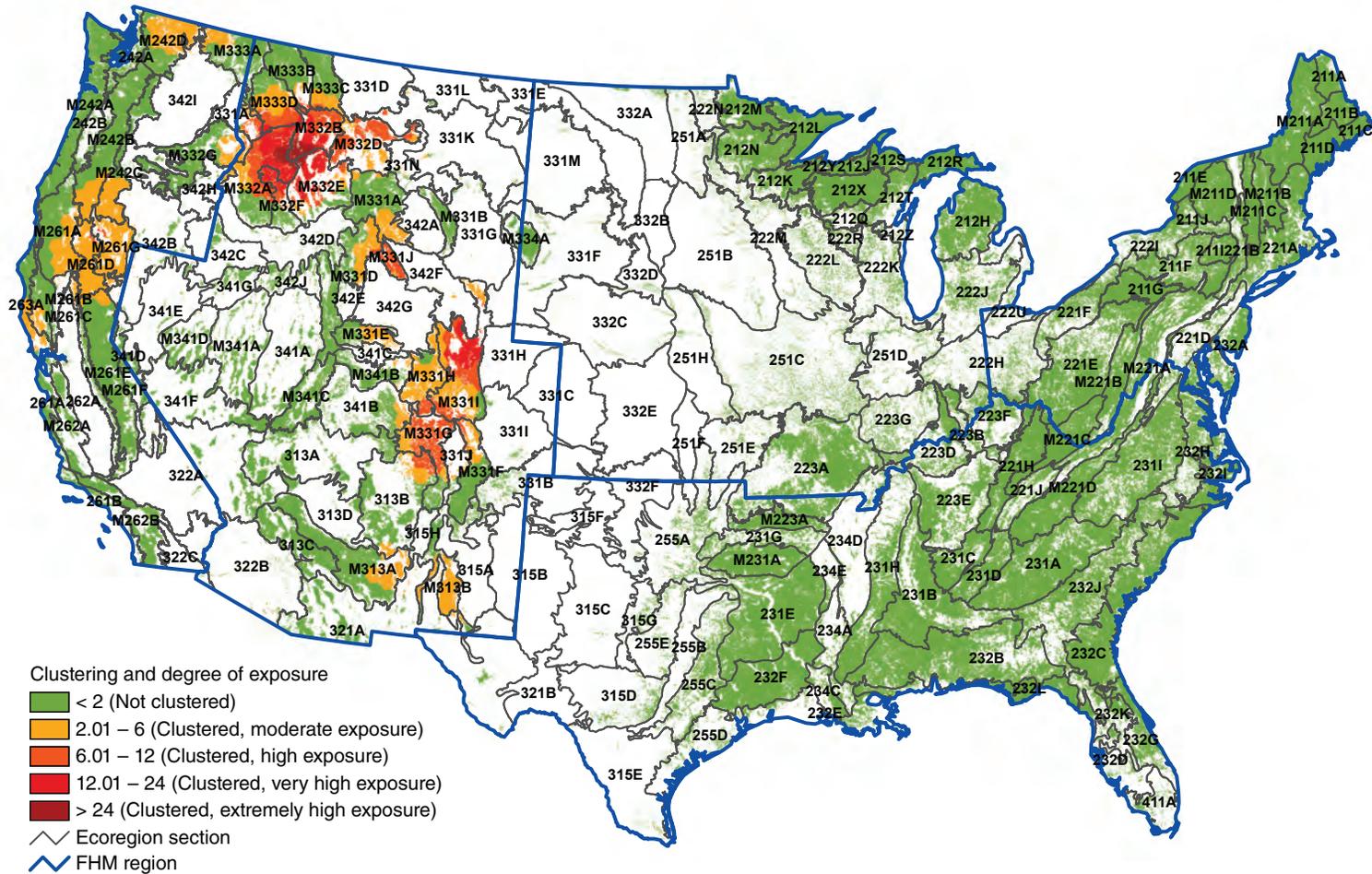


Figure 2.2—Hot spots of exposure to mortality-causing insects and diseases in 2012. Values are Getis-Ord  $G_i^*$  scores, with values  $>2$  representing significant clustering of high percentages of forest area exposed to mortality agents. (No areas of significant clustering of low percentages of exposure,  $<-2$ , 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 Moderate Resolution Imaging Spectroradiometer (MODIS) imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

ecoregion, and extending west and north into M331D–Overthrust Mountains and M331A–Yellowstone Highlands.

Finally, a less intense hot spot of mortality was located in southern New Mexico, in M313A–White Mountains-San Francisco Peaks-Mogollon Rim and M313B–Sacramento-Monzano Mountains. Western pine beetle (*Dendroctonus brevicomis*) and *Ips* engraver beetles were the primary mortality agents.

Mountain pine beetle also was the leading cause of mortality in the West Coast region, where detection efforts recorded mortality-causing agents and complexes on nearly 410 000 ha (table 2.4). Several other types of bark beetles, especially western pine beetle, fir engraver, and spruce beetle, were also important causes of mortality in this region. Mountain pine beetle and western bark beetle, in particular, were associated with a relatively extensive geographic hot spot of mortality in northeastern California and south-central Oregon, which encompassed five ecoregion sections: M261G–Modoc Plateau, M261D–Southern Cascades, M261A–Klamath Mountains, M242B–Western Cascades, and M242C–Eastern Cascades (fig. 2.2).

A less intense hot spot in north-central Washington (M242D–Northern Cascades and M333A–Okanagan Highland) was caused primarily by the activity of a wide range of bark beetles, including mountain pine beetle, spruce beetle, Douglas-fir beetle, western balsam bark beetle, and fir engraver. Sudden oak death

mortality in tanoak (*Lithocarpus densiflorus*) forests caused another mortality hot spot in California (263A–Northern California Coast).

No geographic hot spots of mortality were detected in the North Central, North East, and South FHM regions. In the North Central region, however, the FHP survey recorded mortality-causing agents and complexes on approximately 98 000 ha (table 2.4). Spruce budworm was the most widely detected mortality agent in the region, followed by emerald ash borer (*Agrilus planipennis*), eastern larch beetle (*Dendroctonus simplex*), and mountain pine beetle.

In the North East FHM region, mortality was recorded on almost 43 000 ha, where forest tent caterpillar (*Malacosoma disstria*) was the most widely identified causal agent. Beech bark disease and emerald ash borer also affected somewhat large areas. In the South, mortality was detected on fewer than 10 000 ha, with bark beetles being the most commonly detected agent (table 2.4).

As with agents of mortality, the Interior West FHM region had the largest area on which defoliating agents and complexes were detected in 2012, approximately 1.6 million ha (table 2.5). Western spruce budworm was by far the most widely detected defoliator in the region, followed by pinyon needle scale, larch needle cast (*Meria laricis*), and general aspen (*Populus tremuloides*) defoliation.

Three geographic hot spots of intense defoliation occurred in the region (fig. 2.3). The largest, caused by western spruce budworm,

**Table 2.5—The top five defoliation agents or complexes for each Forest Health Monitoring region in 2012**

Defoliation agents and complexes, 2012	Area <i>ha</i>	Defoliation agents and complexes, 2012	Area <i>ha</i>
<b>Interior West</b>		<b>South</b>	
Western spruce budworm	1 189 386	Fall cankerworm	1 077 993
Pinyon needle scale	198 976	Forest tent caterpillar	232 598
Larch needle cast	84 262	Baldcypress leafroller	16 439
Aspen defoliation	55 534	Emerald ash borer	1 767
Pinyon sawfly	33 732	Unknown	125
Other defoliation agents and complexes (25)	67 242	Defoliators	7
<b>Total, all defoliation agents and complexes</b>	<b>1 593 110</b>	<b>Total, all defoliation agents and complexes</b>	<b>1 321 007</b>
<b>North Central</b>		<b>West Coast</b>	
Forest tent caterpillar	136 611	Western spruce budworm	238 896
Spruce budworm	65 692	Pine butterfly	36 851
Cherry scallop shell moth	24 237	Larch needle cast	21 852
Jack pine budworm	21 866	Balsam fir sawfly	7 407
Pine engraver	16 198	Needlecast	5 267
Other defoliation agents and complexes (10)	35 520	Other defoliation agents and complexes (23)	24 219
<b>Total, all defoliation agents and complexes</b>	<b>300 028</b>	<b>Total, all defoliation agents and complexes</b>	<b>333 934</b>
<b>North East</b>		<b>Alaska</b>	
Anthraco-nose	22 666	Defoliators	97 256
Pear thrips	21 302	Aspen leafminer	27 926
Fall webworm	11 038	Willow leaf blotchminer	19 218
Forest tent caterpillar	9 041	Large aspen tortrix	4 934
Fall cankerworm	8 938	Birch aphid	4 346
Other defoliation agents and complexes (30)	43 904	Other defoliation agents and complexes (10)	9 588
<b>Total, all defoliation agents and complexes</b>	<b>90 669</b>	<b>Total, all defoliation agents and complexes</b>	<b>161 981</b>

Note: The total area affected by other agents is listed at the end of each section. All values are “footprint” areas for each agent or complex. The sum of the individual agents is not equal to the total for all agents due to the reporting of multiple agents per polygon.

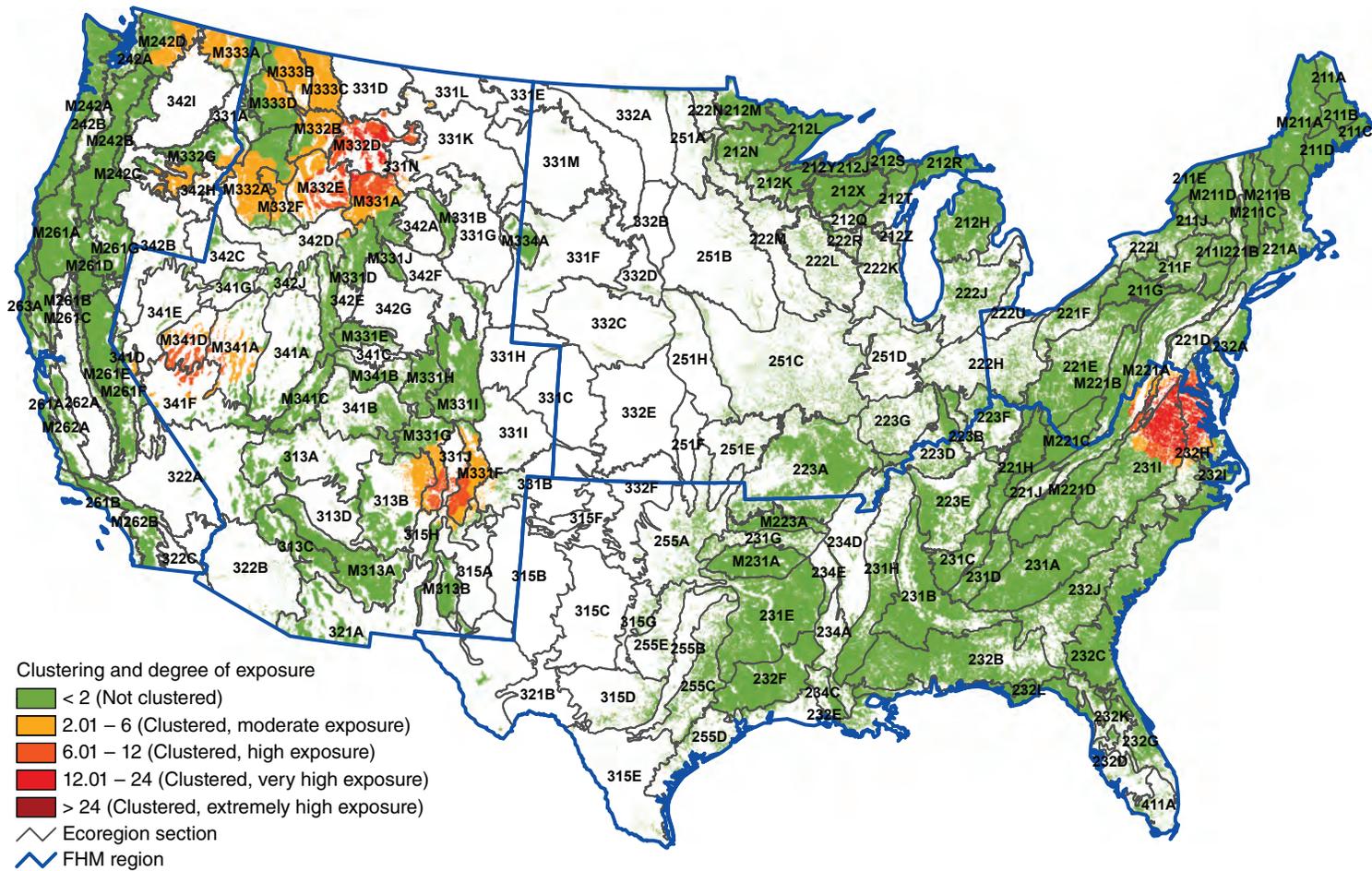


Figure 2.3—Hot spots of exposure to defoliation-causing insects and diseases in 2012. Values are Getis-Ord  $G_i^*$  scores, with values  $>2$  representing significant clustering of high percentages of forest area exposed to defoliation agents. (No areas of significant clustering of low percentages 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 Moderate Resolution Imaging Spectroradiometer (MODIS) imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

was centered on M332D–Belt Mountains, M332E–Beaverhead Mountains, and M331A–Yellowstone Highlands in western Montana. Western spruce budworm was also the main cause, along with a smaller amount of larch needle cast, of two nearby geographic hot spots that were less intense: one in M332A–Idaho Batholith and M332F–Challis Volcanics, and the other in M333D–Bitterroot Mountains, M333B–Flathead Valley, and M333C–Northern Rockies.

Also in the Interior West Region, western spruce budworm and aspen defoliation were the causal factors associated with a geographic hot spot of defoliation in northern New Mexico and southern Colorado (M331G–South Central Highlands and M331F–Southern Parks and Rocky Mountain Range). Meanwhile, pinyon needle scale (*Matsucoccus acalyptus*) and, to a lesser degree, pinyon sawfly (*Neodiprion edulicolus*) were the agents of defoliation associated with a relatively large geographic hot spot in the forested areas of central Nevada (M341D–West Great Basin and Mountains, M341A–East Great Basin and Mountains, and 341F–Southeastern Great Basin).

Western spruce budworm, meanwhile, accounted for about 70 percent of the 334 000 ha of defoliation detected in the FHM West Coast region (table 2.5). While not nearly as widespread, pine butterfly (*Neophasia menapia*) and larch needle cast were the second and third leading defoliators in the region. One geographic hot spot of defoliation occurred in north-central

Washington State (M242D–Northern Cascades and M333A–Okanagan Highland), associated with western spruce budworm and some larch needle cast. Another hot spot was located in M332G–Blue Mountains of eastern Oregon, which was caused by western spruce budworm and pine butterfly.

In the North Central FHM region, forest tent caterpillar was the leading defoliator, recorded on about 137 000 ha, or nearly half of the 300 000 ha of defoliation detected in the region (table 2.5). Spruce budworm, cherry scallop shell moth (*Hydria prunivorata*), and jack pine budworm (*Choristoneura pinus*) were also important agents of defoliation in the region. No geographic hot spots of defoliation were detected in the North Central or North East regions. In the North East, the FHP survey recorded 91 000 ha of forest exposed to defoliators, with anthracnose (*Gnomonia* spp.) and pear thrips (*Taeniothrips inconsequens*) having the greatest geographic extent (table 2.5).

In the South, meanwhile, fall cankerworm was by far the leading defoliation agent, detected across more than 1 million ha in eastern Virginia (table 2.5). The insect outbreak resulted in a geographic hot spot in two Virginia ecoregions, 231I–Central Appalachian Piedmont and 232H–Middle Atlantic Coastal Plains and Flatwoods (fig. 2.3). Across the South, defoliation was recorded on about 1.3 million ha. Forest tent caterpillar was the second most important defoliation agent, detected on 233 000 ha.

## Alaska

In 2012, mortality was recorded on 18 000 ha in Alaska, associated with three agents and complexes (table 2.4). This is a very small proportion of the forested area in Alaska that was surveyed in 2012 (approximately 6.91 million ha). Yellow-cedar (*Chamaecyparis nootkatensis*) decline was the most widely detected mortality agent, found on about 7000 ha in the Alaska panhandle, followed by spruce beetle, also affecting about 7000 ha, and northern spruce engraver (*Ips perturbatus*), which was detected on about 4600 ha. The percent of surveyed forest exposed to mortality agents did not exceed 1 percent in any of Alaska's ecoregions (fig. 2.4).

Defoliators affected a much larger area of Alaska during 2012, when 15 defoliating agents and complexes were recorded on nearly 162 000 ha (table 2.5). For much of that area, approximately 97 000 ha, non-specific defoliators were the assigned cause. Aspen leafminer (*Phyllocnistis populiella*) was detected on 28 000 ha, mostly in the central parts of Alaska. Meanwhile, willow leaf blotchminer (*Micrurapteryx salicifoliella*) was found on approximately 19 000 ha, large aspen tortrix (*Choristoneura conflictana*) was detected on about 5000 ha, and birch aphid (*Euceraphis betulae*) was recorded on about 4000 ha.

The three Alaska ecoregions with the highest proportion of surveyed forest area affected by defoliators were all located in the southwestern portion of the State (fig. 2.5). Defoliators were detected on 6.67 percent of surveyed forest in M213A–Northern Aleutian Range, 6.34 percent of surveyed forest in M131D–Nushagak-Lime Hills, and 4.12 percent of the surveyed forest in M129B–Ahklun Mountains. A few central and east-central Alaskan ecoregions also had relatively high levels of defoliation detection, including 131A–Yukon Bottomlands (3.08 percent), M139C–Dawson Range (2.83 percent), and 139A–Yukon Flats and M139A–Ray Mountains (2.38 percent in each).

## 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 geographic hot spot detection analyses, offer a useful approach for identifying geographic areas where the concentration of monitoring and management activities might be most effective.

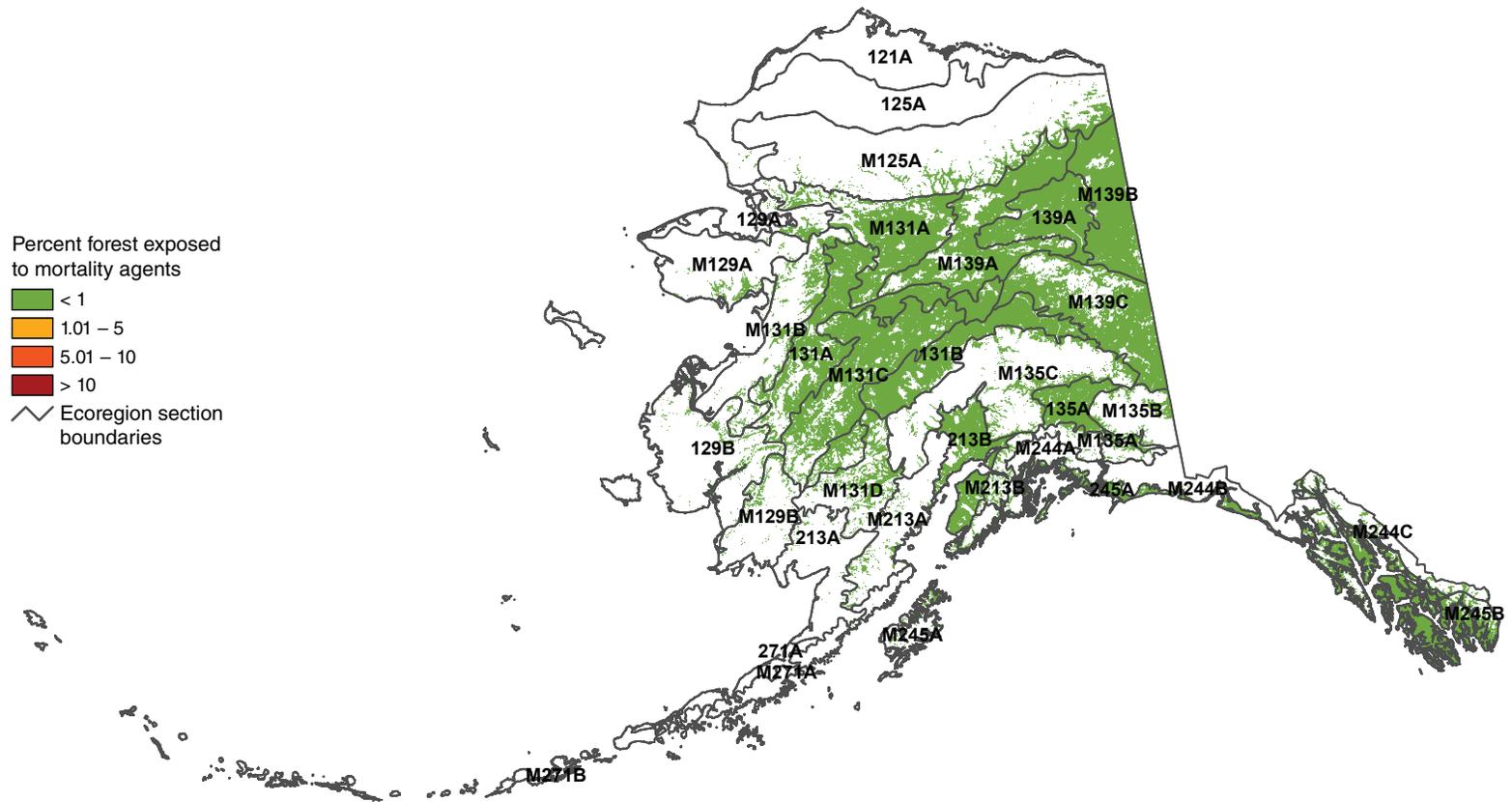


Figure 2.4—Percent of surveyed forest in Alaska ecoregion sections exposed to mortality-causing insects and diseases in 2012. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

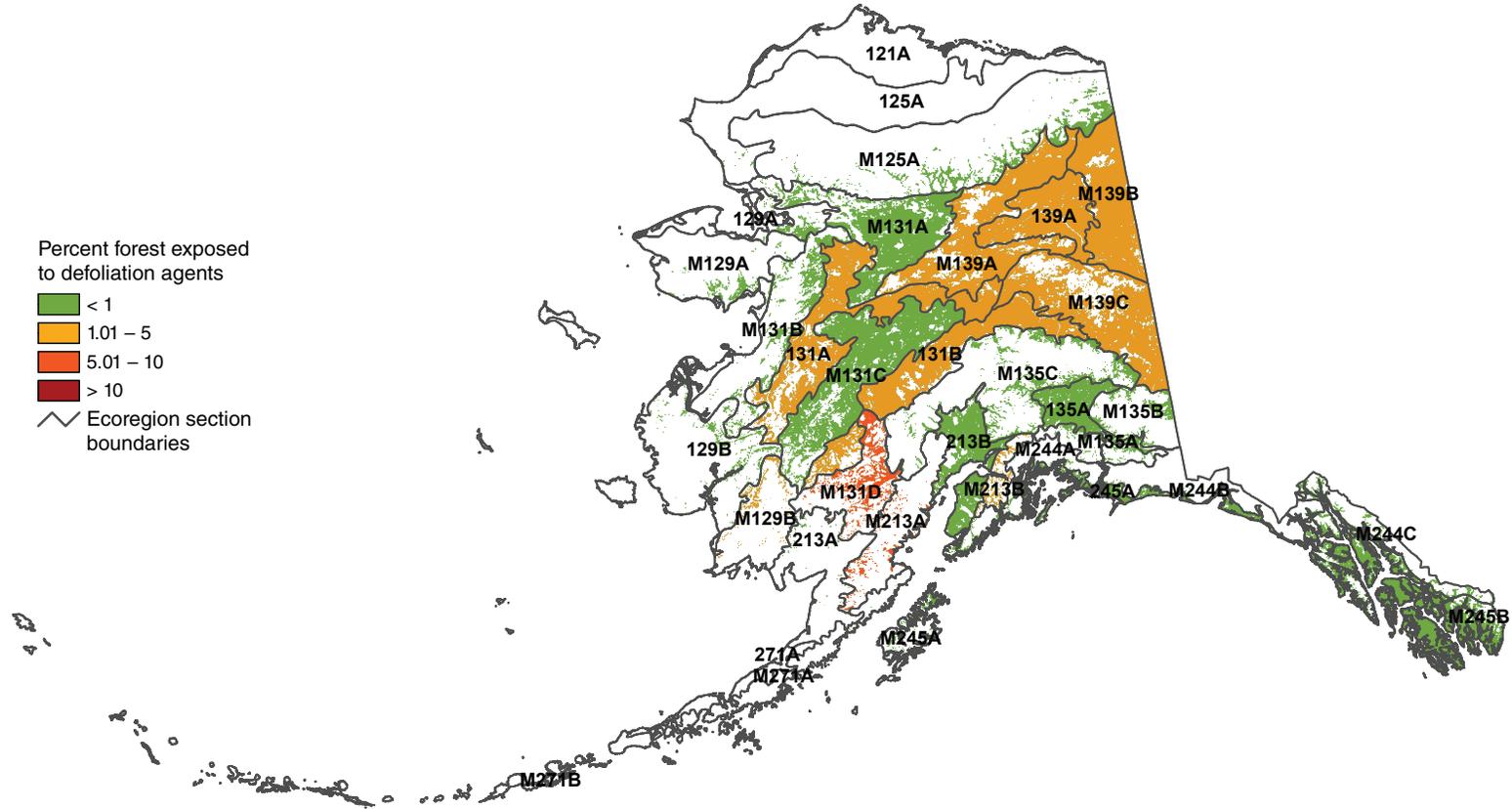


Figure 2.5—Percent of surveyed forest in Alaska ecoregion sections exposed to defoliation-causing insects and diseases in 2012. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

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