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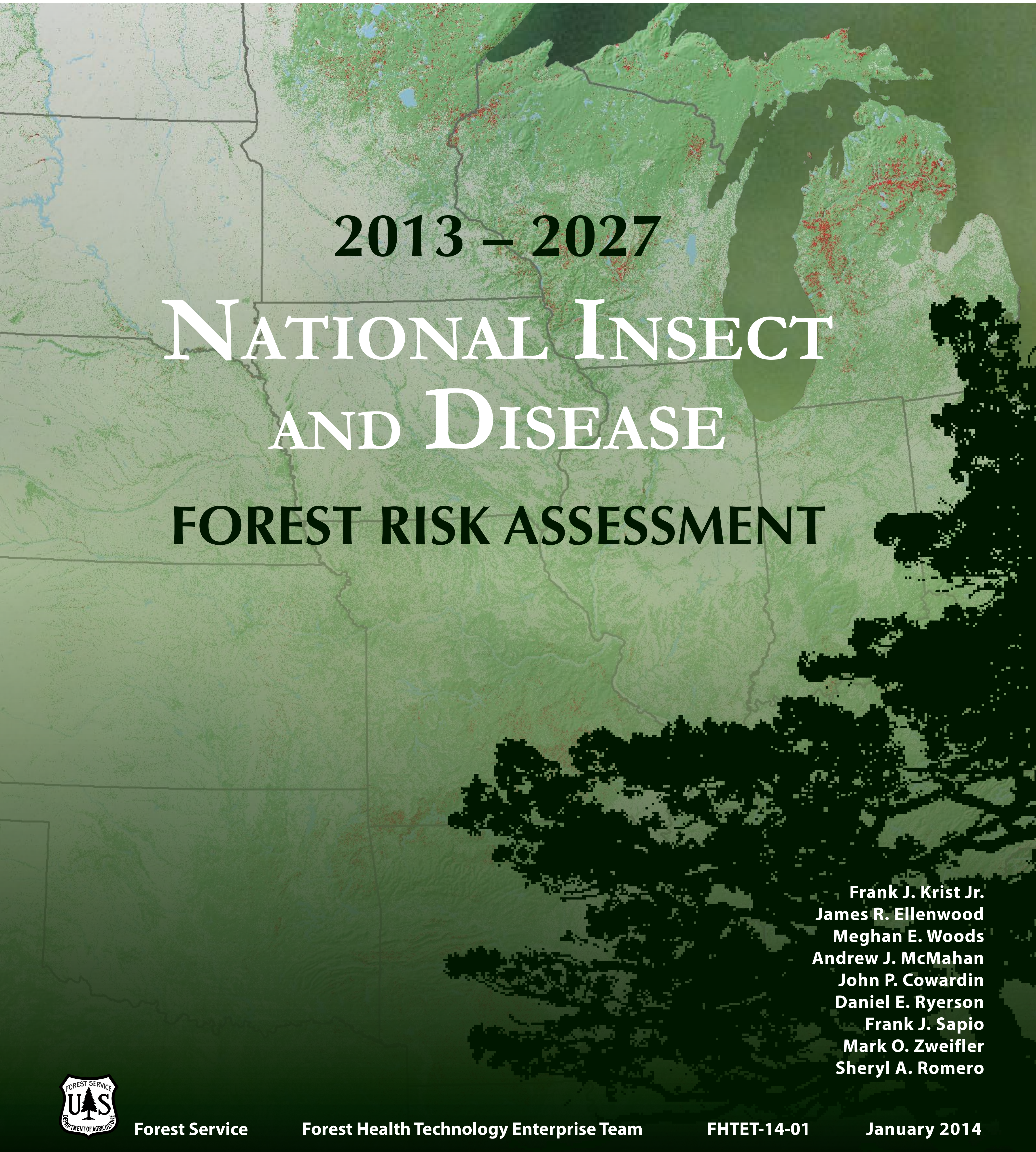


2013 – 2027

National Insect and Disease Forest Risk Assessment

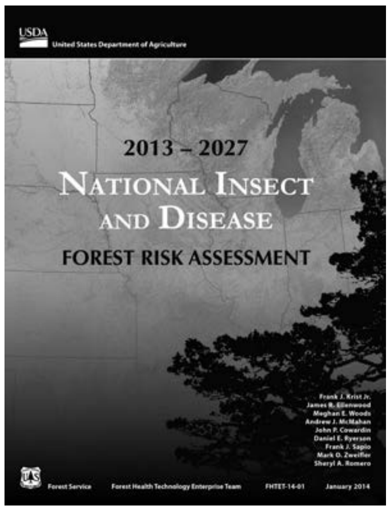
Frank J. Krist Jr.
James R. Ellenwood
Meghan E. Woods
Andrew J. McMahan
John P. Cowardin
Daniel E. Ryerson
Frank J. Sapio
Mark O. Zweifler
Sheryl A. Romero

Forest Service   Forest Health Technology Enterprise Team   FHTET-14-01   January 2014

The Forest Health Technology Enterprise Team (FHTET) was created in 1995 by the Deputy Chief for State and Private Forestry, USDA, Forest Service, to develop and deliver technologies to protect and improve the health of American forests. This book was published by FHTET as part of the technology transfer series.

Forest Health Technology Enterprise Team
2150 Centre Blvd., Bldg. A, Suite 331
Fort Collins, CO 80526

http://www.fs.fed.us/foresthealth/technology



Cover Silhouette of a white bark pine on top of the National 2012 Composite Insect and Disease Risk Map. Cover design by Sheryl A. Romero.

2013–2027
National Insect and Disease Forest Risk Assessment

Frank J. Krist Jr.[1], James R. Ellenwood[1], Meghan E. Woods[3], Andrew J. McMahan[2], John P. Cowardin[2], Daniel E. Ryerson[4], Frank J. Sapio[1], Mark O. Zweifler[2], and Sheryl A. Romero[2]

United States Forest Service

[1]Forest Health Protection (FHP)-Forest Health Technology Enterprise Team (FHTET)
[2]Cherokee Nation Technologies (CNT)-FHTET
[3] Sanborn Map Company, Inc.-Pacific Southwest Region (R5)
[4]Forest Health Protection-Southwest Region (R3)

Key Contributors

Coordination and Modeling

Borys M. Tkacz, FHP-Washington Office
Dale Starkey, FHP-Southern Region (R8)
Sheri Lee Smith, FHP-R5
Michael L. Simpson, FHP-Pacific Northwest Region (R6)
Lia Spiegel, FHP-R6
James R. Steinman, FHP-Northeastern Area (NA)
Tricia Wurtz, FHP-Alaska Region (R10)
Holly S. J. Kearns, FHP-R6

This report on the 2012 National Insect and Disease Risk Map (NIDRM) contains a nationwide strategic assessment of the hazard of tree mortality due to insects and diseases, displayed as a series of maps. Risk, or more appropriately termed *hazard*, is defined as: ***the expectation that, without remediation, at least 25% of standing live basal area greater than one inch in diameter will die over a 15-year time frame (2013 to 2027) due to insects and diseases.***

NIDRM is more than just maps: It is a nationwide, science-based, administrative planning tool that is the product of a process whereby, every five years, the forest health community works together to determine the severity and extent of tree-mortality hazard due to insects and diseases.

NIDRM represents 186 individual insect and disease hazard models, integrated within a common GIS-based, multi-criteria framework, that can account for regional variations in forest health. Applied to all 50 states, and based on the best-available science and data, NIDRM's modeling process provides a consistent, repeatable, transparent, peer-reviewed process through which interactive spatial and temporal hazard assessments can be conducted. This process is consistent with the 2006 effort, allows for flexible analysis to produce hazard assessments for specific insects and diseases, and can be used to inform other agency assessments such as the Integrated Resource Restoration, Watershed Condition Framework, Terrestrial Ecosystem Condition Assessment, Existing Vegetation Classification Mapping and Inventory, and Hazardous Fuels Prioritization Allocation System.

NIDRM products are compiled on a national extent with a 240-meter (approximately 14 acres) spatial resolution and can be updated as new data and/or models become available. This "live" or near-real-time approach will greatly facilitate the production of new hazard maps.

PURPOSE NIDRM's primary purpose is as a strategic, broad-scale planning tool that can be used for administrative activities and work planning. In certain landscapes and at appropriate scales, NIDRM maps may be helpful for on-the-ground tactical management.

NIDRM was a highly collaborative process led by the Forest Health Monitoring program (FHM) of the USDA Forest Service (Forest Service), with participation from FHM staffs from all Regions, State forestry agencies, Forest Service Forest Health Protection, and Forest Service Research and Development.

DATA IMPLICATIONS FOR PARTNERSHIPS To develop NIDRM involved an enormous data-production effort. In turn, the data created for NIDRM have enormous value across the Federal Government and its partners, and can be used across a myriad of projects and applications. An organized *all lands* Spatial Data Library, with over 600 data layers, is available through the Forest Health Technology Enterprise Team (FHTET). Tree species maps—including basal area, stand density index, average diameter, and percent host at 30- and 240-meter resolution—are available to partners. The NIDRM data stack supports forest planning and forest-health hazard assessments at national and regional scales.

DATA SOURCES AND PROCESSING Previous NIDRM assessments defined forests as lands containing at least 10% tree canopy cover, including land that formerly had such tree cover and will be naturally or artificially regenerated. By this definition there are approximately 749 million acres of forested land in the coterminous United States and Alaska. For the 2012 hazard assessment, we extended these limits and modeled 1.2 billion acres of *treed* land (i.e. areas of measurable tree presence) across the US—whether or not these treed lands met some standard definition of forested. This approach improves coverage for rural areas of the Great Plains, as well as urban areas nationally. The 2012 hazard assessment estimates that 81 million of these acres are in a hazardous condition for insects and diseases. Almost 72 million acres are in the coterminous United States, and 9.5 million hazardous acres are in Alaska. In Hawaii, not previously assessed, just under a half-million acres are estimated to be in a hazardous condition. These estimates do not include hazard due to projected climate changes, although this NIDRM report includes an examination of future climate impacts on insect and disease hazards.

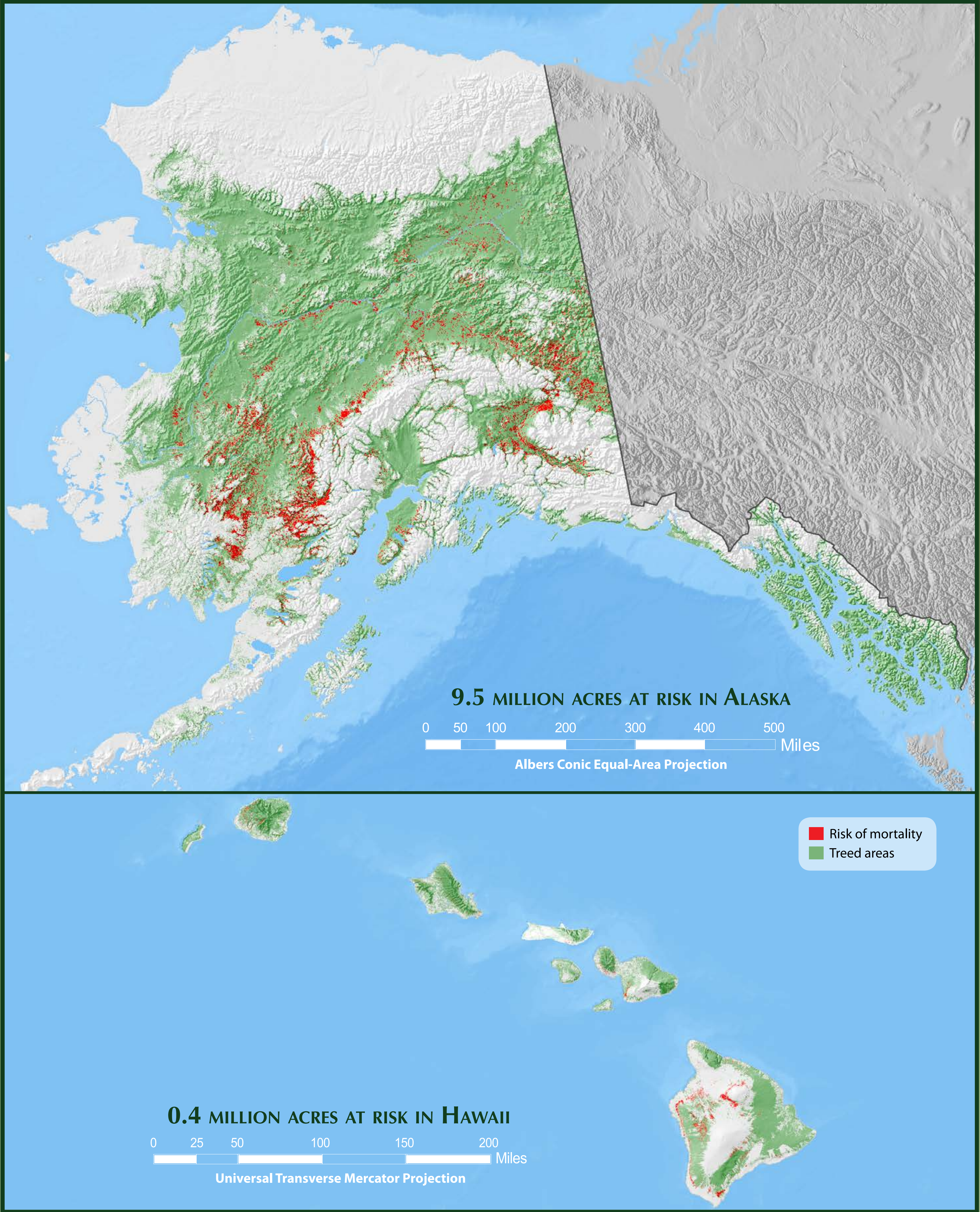
With significant improvements in coverage, accuracy, and precision of the data, the 2012 NIDRM was better able to model risk in the Great Plains, urban areas, and national parks. These improvements also allowed us to model pests, such as emerald ash borer and laurel wilt, that infest rare and/or widely distributed host species. The change from a 1-kilometer to a 240-meter spatial resolution moves the 2012 NIDRM closer to a product that can be used to inform local and regional decision making. This table displays some of the differences in acreage between the 2006 and 2012 efforts.

	Millions of Acres		
FACTOR	2006 NIDRM	2012 NIDRM	Difference
Hazardous conditions mapped in the coterminous United States	55.2	71.7	16.5
Sources of differences			
Host data gaps filled, and non-forested but treed areas modeled (2012)		13	
Increased hazards from new models and improvements in process (2012)		3.5	
Hazardous conditions mapped in Alaska	2.8	9.5	6.7
Sources of differences			
Improved host maps and new models (2012)		6.7	
Hazardous condition mapped in Hawaii	0	0.1	0.1
Sources of differences			
Newly modeled (2012)		0.1	
2012 NIDRM TOTAL HAZARD, all states		**81.3**	**23.3**

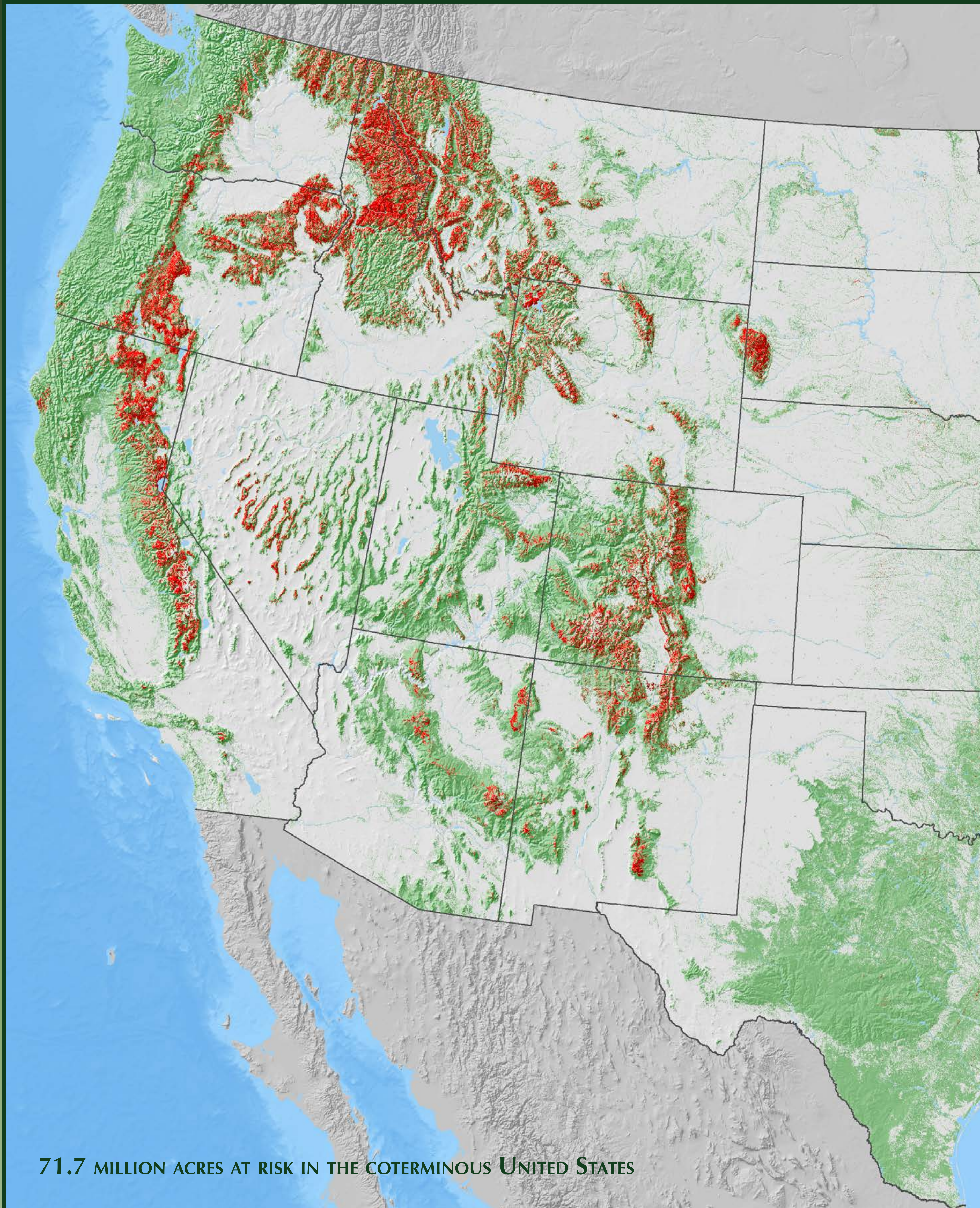
MAJOR HAZARDS Collectively, root diseases, bark beetles, and oak decline were the leading contributor to the risk of mortality in the coterminous United States, while spruce beetle was the most significant contributor in Alaska. The confluence of bark beetles and root diseases has resulted in large contiguous areas at risk across much of the western United States. Emerald ash borer is the most significant exotic forest pest. Tree species with the potential to lose more than 50% of their host volume include redbay and whitebark pine.

While future climate change is not modeled within NIDRM, we expect that the climate changes projected over the next 15 years will significantly increase the number of acres at risk, and will include elevated risk from already highly destructive pests such as mountain pine beetle and engraver beetles (*Ips* spp.). Host trees such as whitebark pine would be at increased risk in future climate-change scenarios. ♦

For more information and access to data
visit the 2012 NIDRM website
http://www.fs.fed.us/foresthealth/technology/nidrm2012.shtml



National 2012 Composite Insect and Disease Risk Map



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This 2012 National Insect and Disease Risk Map (NIDRM) report is the third in a series (see Lewis 2002; Krist et al. 2007) that use Geographic Information Systems (GIS) technology to identify the potential impact of both endemic and non-endemic forest pests in the coterminous Unites States, Alaska, and (new in 2012) Hawaii. Each risk assessment provides a five-year strategic appraisal of the risk of tree mortality due to insects and diseases; each new mapping effort has focused on improving the process and data upon which assessments are conducted.

The 2006 and 2012 NIDRM efforts are noteworthy for moving beyond the typical cartographic uses of GIS to the realm of advanced spatial analysis. In 2006, a GIS-based, multi-criteria modeling framework was introduced along with national, standardized, geospatial datasets. These improvements provided a consistent, repeatable, transparent modeling process that generates comparable results across geographic regions and individual pest assessments. Despite these improvements, a significant challenge for the 2012 risk map effort was to make the sophisticated tools of multi-criteria/weighted-overlay spatial modeling accessible to a broad range of forest health professionals who, in most cases, have little or no GIS training or experience. The Forest Health Technology Enterprise Team (FHTET) defined procedures and built datasets and intuitive custom tools to get these partners directly involved in the risk-mapping process.

Several weaknesses in data availability and data quality identified during the 2006 NIDRM effort have been resolved in the 2012 NIDRM. These include development of spatially explicit, nationwide, individual tree-species parameter layers, such as basal area (BA) (Avery and Burkhart 2002), quadratic mean diameter (QMD) (Reineke 1933), and the stand density index (SDI) (Reineke 1933). Without such host-species information, spatially based risk assessments can be less than optimal even with very accurate models of risk agent effects. Also, with the development of 240-meter resolution forest-parameter layers in 2012, we were able to address data gaps in the Great Plains, national parks, interior Alaska, and urban areas.

NIDRM's assessment exclusively focuses on forest mortality due to pests and pathogens. This focus is not meant to diminish the importance of other factors that contribute to tree mortality or growth loss. For example, browsing from ungulates, defoliation, and competition from invasive exotic plants pose a significant threat to tree health in many regions, but are not included in NIDRM. And while climatological data were included as criteria in many insect and disease models, drought, storm damage, fire, and other abiotic disturbances were not directly modeled as risk agents.

The Team Approach

The creation of NIDRM was a collaborative process coordinated by the Forest Health Monitoring (FHM) Program of the Forest Service. Staff from Forest Service FHM Regions, Forest Health Protection, and Research and Development; state agencies; and universities were invited to participate in creating NIDRM.

Three teams were created to support the effort. A Risk Map Oversight Team (RMOT) was formed to define risk assessment products, provide general process guidance, and schedule project development activities. A Data Development Team (DDT) was created to procure and create geospatial data layers required for input into risk map models. The Model Development Team (MDT) was assembled to design and improve quantitative models that estimate risk from interactive effects among multiple criteria represented in geospatial data layers. A list of RMOT, DDT, and MDT team members and other key participants can be found in Appendix A.

Beginning in 2009, forest health experts met regularly to review published information and to reach consensus on NIDRM models. In April 2011, forest health and GIS experts participated in a national workshop in Loveland, Colorado, to review and run models, display results, and adjust the models. The process culminated with a collective review of results by the RMOT, DDT, MDT, and FHM partners. Model deficiencies and applicability were discussed and plans were made to improve models and input data prior to the final review of models, which took place at the annual FHM meeting in April of 2012.

Principal Objectives and Project Requirements

Considering the lessons learned since the 2006 NIDRM, the goals of the 2012 NIDRM are to:

1. Provide a five-year strategic appraisal (update) for the risk of tree mortality while greatly improving the local utility of NIDRM.
2. Increase participation and expedite NIDRM model development through the development of a custom desktop ArcGIS Risk Modeling Application (RMAP) that allows seamless transfer of GIS multi-criteria modeling technology to resource managers engaged in risk assessments.
3. Develop a set of national, standardized, 240-meter resolution, forest-parameter layers, including layers for Alaska and Hawaii, and other supporting geospatial data for use in NIDRM model development.
4. Provide information on
   a. forest insects and diseases currently of concern,
   b. conditions under which forested areas are at risk from agents of concern,
   c. locations of such conditions and presence of risk agents of concern, and
   d. the identification of significant impacts to individual tree species.
5. Involve state and federal partners in
   a. developing, testing, and implementing RMAP,
   b. identifying important disturbance agents and the host species on which they act,
   c. developing, evaluating, and updating high-resolution, individual, tree-species parameter data,
   d. updating existing, and developing new, forest pest models using the best available information, and
   e. maintaining species-level information on disturbance agents and their hosts.

This report focuses on results and important changes since 2006, including newly added areas, such as Hawaii, national parks, and regions, such as the Great Plains and urban areas, where our ability to model risk improved significantly. This report also describes the new desktop application and geospatial layers utilized in the construction of the 2012 NIDRM. Finally, this report makes limited mention of the core modeling methodology that has been retained from the 2006 NIDRM. We recommend two publications for detailed information on methods and overall processes.

A Multi-criteria Framework for Producing Local, Regional, and National Insect and Disease Risk Maps.

Frank J. Krist Jr., Sapio, F.J., Tkacz, B.M. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 2010. 16 pp.

Online at http://www.fs.fed.us/foresthealth/technology/pdfs/pnw_gtr802vol2_krist.pdf.

Mapping Risk from Forest Insects and Diseases, 2006.

Frank J. Krist Jr., Sapio, F.J., Tkacz, B.M. FHTET 2007-06. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 2007. 115 p.

Online at http://www.fs.fed.us/foresthealth/technology/pdfs/FHTET2007-06_RiskMap.pdf.

MORTALITY, RISK, AND HAZARD

Some level of tree mortality occurs in all forests, but usually at low and predictable rates that are typically offset by growth of residual trees (Smith et al. 2001). Losses from native insects and diseases are often widely scattered throughout the landscape and do not always result in large tracts of dead trees. However, more wide-spread and intensive tree mortality occurs in some areas, particularly when native and non-native (exotic) pests reach epidemic levels.

A key objective is to identify areas at risk of insect- and disease-caused tree mortality at rates well above average background rates. For the 2012 NIDRM, the background mortality rate was defined as "the average growing stock volume of timber dying over a given time due to natural causes, such as insects, disease, fire, and wind throw" (Smith et al. 2001). We used a national average rate of 0.89% per year (Smith et al. 2009), although local or regional background mortality rates can deviate significantly from this level.

During the literature review for this project, the MDT was confronted with issues concerning the terminology used in environmental risk assessment. Risk and hazard are often described differently depending on the discipline (NRC 1983, EPA 1998). Rather than attempt to reconcile the various definitions of risk and hazard, we use a *mortality potential paradigm*, described below.

As it relates to forest health, risk is often composed of two parts: *the probability of a forest being attacked* and *the probability of resulting tree mortality*, referred to as *susceptibility* and *vulnerability*, respectively (Mott 1963). Although we accept Mott's distinction between susceptibility and vulnerability, due to lack of data it is difficult to assign probabilities to insect and disease activity at specific locations. Thus, NIDRM does not represent a probabilistic risk assessment. Instead, we define risk as the *potential for mortality*. Therefore, the 2012 NIDRM represents a *hazard assessment* rather than a true *risk assessment*.

Our threshold value for mapping risk is defined as ***the expectation that, without remediation, at least 25% of standing live basal area greater than one inch in diameter will die over a 15-year time frame (2013 to 2027) due to insects and diseases.*** It is important to note that for NIDRM, risk of mortality does not include impacts from natural causes other than insects and diseases, although in many areas mortality resulting from fire, invasive plants, drought, browsing, storms and other factors can be very significant.

As in the 2002 and 2006 risk assessments, a basal area (BA) mortality rate ≥25% was deemed to represent "an uncommon, rather extraordinarily high amount of mortality." The 15-year period for risk assessment is consistent with the 2002 and 2006 risk assessments and represents "a horizon long enough to avoid being too specific on the timing of outbreaks, yet short enough to be meaningful from a strategic planning standpoint" (Lewis 2002, Krist et al. 2007).

Note: throughout this report, expected mortality is presented in either of two units of measure: either as

- a total BA loss (expressed in square feet) attributed to each risk agent, or
- a total area at risk (expressed in acres) attributed to all (or specifically selected) risk agents present.

The first measure allows us to compare and rank risk agents according to the BA loss attributable to each agent; the second allows us to aggregate the acres that meet the 25% BA mortality threshold. ♦

The 2012 NIDRM employs the same five-step, GIS-based, multi-criteria process used in 2006 (**FIGURE 1**). For details see Krist et al. 2007, 2010. The 2012 effort is distinguished by its use of improved data and the introduction of FHTET's custom RMAP (**FIGURES 2–4**), which produced a standardized national depiction of risk at a 240-meter (approximately 14 acres) pixel/grid cell resolution. Briefly, here is the five-step process.

1. Compile a list of forest pests (risk agents), their target host species and the locations (ecoregions) where the pests pose significant threats to the host.
2. Identify, rank, and weight criteria (GIS layers acting as factors and constraints) that determine host susceptibility and vulnerability to each risk agent.
3. Re-scale from 0 to 10 the risk agent criteria values on each GIS layer and combine the resultant maps in a model of risk potential using a series of weighted overlays.
4. Convert modeled values representing potential risk of mortality for each agent to a predicted BA loss over a 15-year period.
5. Compile the resultant values from Step 4 and identify areas (at a 240-meter pixel resolution) on a national base map that are at risk of encountering a 25% or greater loss of total BA in the next 15 years.*

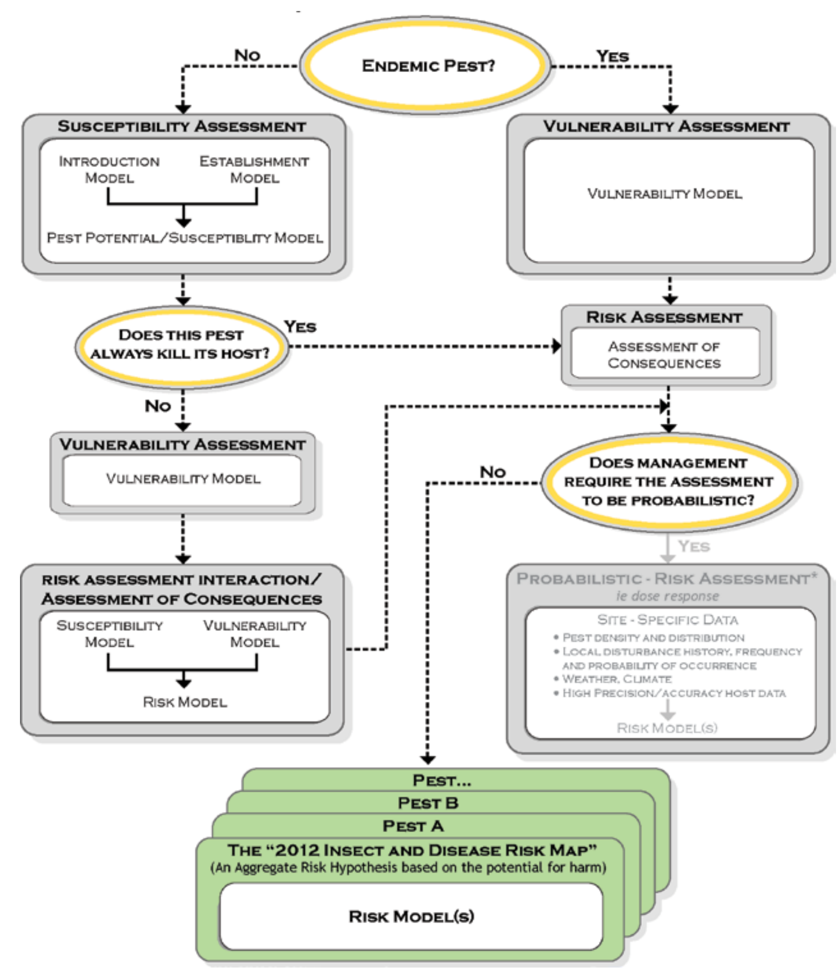


FIGURE 1 Conceptual risk assessment process

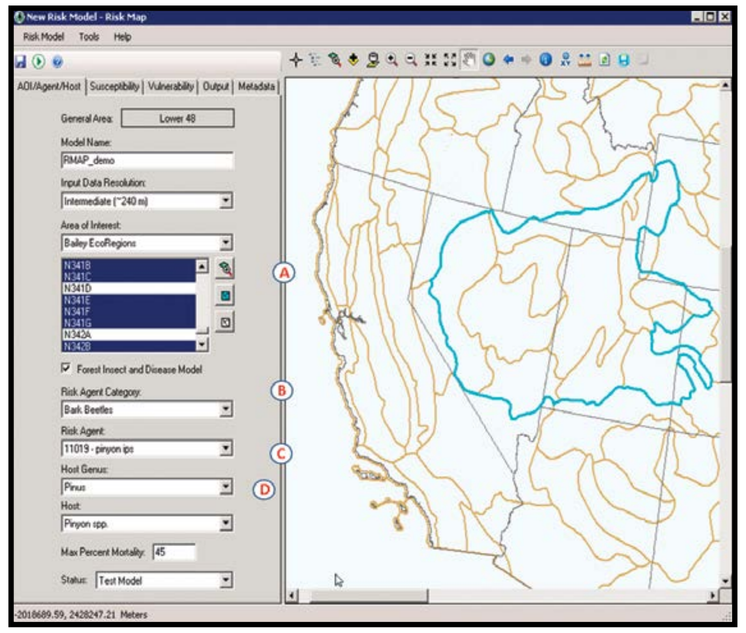


FIGURE 2 RMAP application-parameter selections
Select (A) an area of interest, (B) a risk agent, (C) a target host, and (D) the maximum amount of expected mortality.

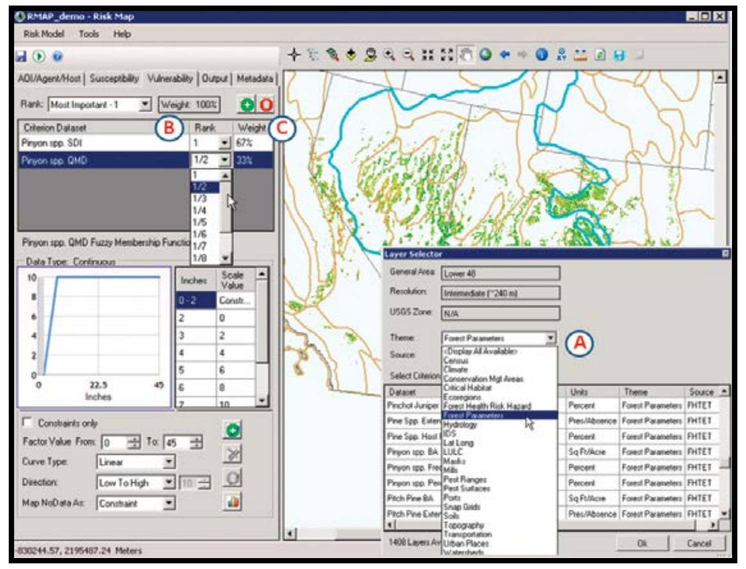


FIGURE 3 RMAP application-mortality display criteria
Select (A) a criterion, (B) a rank, and (C) a weight that determine susceptibility and vulnerability to each risk agent.

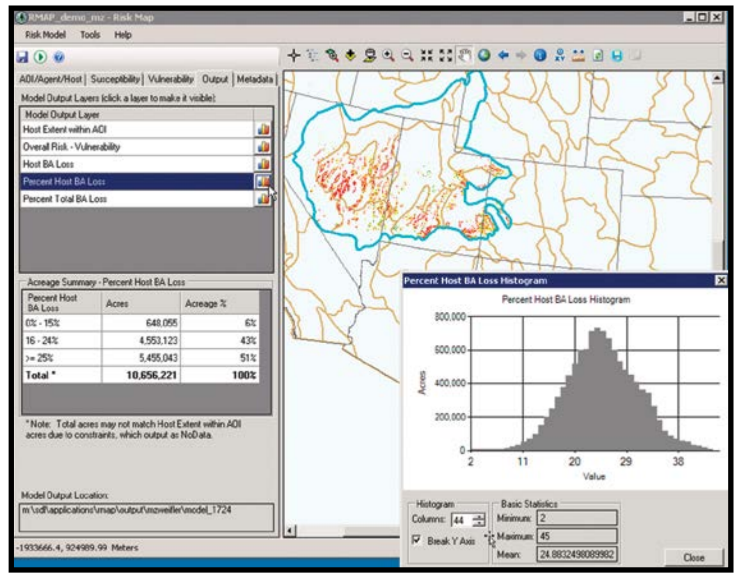


FIGURE 4 RMAP application-modeling results
Run models and view results through maps, charts, and tabular RMAP outputs.

*When more than one agent was responsible for mortality within a single host tree species, the final host-specific BA mortality rate was derived by summing the individual agent mortality rates, and truncating the sum such that it did not exceed 100%. This procedure differs from what is described in Krist et al. 2010, and was used in both the 2006 and 2012 NIDRMs.

RMAP enables forest insect and disease risk mapping specialists to create multi-criteria risk models, run the models against selected datasets, and view the results in multiple ways. The application's user interface includes a map canvas that allows users to inspect spatial data inputs and outputs.

RMAP provides a common, integrative framework that a large and diverse group of forest health specialists, most of whom have limited GIS experience, can use to evaluate criteria and reach consensus on the construction of pest models. This tool also supports a transparent and consistently repeatable process for integrating individual models from all geographic regions into a national composite map showing cumulative risk of tree mortality.

The software is interactive and easy to use. Users can make changes to data inputs or weightings and quickly assess updated results through maps, charts, and tabular RMAP outputs. To support modeling forest health risk at a national scale, FHTET compiled and organized a Spatial Data Library (SDL) with over 600 thematic raster datasets aligned to a common 240-meter resolution snap grid. (Data for Hawaii were assembled at a 30-meter resolution.) The SDL is integrated with RMAP, which facilitates locating and adding desired criteria datasets. Individual tree-species parameters and climate datasets are the primary inputs to forest health risk models (**TABLE 1**).

RMAP automatically maintains metadata on model parameters (criteria datasets, weights, thresholds, hosts, pests, ecoregion-area of interest, citations, etc.) and maintains model-author information; users are allowed to inspect components of all models, and can edit those models they have created. This database can be queried to find all models that meet search criteria, such as all the models for a specific damage agent, host, and ecoregion, singly or in any combination.

Within RMAP, individual tree species serve as insect and disease hosts. Host-tree species parameters, such as BA, SDI, percent host (proportion of host tree species BA relative to total BA) and QMD (reflecting tree size and age), along with other types of criteria within the SDL, such as soils, climate, elevation, etc., are combined to create the individual pest and pathogen models (**FIGURE 5**). These individual models are compiled to create the composite 2012 NIDRM. Forest host-tree species parameter development is discussed in the next section.

TABLE 1 Usage Frequency for 2012 NIDRM Model Criteria

CRITERIA CATEGORY	% OF MODELS
Diameter	**66%**
QMD by species or species group	
Species frequency by diameter class thresholds	
BA / Density	**63%**
BA by species, species group or total	
SDI by species, species group, or total	
Canopy closure	
Trees per acre	
Host Prevalence	**59%**
Percentage of host by species or species group	
Frequency of species or species group presence	
Climate	**46%**
Drought frequency	
Annual, monthly and growing season precipitation	
Monthly temperature (min, max, average)	
Monthly relative humidity	
Frost-free period, last frost	
Proximity to Infestation	**40%**
Proximity to infestation by pest range	
Soils	**22%**
Soil drainage index	
Soil nutrient index	
Soil moisture regimes	
Topography	**17%**
Slope	
Elevation	
Aspect	
Curvature, position index	
Other	**10%**
Distance to roads, streams, urban areas, coast	
Housing density, fenced area, harvested stands	
Latitude	

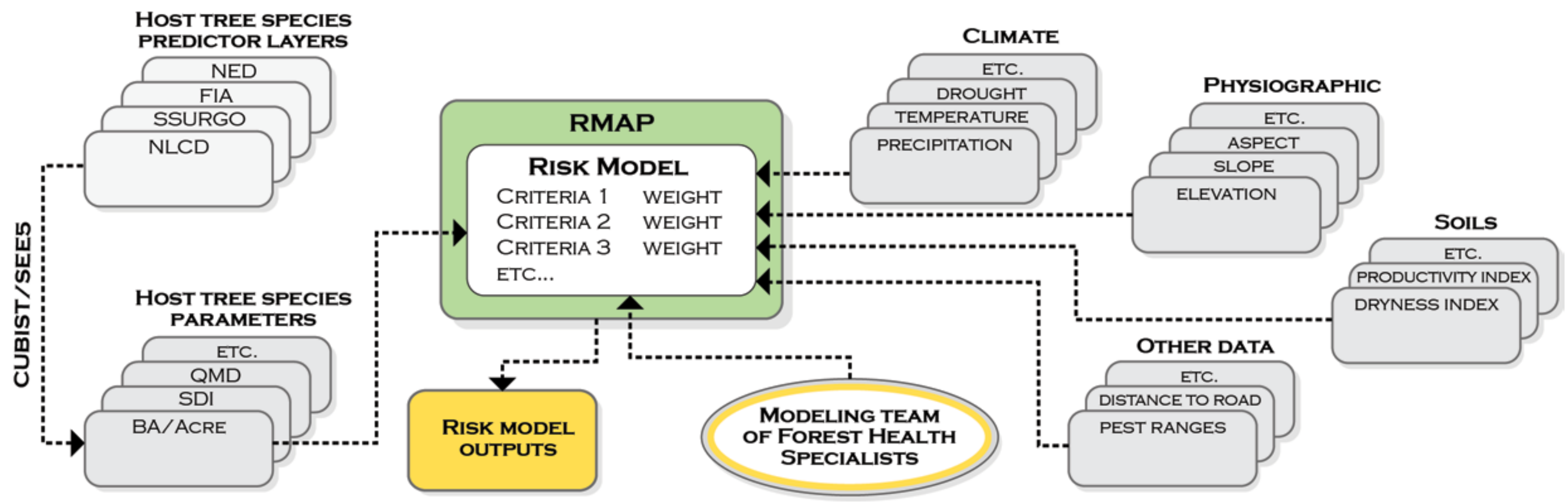


FIGURE 5 Risk modeling overview

FOREST HOST-TREE SPECIES PARAMETER DEVELOPMENT

Large portions of this section are taken from an in-process manuscript under the lead authorship of FHTET Remote Sensing Program Manager James Ellenwood (Ellenwood et al. In press).

The identification of areas at risk to a particular forest pest or pathogen first requires the production of host-tree species distributions and parameters, such as basal area (BA), stand density index (SDI), and quadratic mean diameter (QMD) (Krist et al. 2007). The accuracy and the precision of the risk models are largely determined by the quality of these host-tree datasets. **FIGURE 6** shows a simplified overview of how individual tree-species parameters were generated and used for risk modeling. The sections below provide important details on the host-parameter development process.

Numerous forest-type and range maps are available for the United States (e.g., Little 1971, 1977); however, these maps typically use classification schemes that describe commonly occurring species associations. For example, the "Northern Hardwood" association may contain sugar maple, red maple, white ash, hemlock, yellow birch, and American beech. Such generalized forest type datasets fail to provide key information on the density and distribution of individual host species, so they are of limited use in predicting pest behavior (Krist et al. 2007). In addition, many forest pests and pathogens are highly host-specific, and an individual tree species may or may not be present throughout the mapped association unit. Therefore, to adequately represent forest health risk and hazards, individual tree species distributions and densities are needed. To meet this need, the RMOT developed its own individual tree species (i.e. host) parameter layers for both the 2006 and 2012 assessments. The 2012 dataset involved a massive, multi-year effort by the FHTET Remote Sensing Program to develop raster surfaces of forest parameters for each of the tree species measured in the Forest Service's Forest Inventory and Analysis (FIA) program.

Statistical methods for modeling tree species extents tease out forest attributes by identifying unique site-specific spectral signatures from satellite imagery and patterns in parameters such as climate, terrain, and soil indices (Ruefenacht et al. 2008). For example, red and white pines may be difficult or impossible to distinguish through a spectral signature alone; however, when that signature is combined with a limiting factor, such as a known soil type, individual pine species can often be distinguished more precisely.

The previous versions of NIDRM utilized coarse renditions of forest host maps. The 2000 NIDRM employed a national forest-type map developed at a 1-kilometer scale (Lewis 2002). The map categories had broad definitions, which did not allow for modeling individual pests using forest parameters. The 2006 NIDRM utilized an Inverse Distance Weighting (IDW) interpolation of FIA plot data to produce 1-kilometer resolution surfaces depicting forest parameters (BA, SDI, and QMD) by tree species. Although host parameters were coarsely represented, it allowed forest health specialists to build models that were more representative of actual forest health conditions. The desire to improve the resolution of pest and pathogen models was the prevailing impetus for developing host layers at their original resolution of 30 meters. Due to data-processing concerns associated with using very large, national-extent, 30-meter datasets, all host layers were re-sampled to a 240-meter resolution prior to forest pest and pathogen model development in RMAP.

Unlike spatial surfacing method employed in the IDW in 2006, the 2012 NIDRM statistically models host distributions. The statistical modeling approach takes advantage of data-mining software and an archive of geospatial information to find the complex relationships between GIS layers and the presence/abundance of tree species as measured over 300,000 FIA plot locations. To describe in simple terms the difference between the 2006 surfacing and the 2012 statistical modeling methods, consider the challenge of estimating ponderosa pine BA between two plot locations: on one plot, 100 square feet per acre of BA is measured, while a neighboring plot measures 50 square feet per acre. An IDW surface would estimate 75 square feet per acre of ponderosa pine at a forested location midway between these two plots. In contrast, the 2012 statistical modeling approach generates a simple predictive model from what is known about ponderosa pine distribution and density, based on a GIS overlay analysis of FIA plots with thematic layers such as soils, slope, aspect, and imagery characteristics. The predictive model generated from this overlay analysis is then used to model (predict) ponderosa pine BA for our hypothetical midpoint using that location's values from the same set of thematic layers.

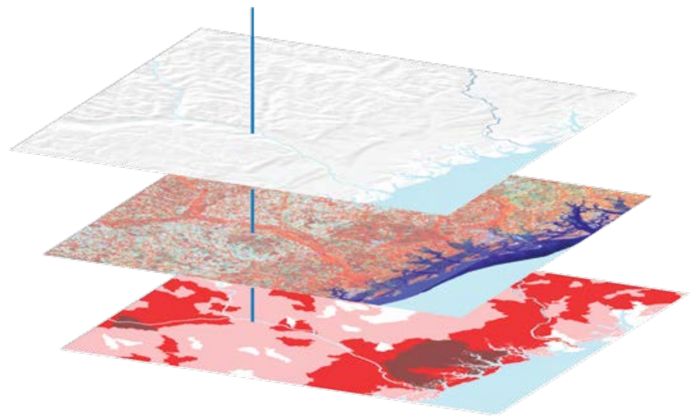
PREDICTOR LAYERS

The occurrence of an individual tree species within any given area depends upon a number of factors related to the environmental conditions, cultural practices, and the biogeography of the species. The approach for many species distribution models has been to model representations of these factors. A number of different predictive techniques and variables have been analyzed, and few standard modeling approaches have been accepted (Austin 2007, Elith and Graham 2009). Nearly all species-distribution model approaches focus on characterizing the presence/absence or relative dominance of the species of interest and very seldom address density measures such as BA or SDI.

Three domains are important with respect to tree species modeling: presence, density, and dominance. The presence of a species is an indication of its ability to become established on a site; the density of a species is an indication of how well a species can occupy a site; and the dominance of a species is an indication of how well it competes with other tree species on a site.

In order to expedite the development of host-tree species data layers and the 2012 NIDRM, existing national datasets were used to develop host-predictor datasets at 30-meter resolution and site-parameter datasets of non-host criteria (elevation, slope, aspect, soil moisture, etc.) at 240-meter resolution. These national datasets included the

1. National Land Cover Database (NLCD) 30-meter resolution, three-season, Landsat dataset (Homer et al. 2004);
2. USDA National Resource Conservation Service (NRCS) localized soils dataset, Soil Survey Geographic Database (SSURGO), and a regionalized dataset, STATSGO2 (Digital General Soil Map of the United States) (http://soils.usda.gov/survey/geography/ssurgo/index.html);
3. USDA Forest Service FIA nationwide forest inventory (Woudenberg et al. 2010);
4. National Elevation Dataset (Gesch et al. 2009); and
5. National Climate Data Center US standard normal data for 7,937 climate stations in the US (NOAA-NCDC 2001).

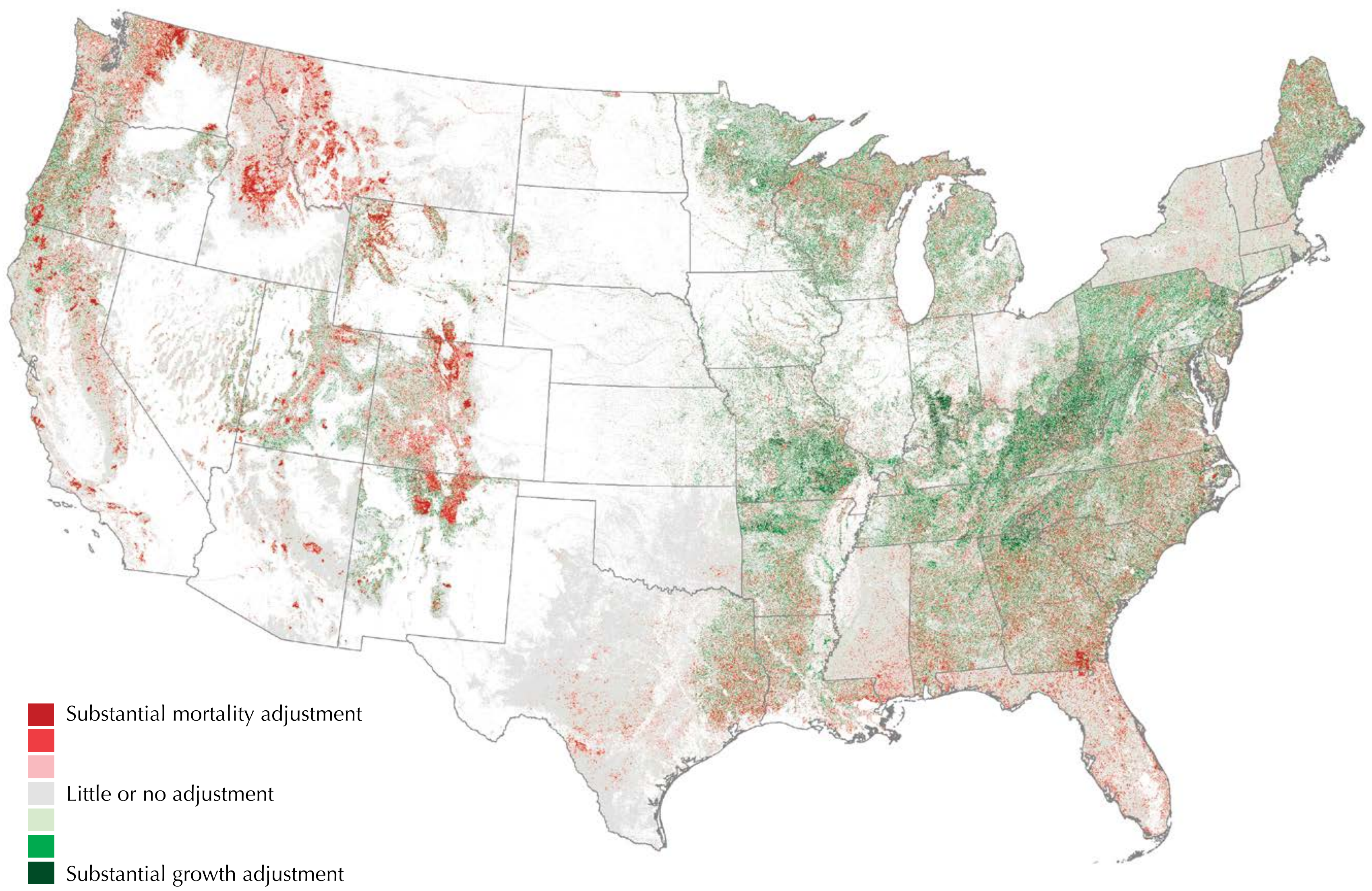


STEP A: Predictor layers and parameter samples

Establish relationship between predictor layers (Soils, Climate, Terrain, Landat satellite reflectance values) and individual tree species Basal Area (BA) and Density (SDI) measurements from hundreds of thousands of inventory plot locations.

STEP B: Parameter modeling

- Use statistical models to apply that relationship and generate initial BA and SDI data surfaces for 289 tree species.
- Outputs are adjusted to ensure, for example, that the sum of each individual tree species' BA at each location does not exceed a separately modeled total for all species' BA data layer.



STEP C: Tree growth and mortality layer used to adjust tree species parameters

- The vintage of the Landsat satellite imagery and the inventory plots is roughly 2002. To account for recent (2001 -2012) growth and mortality, MODIS satellite phenology datasets are used to further adjust BA and SDI outputs from step B.
- The final adjusted BA and SDI layers for each tree species are used to derive other forest parameters useful for risk modeling such as average diameter (QMD) and trees per acre.

FIGURE 6 Overview of individual tree species parameter development

Climate

Often, climate variables are significant for modeling individual tree species extents. Because climate is a broad characterization of conditions over a long period of time, it is difficult to represent local climate with any degree of certainty. Local climate at the fine scale is considered micro-climate and can be represented through terrain variables.

Several national climate layers exist; unfortunately, they range from 800 meters to two kilometers in resolution. In order to support development of host maps at 30- and 240-meter resolutions and simulate the potential effects of climate change within pest and pathogen models (discussed later in this report), we constructed 12 monthly climate variables each for precipitation, average mean temperature, average maximum temperature, and average minimum temperature, which could be used both as predictor layers for host parameter surfaces and as stand-alone climate criteria for NIDRM modeling.

Using the ANUSPLIN application (Hutchinson 1991) and techniques developed by Rehfeldt (2006), climate variables were simulated using 7,939 monthly station normals extracted from a CLIM81 (Climatography of the U.S. No. 81) 30-year (1971–2000) climate-normal dataset (NOAA-NCDC 2002). The monthly station normals were separated into two sets: one for the coterminous United States and the other for Alaska. For the coterminous United States, regression splines were built for precipitation from 7,467 stations. For three temperature variables (monthly average mean, monthly average maximum, and monthly average minimum), regression splines were built using 5,332 stations. For Alaska, regression splines were built for precipitation from the 124 stations. For the three temperature variables, regression splines were built using 119 stations. For the Southeast Alaska panhandle, the narrow nature of the landform in relation to the climate data stations proved to be problematic in creating splined surfaces that reflect expected climate surfaces. Instead, Rehfeldt's (2006) original spline models for western North America were utilized for this area. Seasonal moisture index and seasonal moisture precipitation were derived from the ANUSPLIN-generated climate variables utilizing techniques from Crookston (in Rehfeldt 2006).

Soils

Two components of soils are significant in forest type mapping: water holding capacity and productivity (Schaetzl et al. 2009). However, current metrics available from the NRCS, such as available water holding capacity (AWC), do not adequately describe natural soil wetness. This is because measures such as AWC reflect only the ability of a soil series to retain and release water to plants, not the long-term mean amount of water that is in the soil.

In order to address this data gap, a soil drainage index (DI) layer was developed from SSURGO and STATSGO2 soil databases by Schaetzl et al. (2009) for use in forest pest and pathogen modeling (Krist et al. 2007) and forest host modeling. The DI indicates the relative amount of water (wetness) that a soil contains long-term and makes available to plants under normal climatic conditions. It is not meant to mimic the concept of plant-available water, which is largely dependent on soil texture. The DI only secondarily takes soil texture into consideration.

The main factors affecting DI are the depth to the water table, soil moisture regime, volume available for rooting, and soil texture. The DI is calculated primarily from the soil's taxonomic subgroup classification in the U.S. system of soil taxonomy (Soil Survey Staff, 1999). Drainage index values range from 0 to 99; the higher the DI, the more water a soil can supply to plants. Sites with a DI of 99 are almost constantly waterlogged, while a soil with a DI value of 0 is almost thin and dry enough to be bare rock or raw sand. Because a soil's taxonomic classification is not (initially) affected by such factors as irrigation or artificial drainage, the DI does not change as soils are irrigated or drained, unless the long-term effects of this involve a change in the soil's taxonomic classification. Instead, the DI reflects the soil's *natural* wetness condition.

The Productivity Index (PI) is an ordinal measure that represents the productivity of a soil (Schaetzl et al. 2012). A layer for PI also was developed from the SSURGO and STATSGO2 soil databases. The PI uses family-level soil taxonomy information (i.e., interpretations of taxonomic features or properties that tend to be associated with low or high soil productivity) to rank soils from 0 (least productive) to 19 (most productive). The index has wide application because, unlike competing indices, it does not require copious amounts of soil data (pH, organic matter, or cation exchange capacity, etc) in its derivation. For regionally extensive applications, such as NIDRM and host modeling, the PI may be as useful and robust as other productivity indexes that have much more exacting data requirements.

PARAMETER SAMPLES

FIA data were extracted from FIADB v4.0 (Woudenberg et al. 2010) for the plot and tree data. Plot data were limited to state inventory cycles that were aligned most closely with the imagery dates and generally ranged from 1999 to 2005, with some plots in the western United States sampled as late as 2009 (**FIGURE 7**). Approximately 80% of the FIA plots were sampled within five years of collection dates for corresponding NLCD project, 30-meter, three-season, Landsat imagery (**FIGURE 8**). Tree data were limited to live trees and trees of one inch diameter at breast height (DBH) or greater.

For Alaska, annualized FIA inventories were limited to south-central and southeastern-panhandle areas. Interior Alaska plots were installed in limited areas and do not provide complete coverage of the forested area. These interior Alaska plots date from 1968 to 1991 and utilized an older variable plot-radius cluster design.

A *Memorandum of Understanding* was signed by each of the FIA unit directors and the FHTET director to allow FHTET to utilize actual FIA plot coordinates. Spatial data for the requested cycles in each of the States were acquired from the FIA Spatial Data Services unit. Best-available plot coordinates were extracted from FIA in February of 2011.

FIA plots were installed using the annualized FIA plot design, consisting of four 1/24th-acre subplots for larger trees (≥ 5 inches DBH) nested with 1/300th-acre subplots for saplings (1 inch to < 5 inches DBH) (Bechtold and Patterson 2005). FIA subplots were used in the forest parameter modeling to improve the precision of the parameter samples. Sub-plots were linked to the FIADB header data and the installation date was used to calculate magnetic declination for each sub-plot location using the U.S. Geological Survey (USGS) magnetic declination and secular variation datasets (Tarr 2000a, 2000b). Sub-plot locations were determined based upon the calculated magnetic declination and the plot design using an equidistant-azimuthal projection from the plot center.

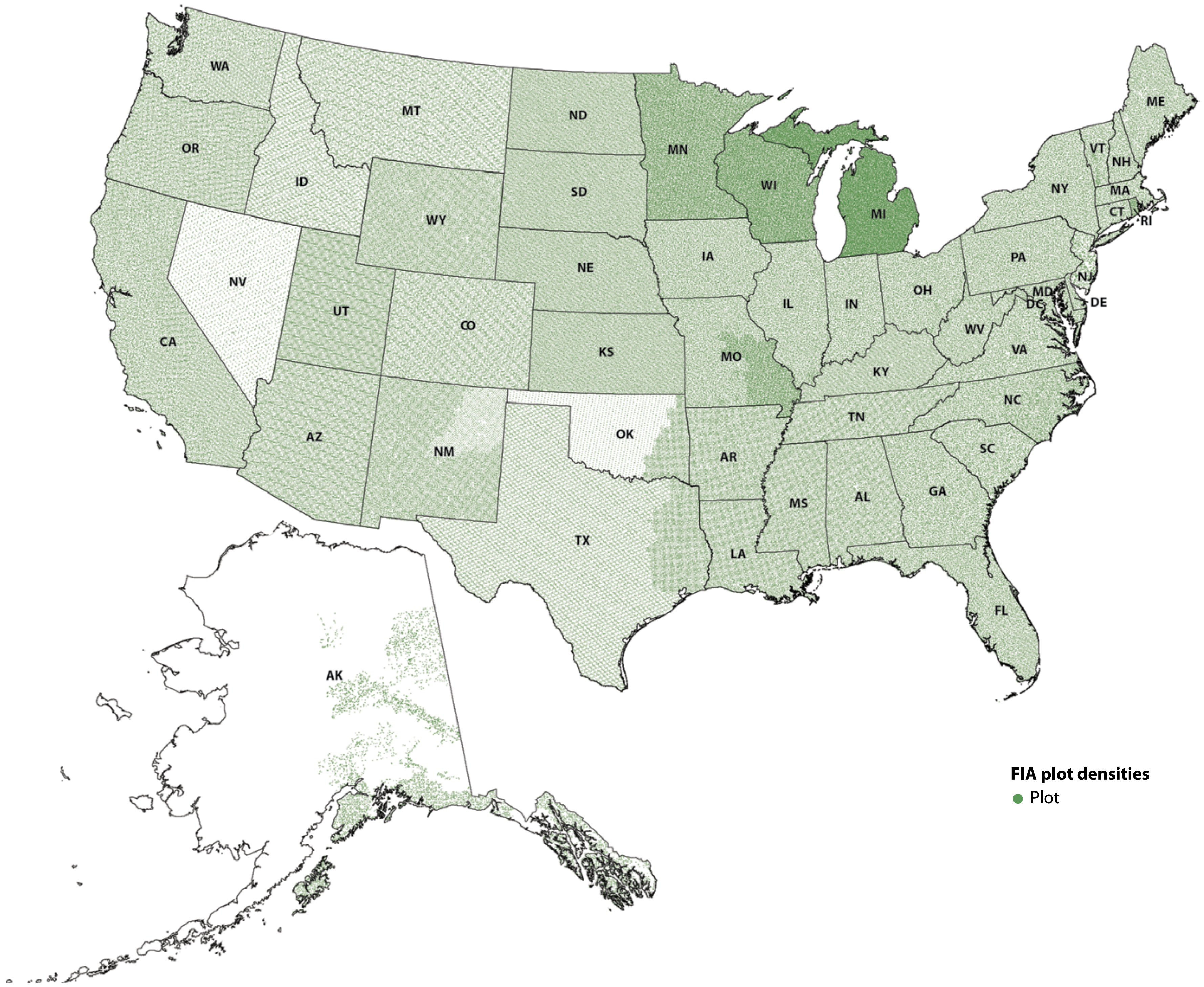


FIGURE 7 Distribution of FIA plot data used to create tree species parameters

To supplement the FIA plots, tree inventory data were also acquired from Forest Service Pacific Northwest and Southwest Regions, the Great Plains Initiative (GPI) non-forestry inventory (Lister et al. 2012), and the Bureau of Land Management (BLM) Oregon State Office. Plot locations identical to FIA locations were eliminated, with the FIA data being given priority. The GPI dataset used single isolated points, while the other non-FIA datasets used a five-point, cluster-plot design installed on an intensified grid. Predictor sample files were linked to the subplot coordinates and parameter summaries. Parameter null values were set to 0 to reflect the absence of a given species on a subplot.

PARAMETER MODELING

Tree species presence/absence, BA, and SDI were constructed from a stack of independent variables (predictor layers discussed above) using a classification and regression tree (CART) modeling method. FIA researchers have frequently used CART for modeling forest type and parameters (Blackard et al. 2008, Ruefenacht et al. 2008). Loh (2011) describes CART as, "…machine-learning methods for constructing prediction models from data. The models are obtained by recursively partitioning the data space and fitting a simple prediction model within each partition. As a result, the partitioning can be represented graphically as a decision tree."

The advantage of a species-specific approach is that models are optimized for a given species. The disadvantage of this approach is that each individual species model is created independently of the others and anomalies between models occur. We decided the species-specific approach would provide a better risk assessment, because insect and disease risk models are keyed to individual tree-species parameters.

The presence/absence of total (all species) live tree basal area greater than one inch DBH was independently modeled from the predictor sample files using See5, version 2.06. The model derived from

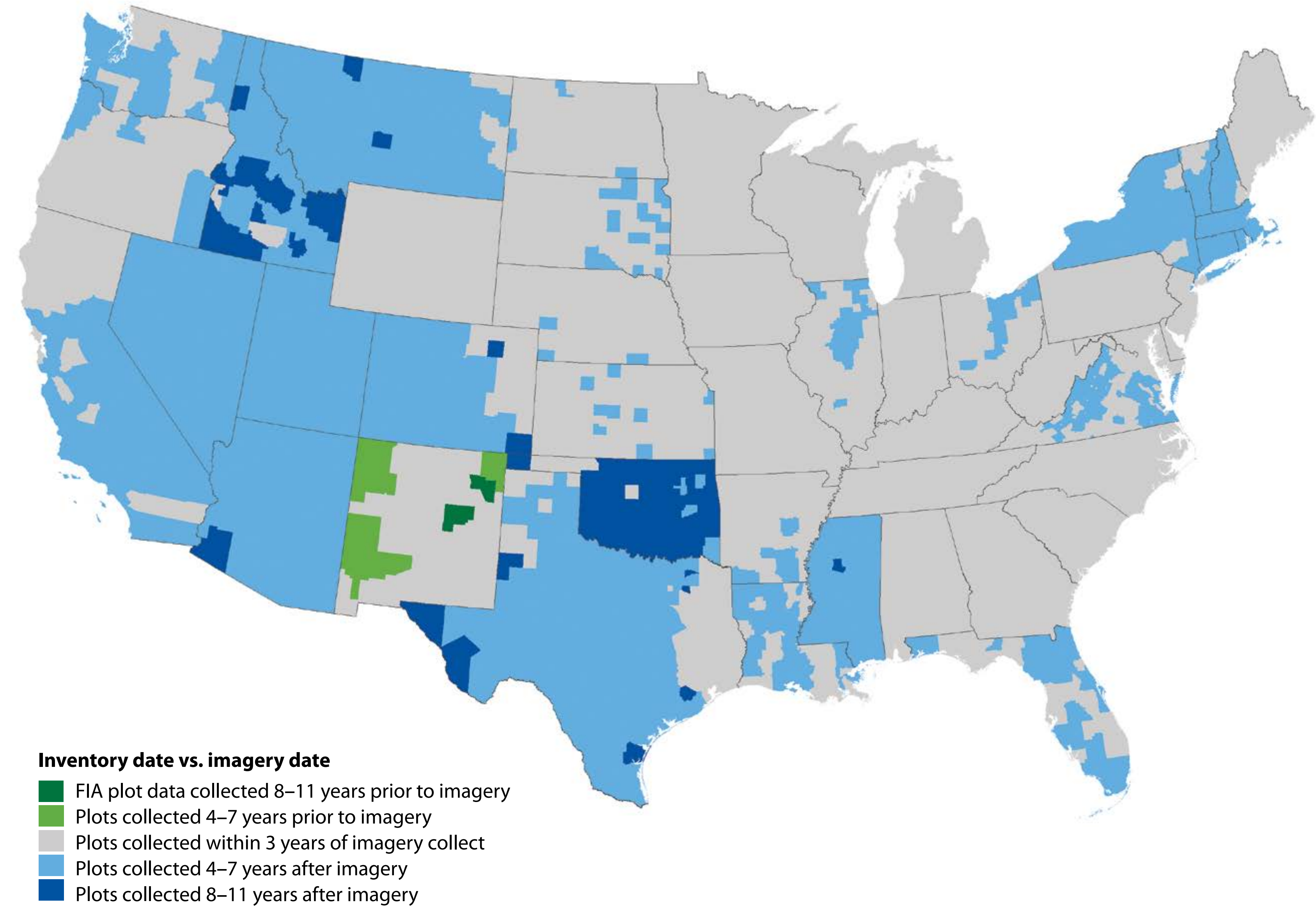


FIGURE 8 Acquisition date differences between FIA plot data and Landsat imagery

See5 was converted to a raster surface using the RSAC Cubist/See5 toolset (Ruefenacht et al. 2008). We consider this layer a geospatial representation of treed area, and it was utilized as a subsequent mask for all other host layers. The minimum density that can be measured on an FIA sub-plot is 1.7 square feet per acre of trees over one inch DBH. Therefore, a single pixel cannot represent less than 1.7 square feet per acre.

A set of models estimating BA and SDI for all tree species was generated from Cubist, version 2.07, using selected layers available in each of the predictor sample files. The RSAC Cubist/See5 toolset was used to convert models from Cubist to geospatial representations of host parameters.

Methods for developing forest parameter layers for Hawaii differed significantly from the process used for the rest of the United States The absence of FIA plots and limited validation data led to a reliance on species range maps obtained from a variety of sources, including the 2004 HI-GAP land cover data (US Geological Survey 2011), LANDFIRE Existing Vegetation Type and Existing Vegetation Cover data (Rollins and Frame 2006), and the NLCD canopy closure layer (Homer 2004). Host presence maps were then reviewed for accuracy by local forestry and forest health experts. Local experts also provided hand-digitized polygons depicting areas of host presence and density. Reviewer comments were incorporated into a new iteration of host maps; some areas were removed, others added, and then new maps were made available for additional review. All host presence maps were assembled at a 30-meter resolution.

GROWTH AND MORTALITY ADJUSTMENTS

For the coterminous United States, host parameter layers were derived from ground inventories and imagery datasets that contain information collected from various time frames. With image collection dates ranging from 1985 to 2005, and a mean collection date for treed areas of 2002, the vintage of the resultant parameter datasets should be considered as 2002. Plot-data evaluation datasets were purposely selected to closely correspond to the satellite imagery (**FIGURE 8**). However, for any specific area, the mismatch between ground measurements and imagery collection dates can be significant.

For most eastern states, the annualized inventory has been installed on a 5-year cycle, while nine of the twelve western states' inventories have been installed on a 10-year cycle. For this project, ground data included inventory panels collected prior to the completion of the western panels (up to the 2009 inventory year). Given these regional differences in survey frequency and plot intensity in the United States, the differences in imagery collection and plot measurement dates in the East are less substantial than in the West. In California, Oregon, and Washington, intensified plots on Forest Service and BLM lands were included to offset the incomplete representation of FIA annualized panels. Though not annualized, inventories in Nevada, Wyoming, and New Mexico are older but have a vintage that is close to satellite imagery collection dates. New Mexico plots date from 1985 to 1999; as a result, they may be the least representative of current forest conditions.

Despite these date discrepancies, a county-based validation of the 2002-vintage parameters shows that modeled cumulative BA appears to be within -3% of the 2011 FIA estimate (current as of 2/28/2013). In order to better represent 2012 conditions, forest parameter outputs were then post-processed to account for growth and mortality that occurred between 2002 and 2012. With this adjustment, the modeled cumulative BA is within -4% of the current 2011 FIA estimate. Due to the frequency and nature of the FIA inventory, recent mortality is often under-represented in FIA estimates.

The adjustment process for the coterminous United States utilized a MODIS phenology dataset (2001–2010) from NASA-Stennis (Hargrove et al. 2009, McKellip et al. 2010) and the FHTET Pest Portal Forest Disturbance Mapper (FDM) (http://foresthealth.fs.usda.gov/portal/FDM) dataset (2008–2012). The NASA-Stennis dataset was utilized for the entire coterminous United States, whereas the FDM dataset was utilized in key portions of Colorado, Utah, and Wyoming to account for recent fire and mountain pine beetle mortality. Building upon techniques developed by Hargrove et al. (2012), a linear regression was performed on a stack of the annual 80% Normalized Difference Vegetation Index (NDVI) layer for the years ranging from 2001 to 2010. Geospatial products of the resultant regression slope (greenness trend) and regression *r*-square were created.

A second set of regressions was created in order to scale the phenology regression layers. A collection of approximately 170,000 re-measured FIA sub-plots was used to create an annual BA percent change (including both growth and mortality), by subtracting current-period BA from the previous-period BA and dividing the result by the period length between plot measurements.

Two versions of annualized change (growth and mortality) models were created. The first version employed the phenology slope and the *r*-square layers as independent variables with annualized change as the dependent variable. Visual inspections with the past insect and disease aerial survey data and large-fire occurrences indicated that the layer generated from this annualized change model underestimated mortality. A second model was created with the phenology slope independent variable weighted by the *r*-square variable to predict annualized change. In an effort to compensate for the under-representation of mortality, the annualized change regression was shifted to set the dependent variable intercept to 0.

For each county, the average ground-plot collection year was subtracted from 2011 to compute an average inventory age (in years) and limited from 1 to 10 years. This inventory age layer was used to weight the annualized BA percent-change layers. From the two annualized change layers, a composited annualized-change product was generated by giving preference to the greater negative change (mortality) over the positive change (growth). The composited BA percent-change layer was applied to each of the host layers to account for growth and mortality as observed from the phenology change layers, thus giving the input forest parameters datasets a 2012 time-stamp. The final tree growth and mortality layer used to adjust the host layers in this assessment are represented in **FIGURE 6,** page 6.

As with the coterminous United States, Alaska host-parameter layers were derived from ground inventories and imagery datasets that contain information from various time frames. Image collection was limited to early summer and late summer, with collection dates from 1994 to 2006. Coastal Alaska ground samples were collected on a ten-year annualized inventory with collection dates from 2004 to 2009. Interior Alaska had a very limited dataset, with dates from 1968 to 1994. Given the age of the Interior Alaska dataset and the lack of coverage, the representation of the current forest conditions is less than ideal, and a vintage is difficult to determine.

Unlike adjustments for the coterminous United States, the growth and mortality adjustment for Alaska was limited to fire-related mortality. Input for fire-related mortality was taken from the Monitoring Trends in Burn Severity (MTBS) archive (Eidenshink et al. 2007). All MTBS data were collected between 2001 and 2008 (the most recently available data in 2011). Each burn severity class was assigned a percent BA-loss rate: Unburned/Very Low (0% loss); Low Severity (25% loss); Moderate Severity (50% loss); and Severe Severity (75% loss). The 30-meter dataset was up-scaled to 240-meter resolution by applying an average of the quantitative percent-loss values. The 240-meter percent-loss dataset was applied to each of the forest parameter layers to yield a dataset with an approximate representation of forest conditions in 2008.

ADDITIONAL MODEL INPUTS

Many forest health risk and hazard models utilize metrics such as percent-host composition, quadratic mean diameter (QMD), and trees per acre (**TABLE 1**, page 4). However, these metrics are difficult to model directly; therefore, they were derived from modeled SDI and BA parameters, instead.

While host layers are the most critical model inputs, a variety of other data sources are important for running pest and pathogen risk models. Apart from host parameters specifically modeled for the 2012 NIDRM, over 600 layers representing various characteristics important to understanding risk agent behavior were included in the SDL for use in RMAP. These layers include monthly and annual climate parameters, pest and pathogen ranges, land use, soil characteristics, topography, census data, and plant hardiness zones, among others. Several of these layers were discussed in detail in the previous section and are grouped in **TABLE 1** by general category.

Drought layers were not used to model the forest host surfaces; however, drought was a key criterion in many of the NIDRM models and merits further explanation. Drought index and frequency data layers were derived from PRISM climate data (www.prism.oregonstate.edu) consisting of precipitation and temperature grids for every month from January 1895 to October 2009. From the temperature grids, together with latitude, monthly potential evapotranspiration (PET) grids were derived. From PET and precipitation grids, a dimensionless monthly moisture index (scaled between -1 and 1) was computed for each grid cell. Twelve-, 36-, and 60-month (1-, 3-, and 5-year) running average moisture indices were derived for each year, and then normalized to derive 1-, 3-, and 5-year moisture-index departure scores, which can be classified into moisture deficit or surplus classes that range from extreme moisture surplus to extreme drought. Drought frequencies of 1-, 3-, and 5-years were derived from the drought index departure layers, and represent the proportion of times grid cells experience moderate, severe, or extreme drought (Koch et al., in press). ♦

The change from a 1-kilometer to 240-meter spatial resolution moves the 2012 NIDRM closer to a product that may be used to inform local and regional decision-making.

DATA USE GUIDELINES

We offer two basic guidelines for the appropriate use of information derived from the 2012 risk assessment.

1. **Maximum Display Scale** To highlight meaningful patterns of risk and avoid maps that appear pixilated, NIDRM and any of its derivative products should be displayed at a maximum scale ranging from 1:250,000 to 1:500,000. At the 1:250,000-scale, a typical eastern US county will plot onto an 8.5 x 11-inch sheet of paper (a map extent that covers approximately 500,000 acres or 800 square miles). At this resolution, users with local knowledge can view enough map area to understand broader landscape-level magnitudes and patterns of risk and still be zoomed-in close enough to associate blocks of risk with familiar forest landscapes. A 240-meter pixel covers approximately 14 acres, a typical area for delineating forest stands. Zooming in closer than 1:250,000-scale invites a per-pixel, stand-level type analysis that *is not* the intended or recommended use of NIDRM.
2. **Minimum Analysis Unit** NIDRM is primarily a national planning tool designed to describe broad regional and national trends. Inquiries regarding units smaller than a county or national forest should be posed to regional and state experts, who may have conducted finer-resolution risk assessments and are familiar with local variation. Local implementation of finer-resolution assessments will be encouraged by continued development of 30-meter datasets and the RMAP application.

DATA FLEXIBILITY AND WATERSHED ANALYSIS UNITS

A major advantage of the NIDRM modeling framework is that, in addition to its representation of the discrete risk/no-risk classes, it allows for the production of maps depicting continuous data, such as BA losses. In turn, this allows the data to be summarized in a variety of ways at local, regional, and national scales. Depending upon analysis objectives, potential pest and pathogen impacts might be characterized by individual tree and pest species (or their combination) in multiple ways. For example, it may not be practical to treat specific areas with the highest risk potential, while areas at or near an intermediate mortality threshold may be better candidates for management. Here are some common examples.

- Acres with any amount of host impact by pest or pest combination can be used to determine the affected area or "footprint" on the ground.
- Acres with impacts over any user-defined BA loss threshold can be used to prioritize areas for management and restoration.
- BA loss by geographic region, by pest, host, or combinations of these can be used to identify areas
  - where individual tree host species may be extirpated or severely impacted,
  - that require further monitoring, or
  - that have management or restoration potential.
- The proportion of host BA loss and/or total BA loss can be used to determine overall impacts on the forest.

It can be difficult to clearly display regional patterns when 240-meter cells are used to represent risk. Throughout the remainder of this report, NIDRM outputs are often summarized by 12-digit or 6th-level USGS subwatersheds, which we refer to as "watersheds." These 10,000- to 40,000-acre units are consistent with those in the Forest Service *Watershed Condition Framework* (Potyondy and Geier 2011). At regional and national scales, watershed summarizations make it easier to visualize these patterns and provide a good basis for discussing how best to target local resources and respond to detailed inquiries. There are two types of cumulative (i.e. combined hazard from all agents) watershed summaries presented in this report.

1. Percentage of treed area at risk—allows comparisons between watersheds regardless of their differences in overall BA or proportion of treed area.
2. Ranking of watersheds by the amount of BA loss—identifies the watersheds with the greatest potential BA loss.

To create the percentage of treed area at risk by watershed, first we counted the number of 240-meter cells in each watershed that are at risk, and then determined the area these cells represent. Then, we determined the proportion of treed land at risk by dividing the area of the cells at risk in a watershed by the total treed area in a watershed.

We calculated the ranking of potential BA loss by adding together all the 240-meter cells with BA loss occupying each watershed. Once summed, we divided the BA losses across all watersheds into 100 classes through an equal-area stretch. The equal-area stretch begins by ranking watersheds based on the amount of BA loss. Next, the equal-area stretch assigns each watershed to a category and ensures that a nearly equal number of watersheds occupy each category. Watersheds are assigned to only one category and are not split among categories. Depending on watershed size, some classes may contain slightly more area than other classes. Finally, we divided the 100 classes into five categories: 1) little or no loss, 2) the 49% least impacted watersheds, 3) 50% –74%, 4) 75%–95%, and 5) top 5% - most severely impacted watersheds.

In some cases, watersheds that are categorized as having little or no risk as a percentage of treed area at risk may still have significant potential BA losses. For example, in the Southeast Alaska panhandle, where there are very productive forests, potential BA losses may be substantial but never meet or exceed the risk threshold of 25% BA loss over the next 15 years for any 240-meter pixel.

Summarizing by watershed enables integration with the Forest Service Watershed Condition Framework (WCF) (Potyondy and Geier 2011). In an effort to focus resources, the WCF establishes a consistent, comparable, and credible process for assessing and improving the health of America's watersheds. In 2011, priority watersheds were identified and Watershed Restoration Action Plans were issued for the National Forest System. The 2006 NIDRM was part of this watershed prioritization process, and it is our intent to continue to support the WCF through the development of watershed summaries for the 2012 assessment.

Watershed summaries by agent and composite, all-agent, risk-pixel maps are useful for clear portrayals of NIDRM outputs at a national extent. However, behind these summaries are NIDRM outputs that show continuous estimated BA loss values for individual pests and pathogens at a 240-meter cell resolution. These data can be valuable for local analyses approaching our recommended maximum scales and are available from the 2012 NIDRM website www.fs.fed.us/foresthealth/technology/nidrm2012.shtml. These full-resolution, agent-specific datasets for the ~500,000 acre Sam Houston National Forest in east Texas are shown in **FIGURE 9**.

ACRES AT RISK AND CONTRIBUTING AGENTS

The 2012 national risk assessment employed 186 risk-agent models, representing 43 agents or groups of agents acting on over 60 tree species or species groups. It is common for multiple pests to act on a single location (**FIGURES 10** and **11,** pages 14, 16). Outputs from all models were composited into NIDRM, resulting in about 81 million acres at risk (**FIGURES 12** and **13**, pages 17, 18). Watersheds by percentages of treed land at risk are shown in **FIGURES 14** and **15**, pages 20, 22); watersheds by the absolute amount of BA loss are ranked in **FIGURES 16** and **17**[**] (pages 23, 24).

NIDRM displays approximately 9.5 million acres at or above the 25%-mortality threshold in Alaska, almost 72 million acres in the coterminous United States, and just under a half a million acres in Hawaii. The combined total of approximately 81 million acres represents about 6.7% of the 1.2 billion acres of modeled treed lands within the United States. Of the combined risk, 44% is distributed across state, private, tribal, and other non-federal ownerships (**FIGURES 18** and **19,** pages 26, 28), while almost 56% is located on National Forest System, and other federal lands. Insect and disease risk on tribal lands— 2.3 million acres— is highlighted in **FIGURE 22** (page 32). Many of these tribal areas occupy arid and/or sparsely forested landscapes; therefore, the risk is generally not as widespread as on adjacent lands. However, pinyon ips on the Navajo Reservation in Arizona, Douglas-fir beetle and root disease on the Colville Reservation in northeastern Washington, and forest tent caterpillar, emerald ash borer and oak decline on tribal lands in northern Minnesota are areas of concern.

We included 43 risk agents or groups of agents in this study. Predicted basal area (BA) losses were summed for risk agents, such as mountain pine beetle, a native bark beetle, that required multiple models to represent different ecoregions and hosts. These losses include all areas with potential for activity both above and below the 25% BA mortality threshold. The risk agents, categorized into guilds, facilitate comparisons between and within guilds. Although all root diseases collectively present the greatest individual agent-level hazard, all bark beetles collectively are projected to be responsible for nearly three times the BA mortality of root disease over the next 15 years (**TABLE 2,** page 34).

When summarizing risk by Forest Service region, Region 8 has the most acreage at risk, despite having the lowest proportion of treed to non-treed area at risk (**TABLE 3,** page 35; **FIGURE 13,** page 18). Region 8's risk profile contrasts sharply with Region 1, which has a much higher proportion of treed area at risk than any other region. This contrast can be attributed to the significant amount of bark beetle and root disease activity across Region 1 (**FIGURE 21,** page 30; **TABLE 3,** page 35), where agents individually contribute 25% or more to the total BA loss and a higher number of risk agents acted on tree species across the western regions (**FIGURES 10** and **11,** pages 14, 16). In addition, a large majority of Region 8 is treed, while vast areas of Region 1 contain few or no trees. Also, treed areas across Regions 8 and 9 contain a greater mix of tree species, which hinders the spread, and reduces the overall damage, of host-specific pests and pathogens, such as bark beetles.

Idaho, Montana and Oregon are at the top of the list both in absolute acres and proportion of their treed lands at risk (**TABLE 4**, PAGE 36). The top three risk agents in Idaho and Montana are root disease, Douglas-fir beetle and mountain pine beetle (**FIGURE 21,** page 30). Oregon has a similar cohort with stronger impacts from western spruce budworm as well as mountain and western pine beetles. In the eastern United States, Rhode Island, Connecticut and Massachusetts together have the largest proportion of treed area at risk, principally due to oak decline, winter moth, and root disease. Among southern states, Louisiana has the highest, projected percentage of treed area at risk, largely due to hazards from southern pine beetle, root disease and oak decline.

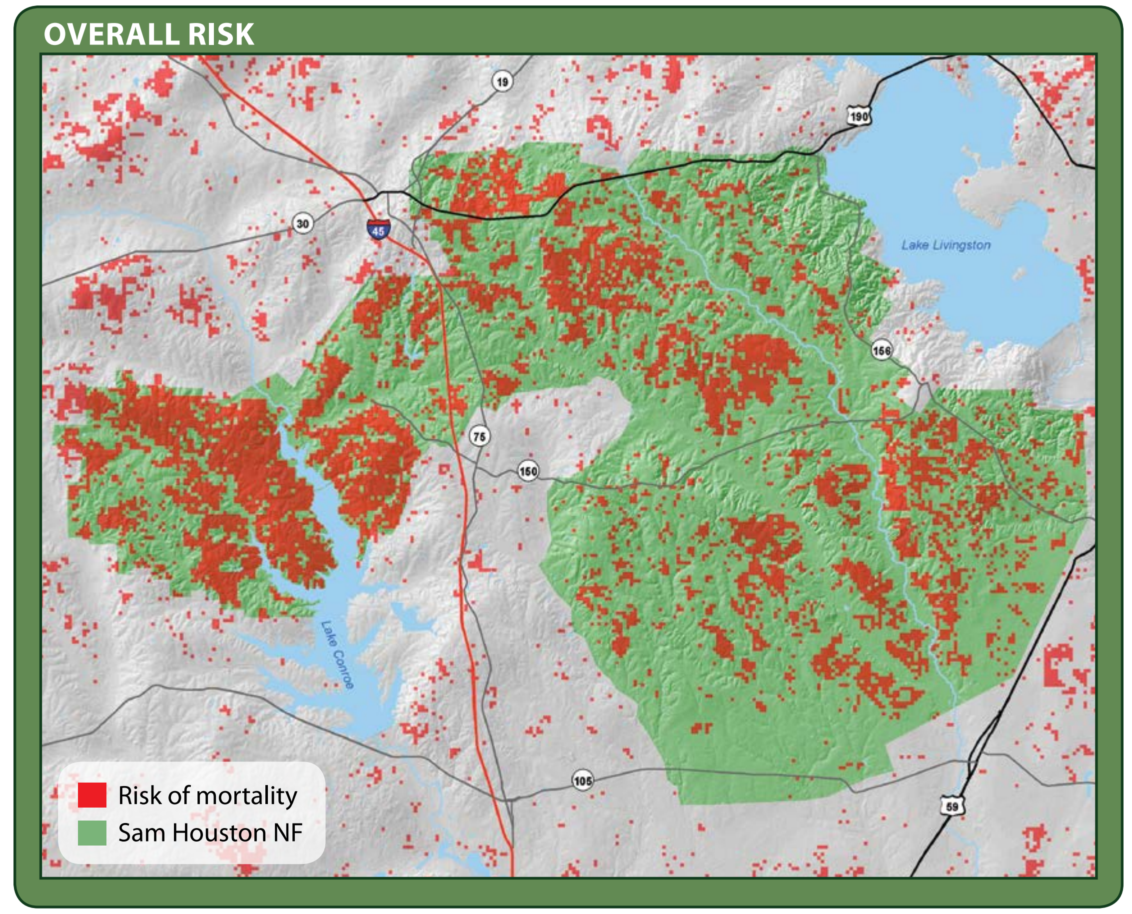
In Alaska, large areas are subject to spruce beetle and northern spruce engraver risk. Myoporum thrips and koa wilt are the two most significant risk agents in Hawaii (**FIGURE 20**, page 29).

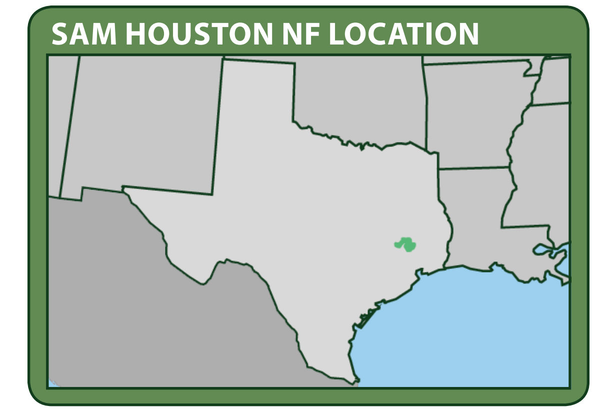
A notable change from the 2006 risk assessment is the increase in the proportion of acres at risk in Region 6, which can be attributed mostly to bark beetle and western spruce budworm activity (**TABLE 3,** page 35). Across Region 2, and despite recent losses due to fires and mountain pine beetle (USDA 2012), a high proportion of treed area remains at risk due to spruce beetle, continued bark beetle activity, and root disease. Since 2006, Region 10 appears to have experienced a notable increase in acres at risk (acres in 2006 v. acres in 2012) (**FIGURE 12**, page 17); however, this change is due to significant improvements in our ability to model host extents and forest parameters, not necessarily an increase in pest and/or pathogen activity.

Results/Discussion, *continued, page 37*

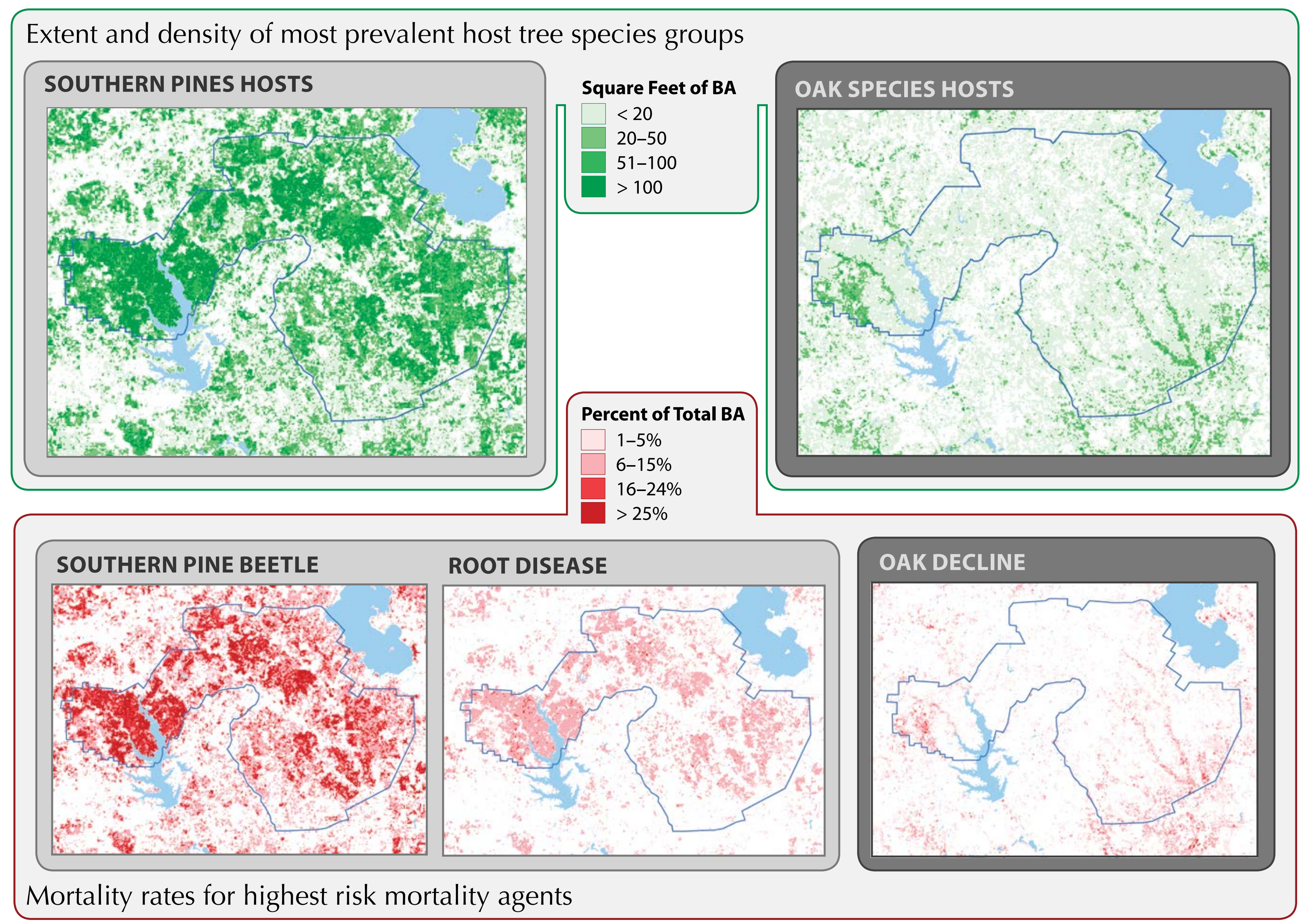
[**]Most of the national maps in this report use a technique called 'shaded relief' that allows us to portray variations in terrain relative to each map's subject matter. Data used to derive the terrestrial shaded relief are from the USGS National Atlas website http://nationalatlas.gov/atlasftp.html. Great Lakes and ocean bathymetry were adapted from imagery available at the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center website http://www.ngdc.noaa.gov/ngdc.html.

FIGURE 9



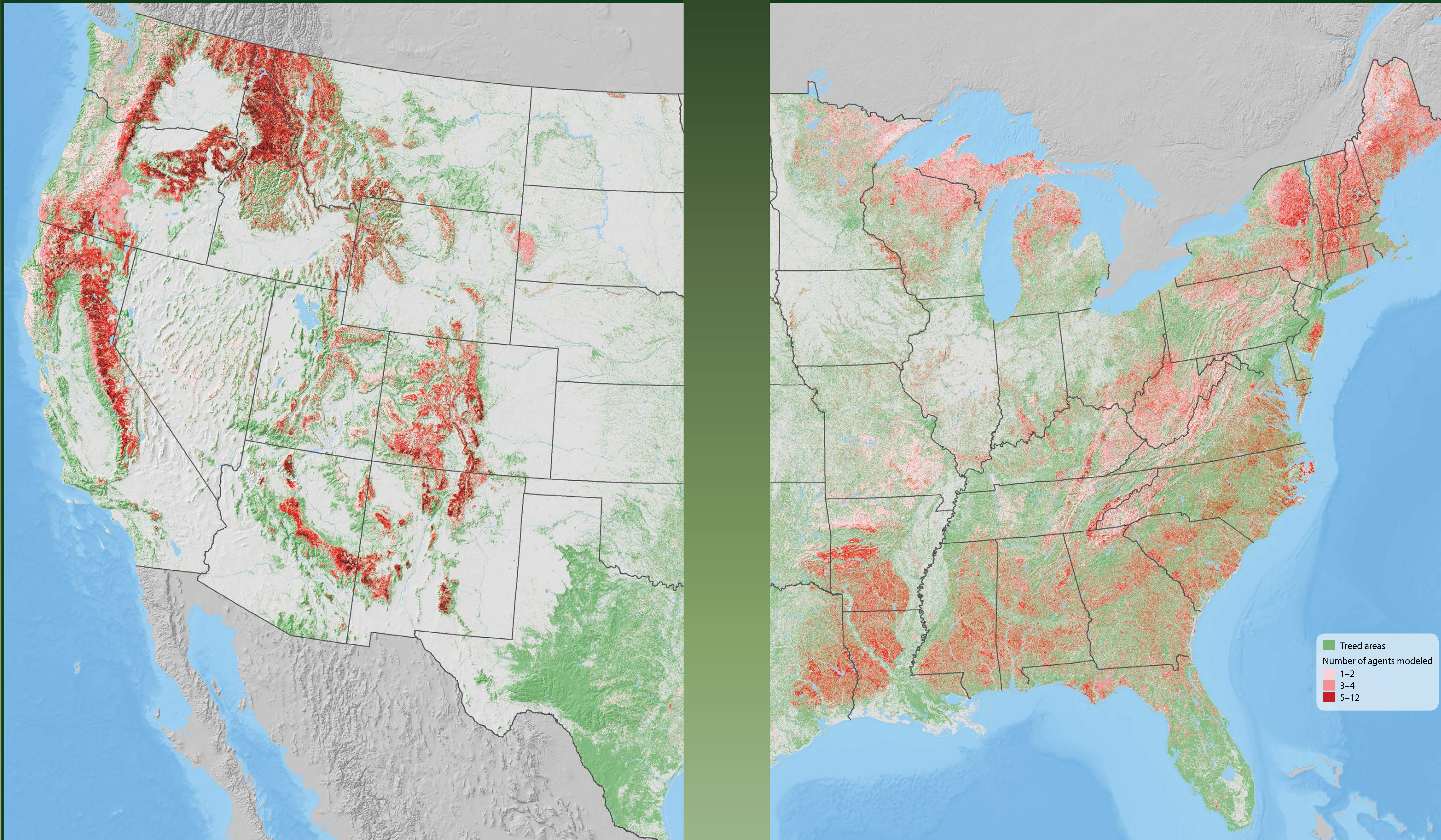


PEST OR PATHOGEN (All numbers are rounded)	**Host's % of Total BA**	**Host BA Loss Rate**	**Total BA Loss Rate**
Southern pine beetle	70.4%	22.2%	15.6%
Root diseases	70.4%	8.3%	5.8%
Engraver beetles (*Ips* spp.)	70.4%	2.5%	1.8%
Fusiform rust	66.4%	0.3%	0.2%
Oak decline	9.6%	8.9%	0.9%
Emerald ash borer	0.1%	10.4%	<0.05%
IMPACT FROM ALL AGENTS			**24.3%**



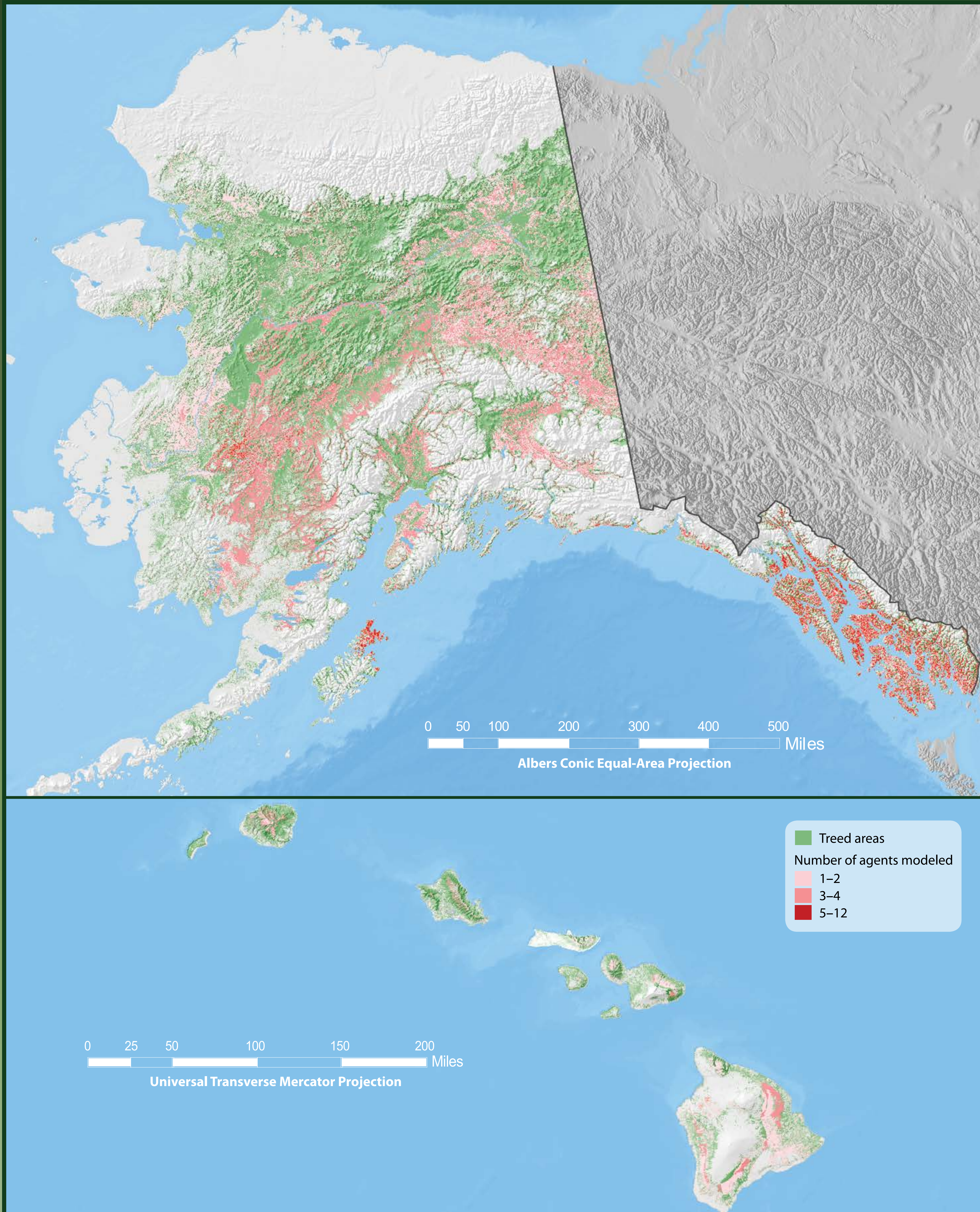
Number of Mortality Risk Agents Modeled on Any Given Location

FIGURE 10



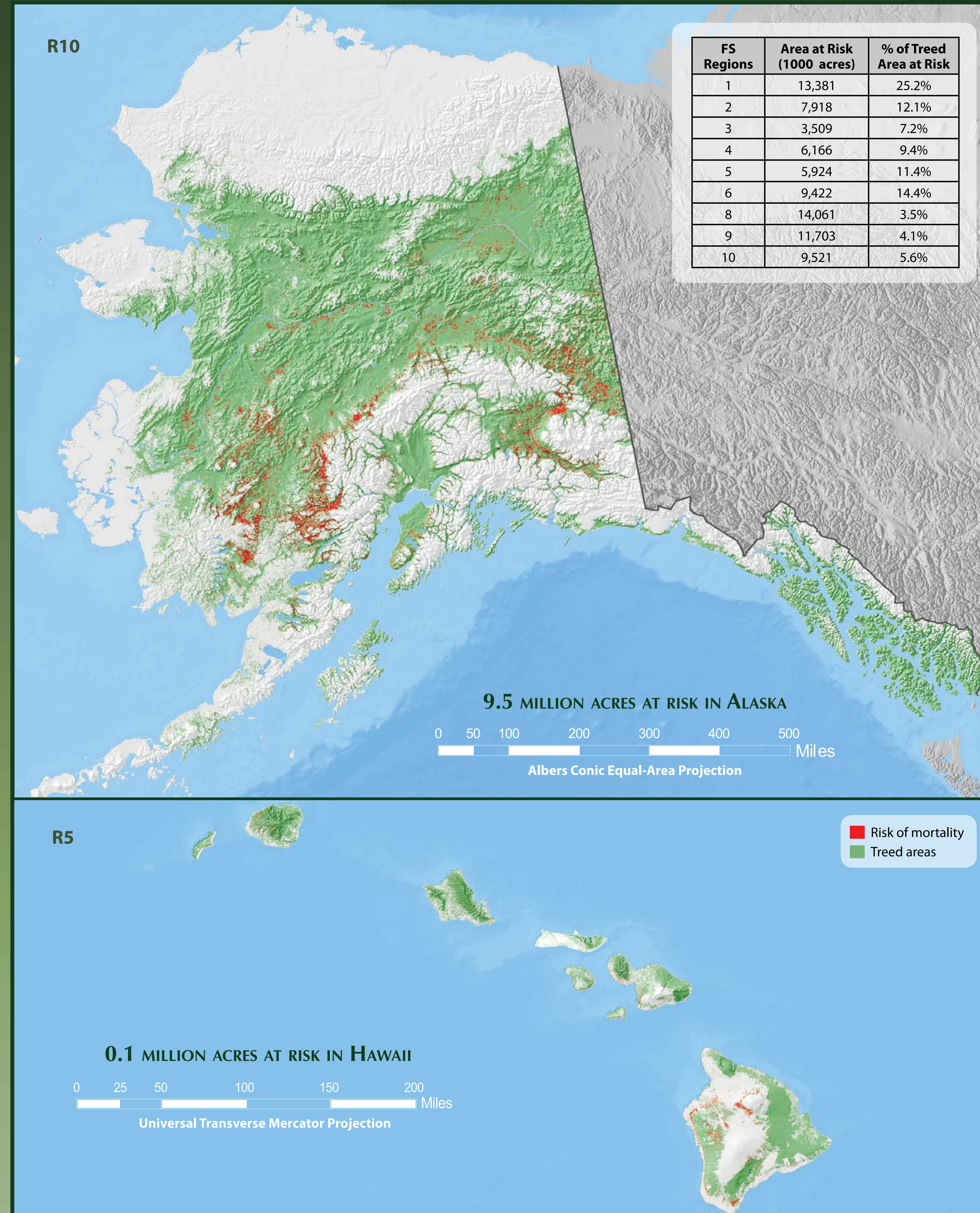
Number of Mortality Risk Agents Modeled on Any Given Location

FIGURE 11



National 2012 Composite Insect and Disease Risk Map

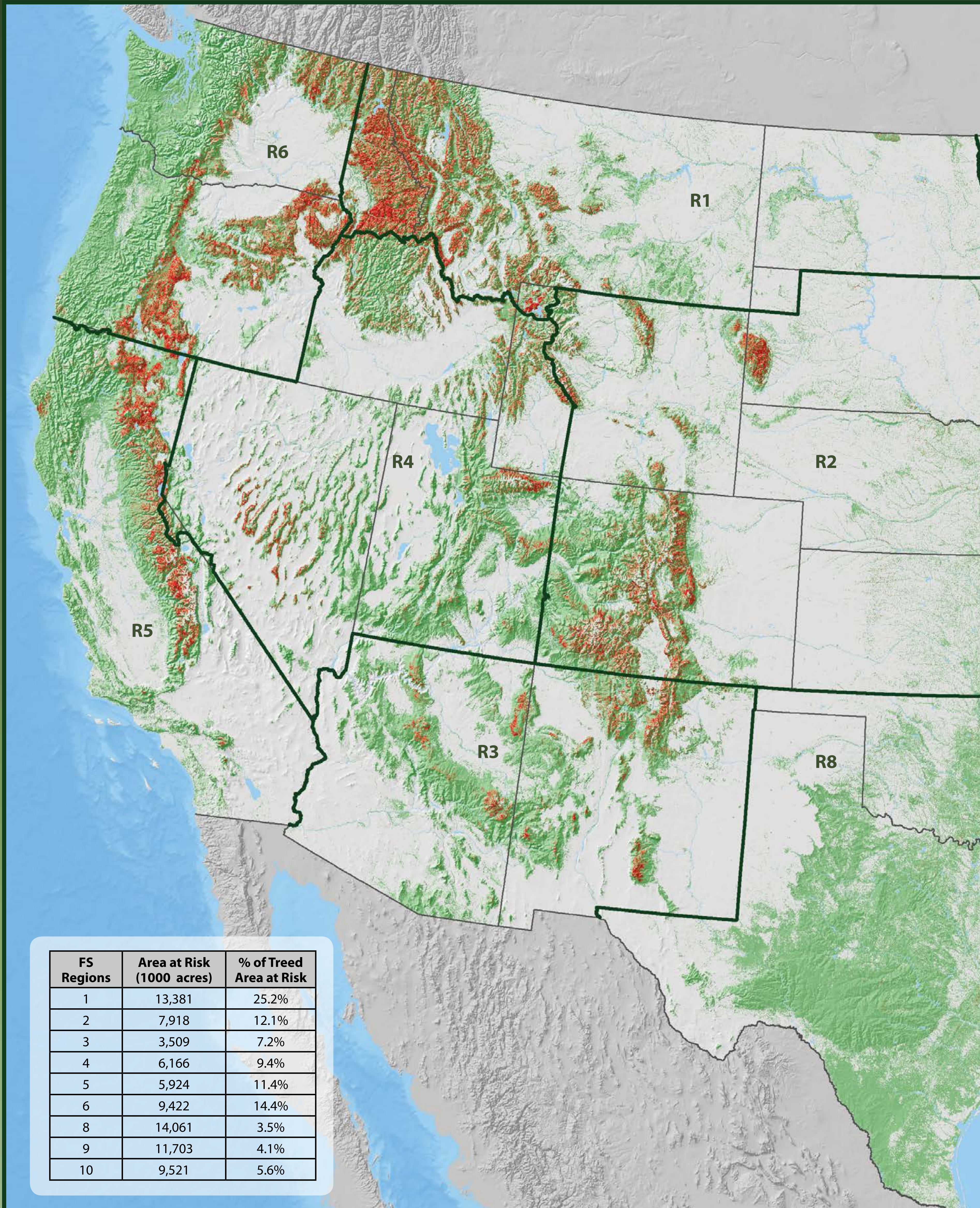
FIGURE 12



FS Regions	Area at Risk (1000 acres)	% of Treed Area at Risk
1	13,381	25.2%
2	7,918	12.1%
3	3,509	7.2%
4	6,166	9.4%
5	5,924	11.4%
6	9,422	14.4%
8	14,061	3.5%
9	11,703	4.1%
10	9,521	5.6%

National 2012 Composite Insect and Disease Risk Map

FIGURE 13



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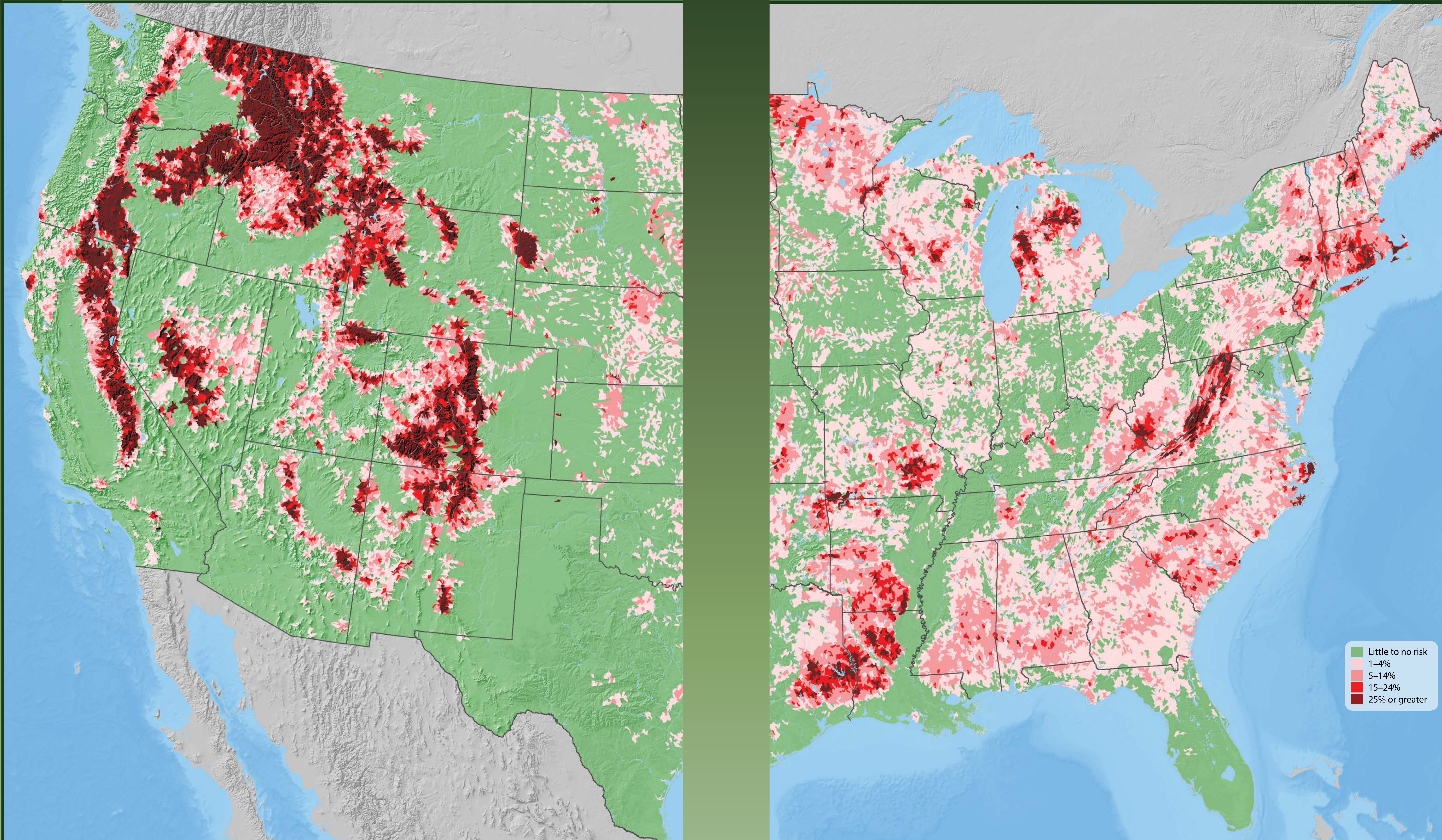
10	9,521	5.6%

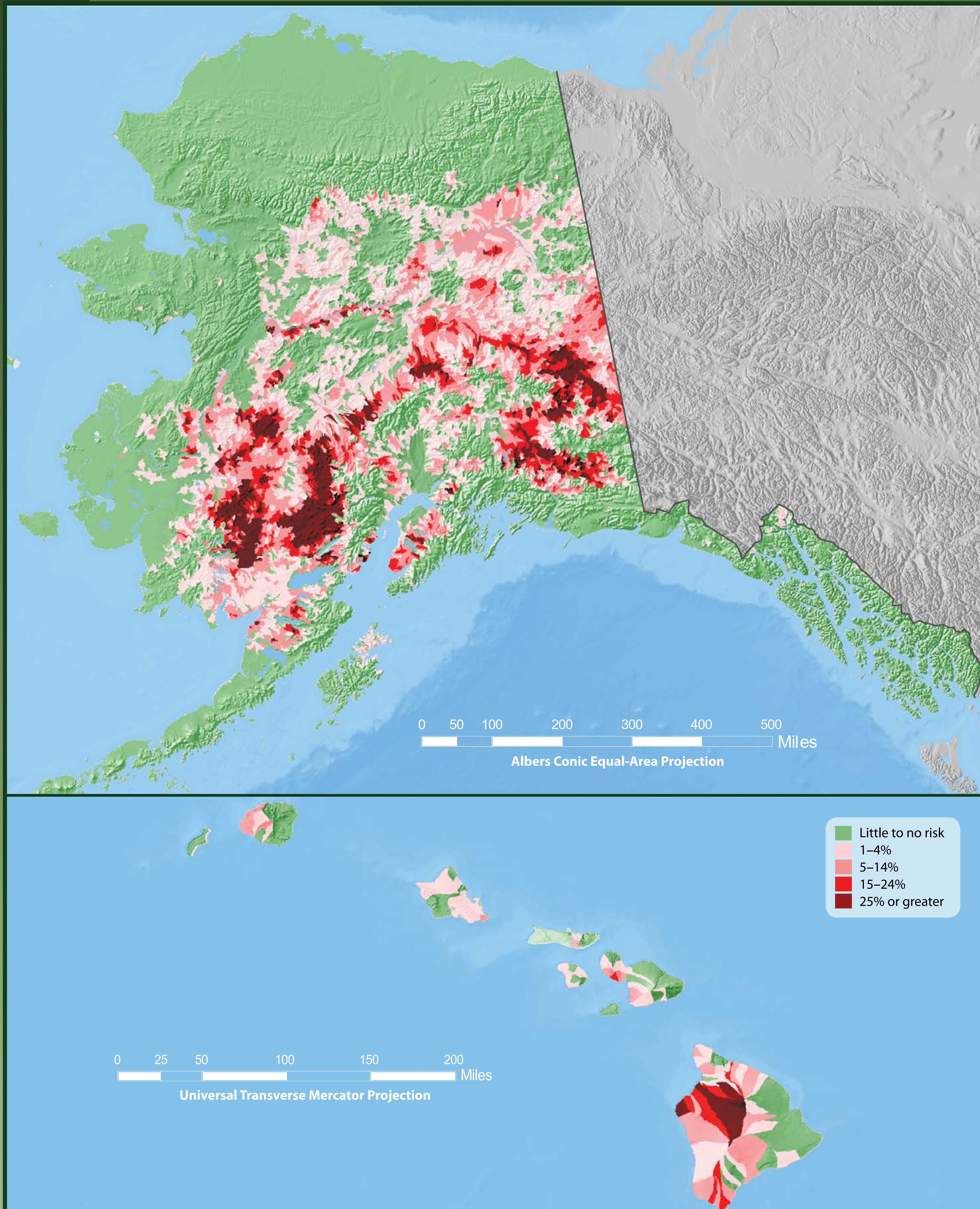
Percentage of Treed Area at Risk by Watershed

FIGURE 14



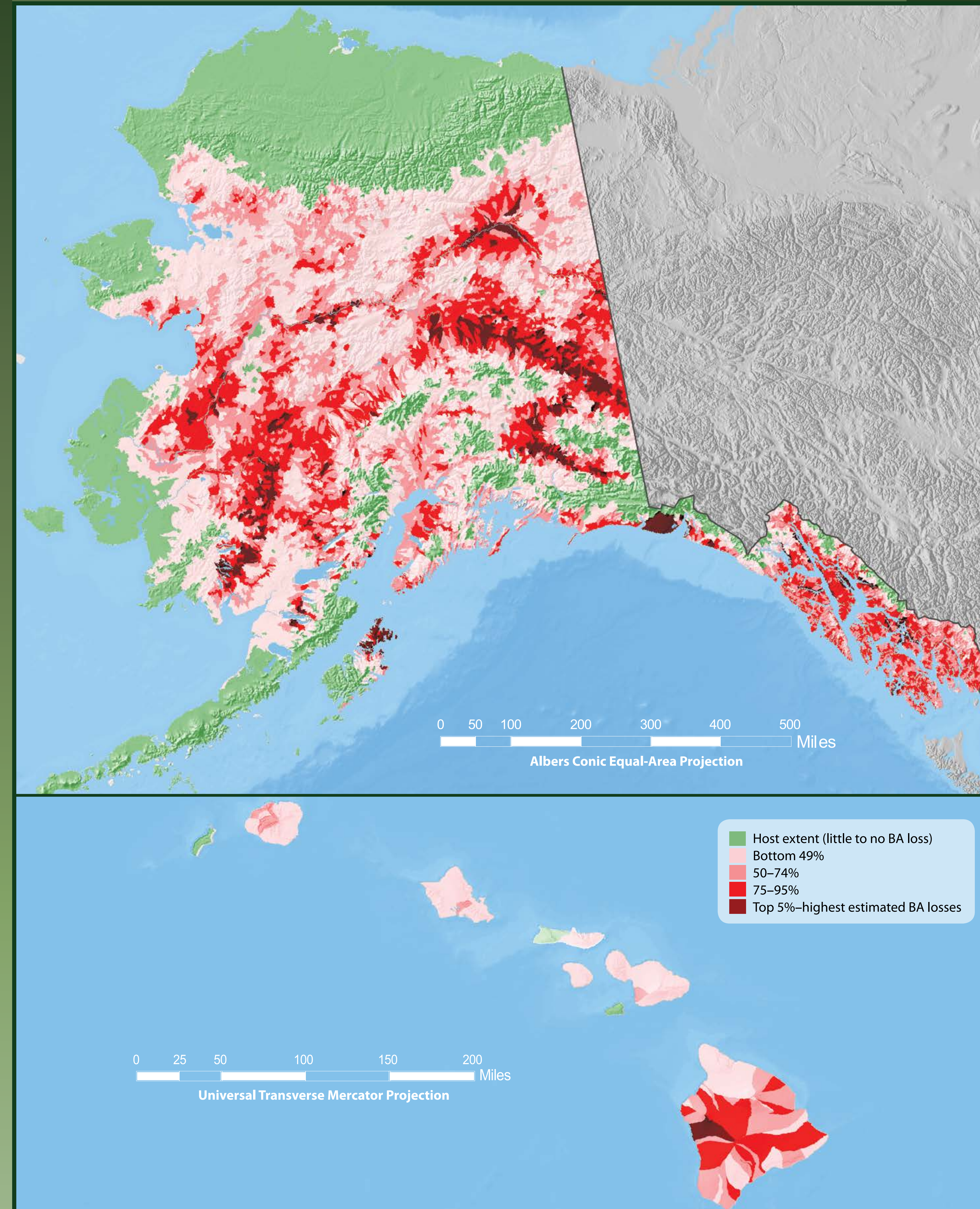
Percentage of Treed Area at Risk by Watershed — Alaska and Hawaii

FIGURE 15



Watersheds Ranked by Basal Area Loss Hazard — Alaska and Hawaii

FIGURE 16



Watersheds Ranked by Basal Area Loss Hazard

FIGURE 17

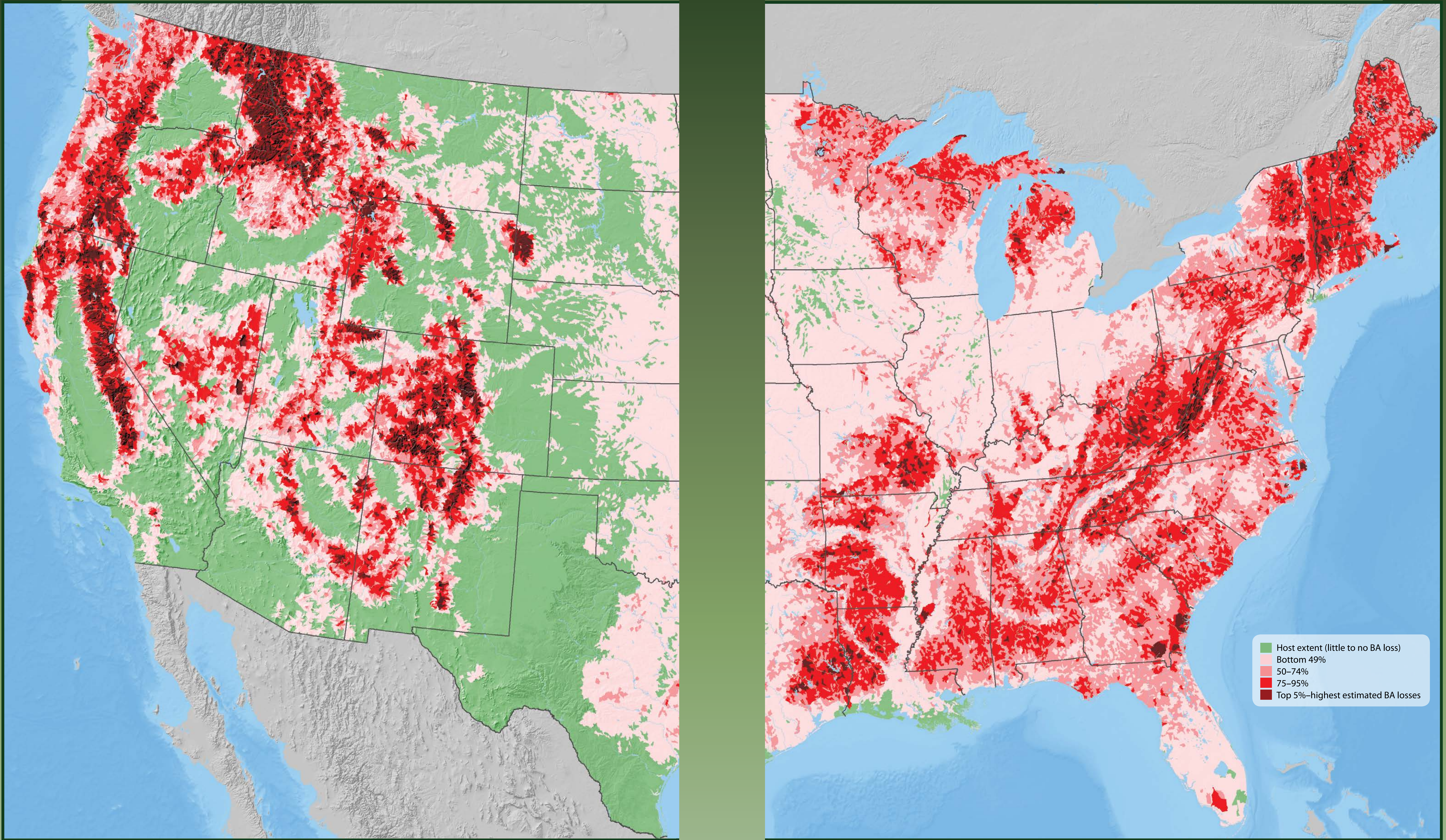


FIGURE 18

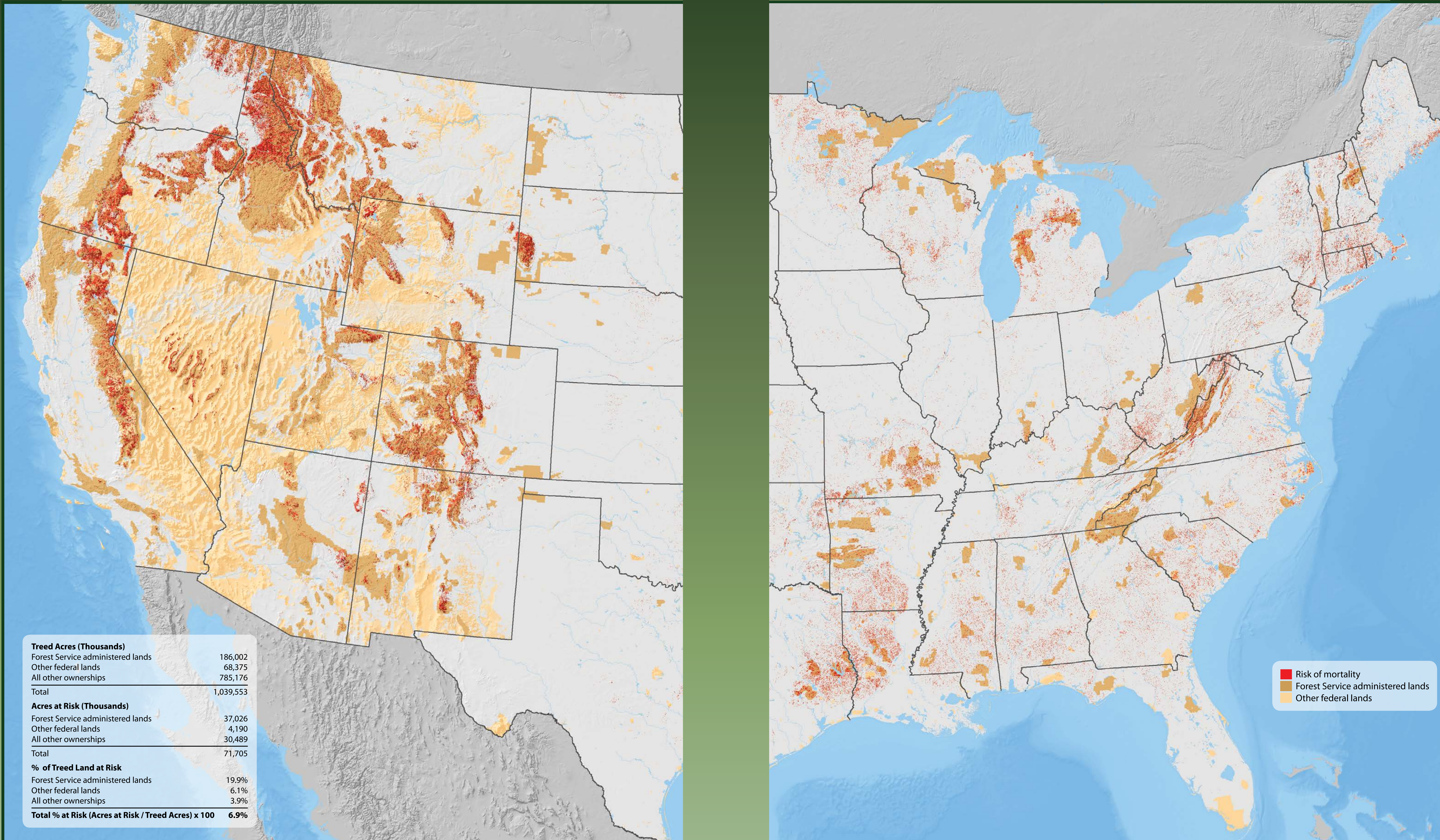
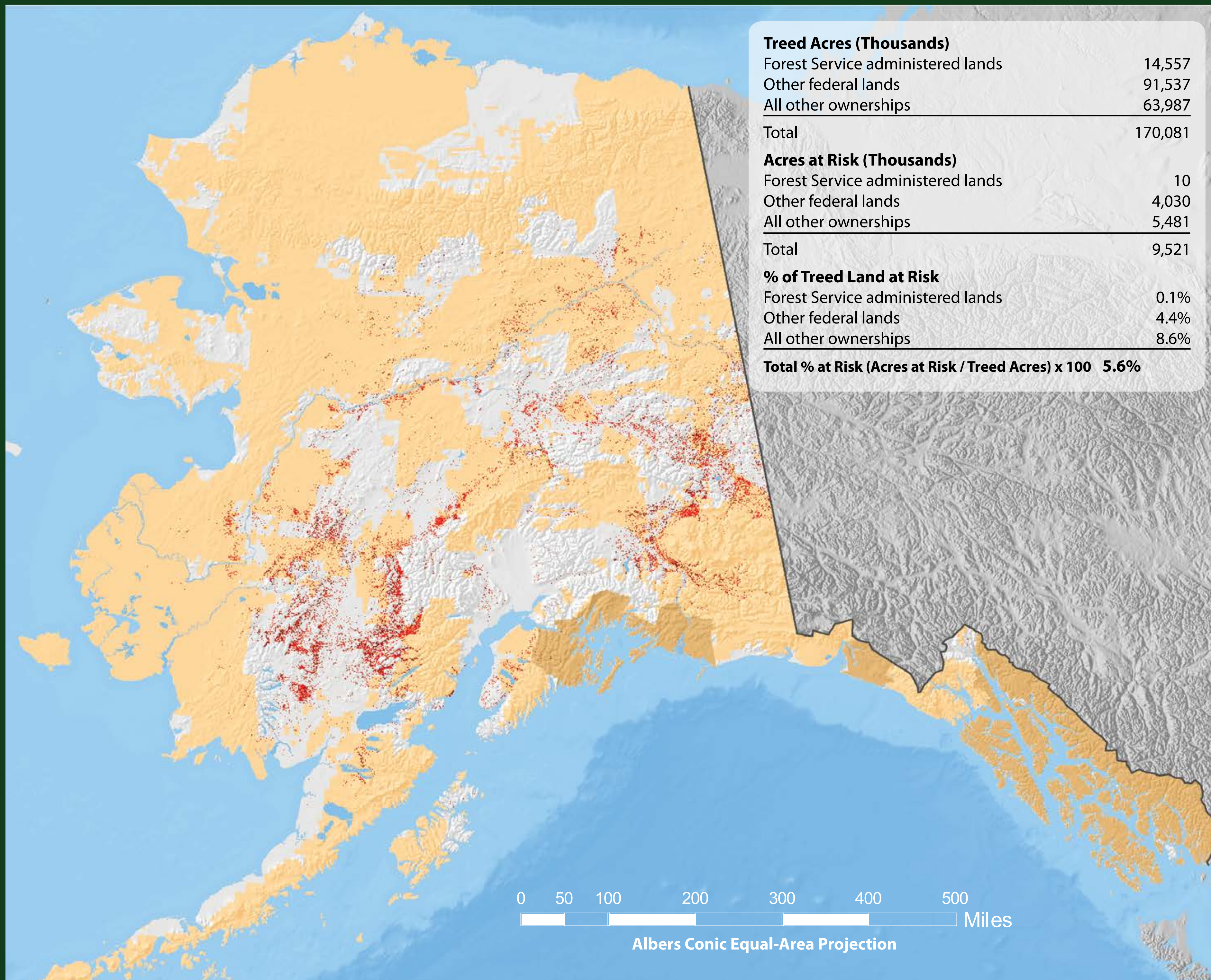
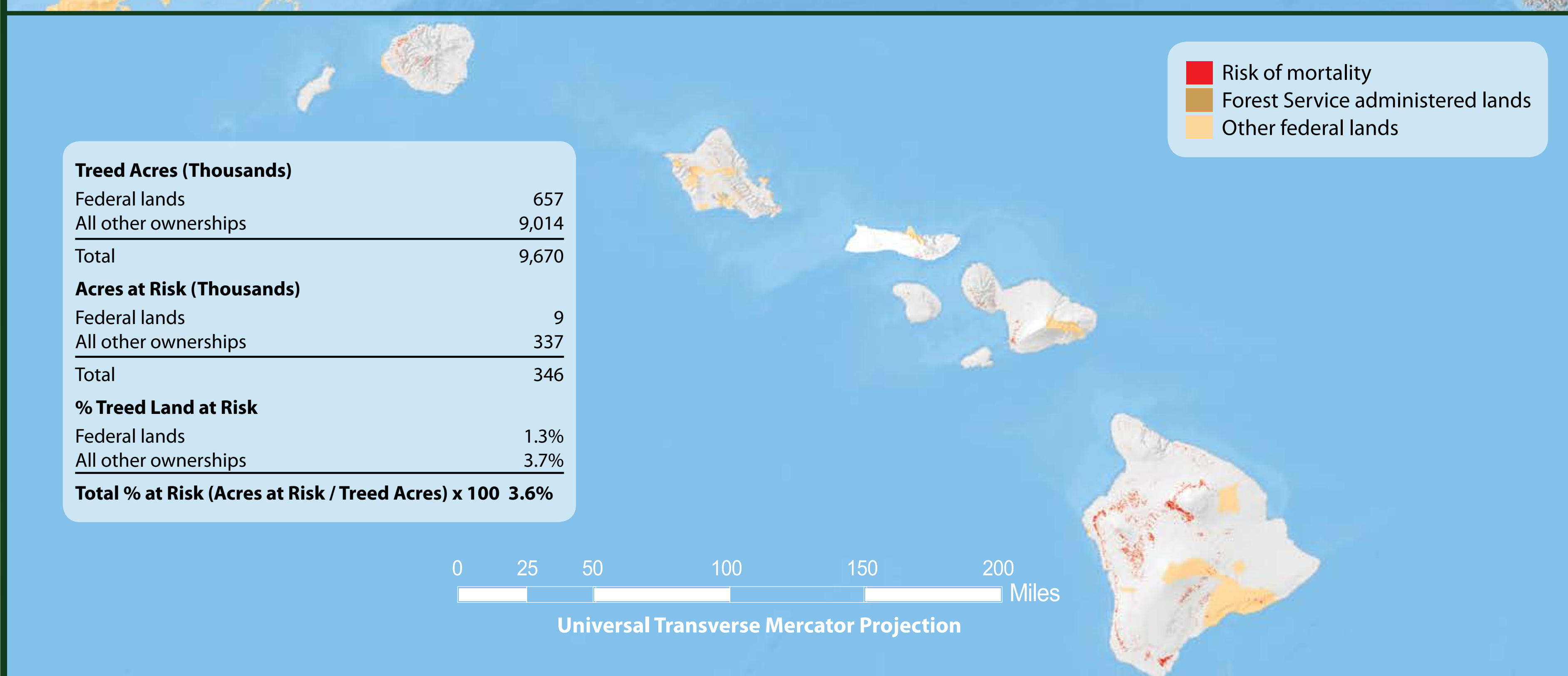

Treed Acres (Thousands)
Forest Service administered lands 186,002
Other federal lands 68,375
All other ownerships 785,176
Total 1,039,553
Acres at Risk (Thousands)
Forest Service administered lands 37,026
Other federal lands 4,190
All other ownerships 30,489
Total 71,705
% of Treed Land at Risk
Forest Service administered lands 19.9%
Other federal lands 6.1%
All other ownerships 3.9%
Total % at Risk (Acres at Risk / Treed Acres) x 100 6.9%
Risk of mortality
Forest Service administered lands
Other federal lands

FIGURE 19

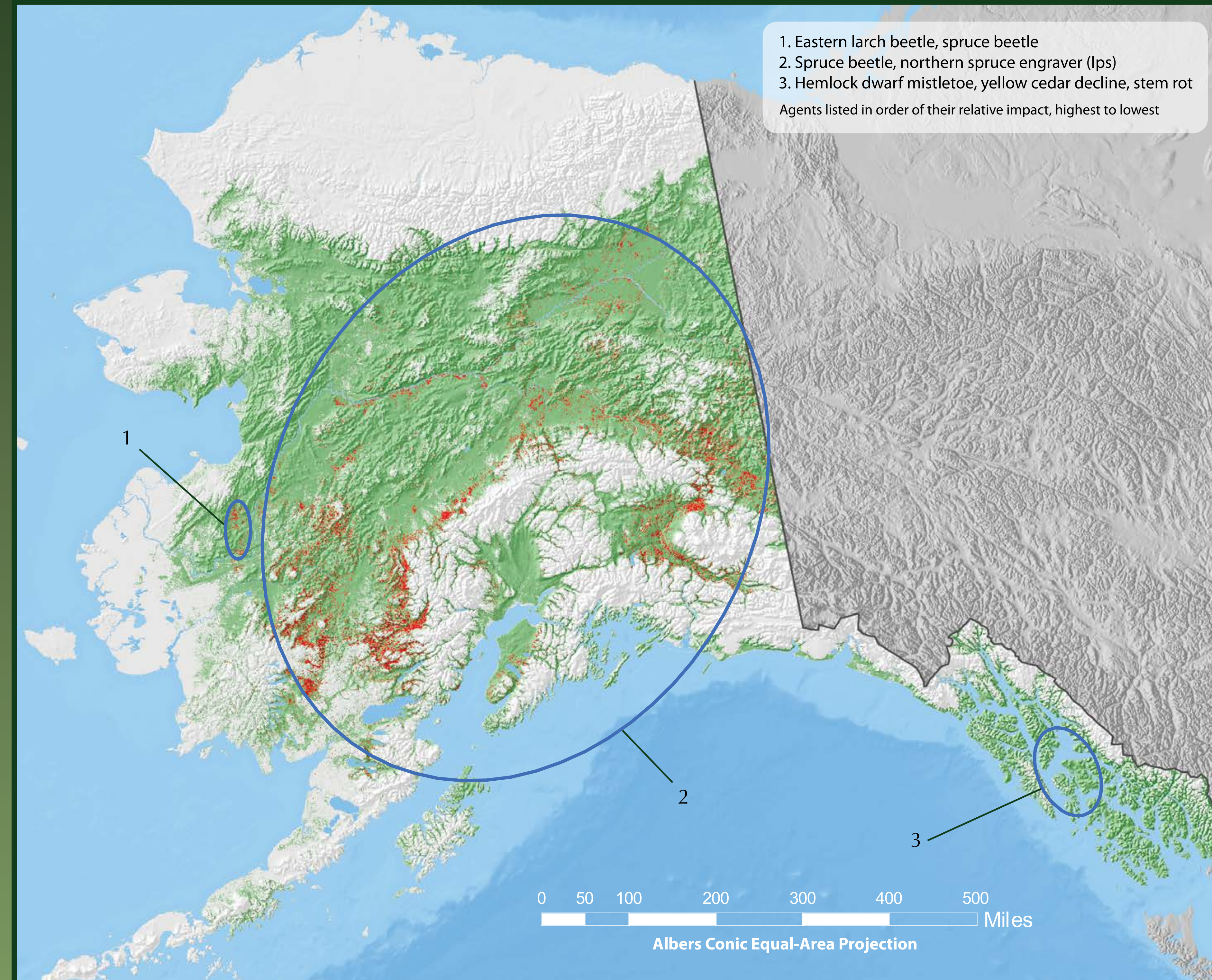


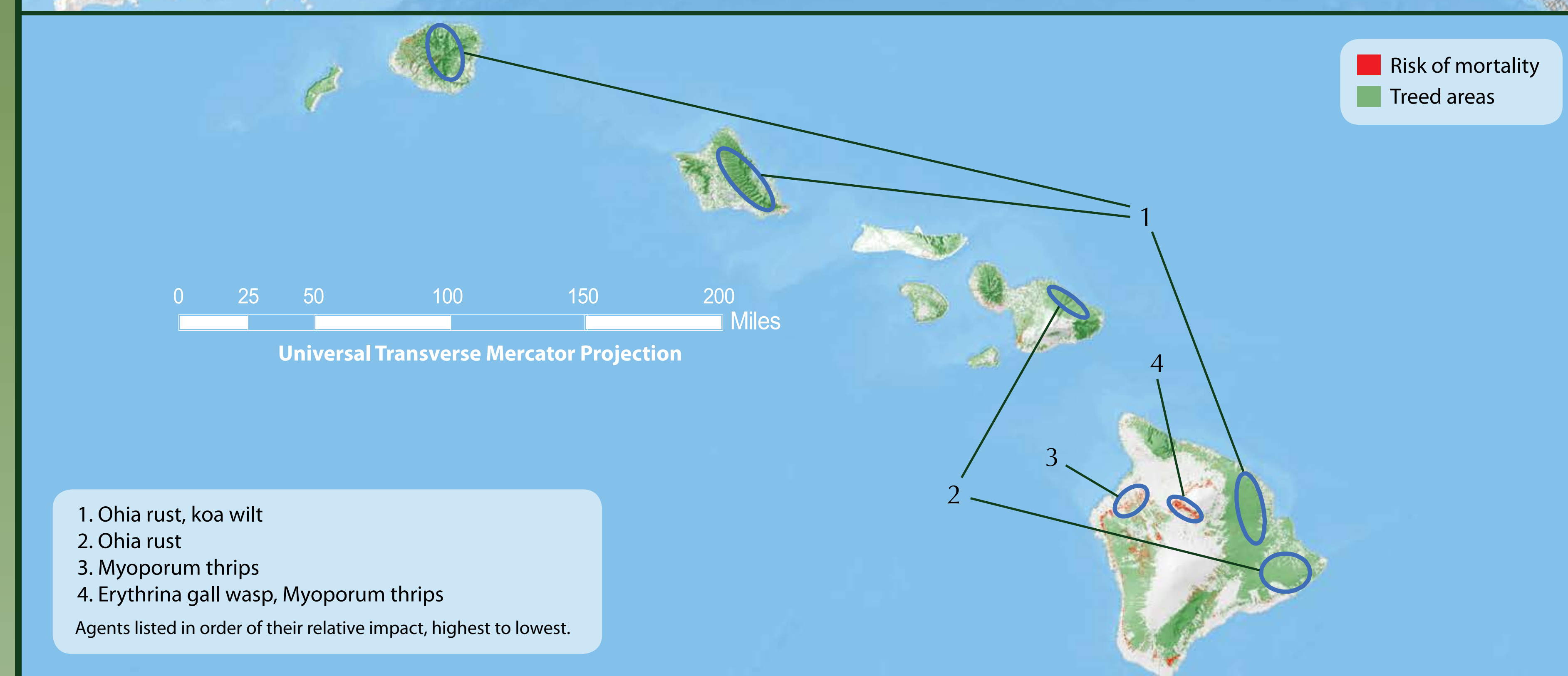
Treed Acres (Thousands)	
Forest Service administered lands	14,557
Other federal lands	91,537
All other ownerships	63,987
Total	170,081
Acres at Risk (Thousands)	
Forest Service administered lands	10
Other federal lands	4,030
All other ownerships	5,481
Total	9,521
% of Treed Land at Risk	
Forest Service administered lands	0.1%
Other federal lands	4.4%
All other ownerships	8.6%
Total % at Risk (Acres at Risk / Treed Acres) x 100	**5.6%**



Treed Acres (Thousands)	
Federal lands	657
All other ownerships	9,014
Total	9,670
Acres at Risk (Thousands)	
Federal lands	9
All other ownerships	337
Total	346
% Treed Land at Risk	
Federal lands	1.3%
All other ownerships	3.7%
Total % at Risk (Acres at Risk / Treed Acres) x 100	**3.6%**

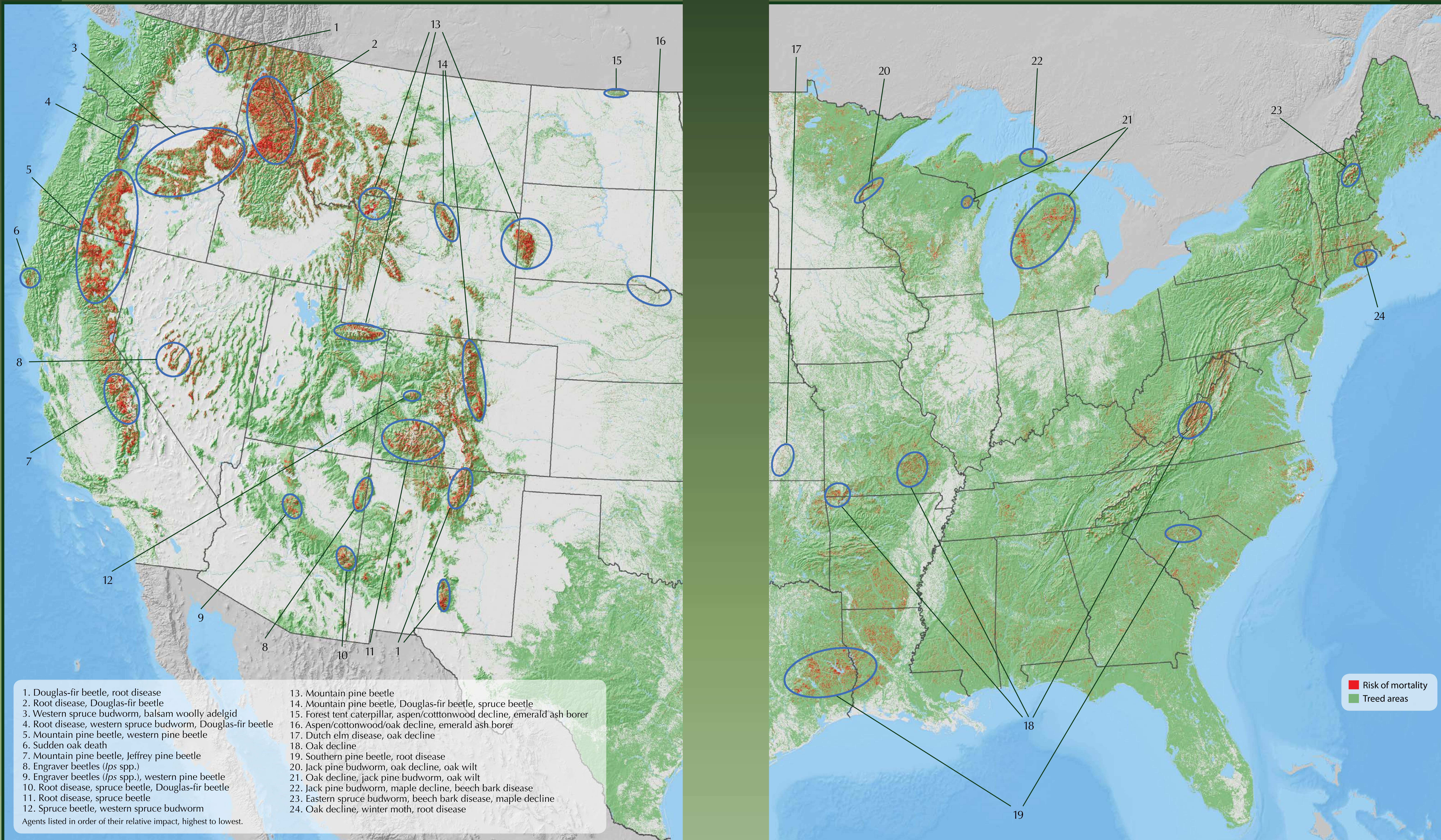
FIGURE 20





Major Risk Agents Contributing to the 2012 NIDRM

FIGURE 21



Insect and Disease Risk on American Indian Lands

FIGURE 22

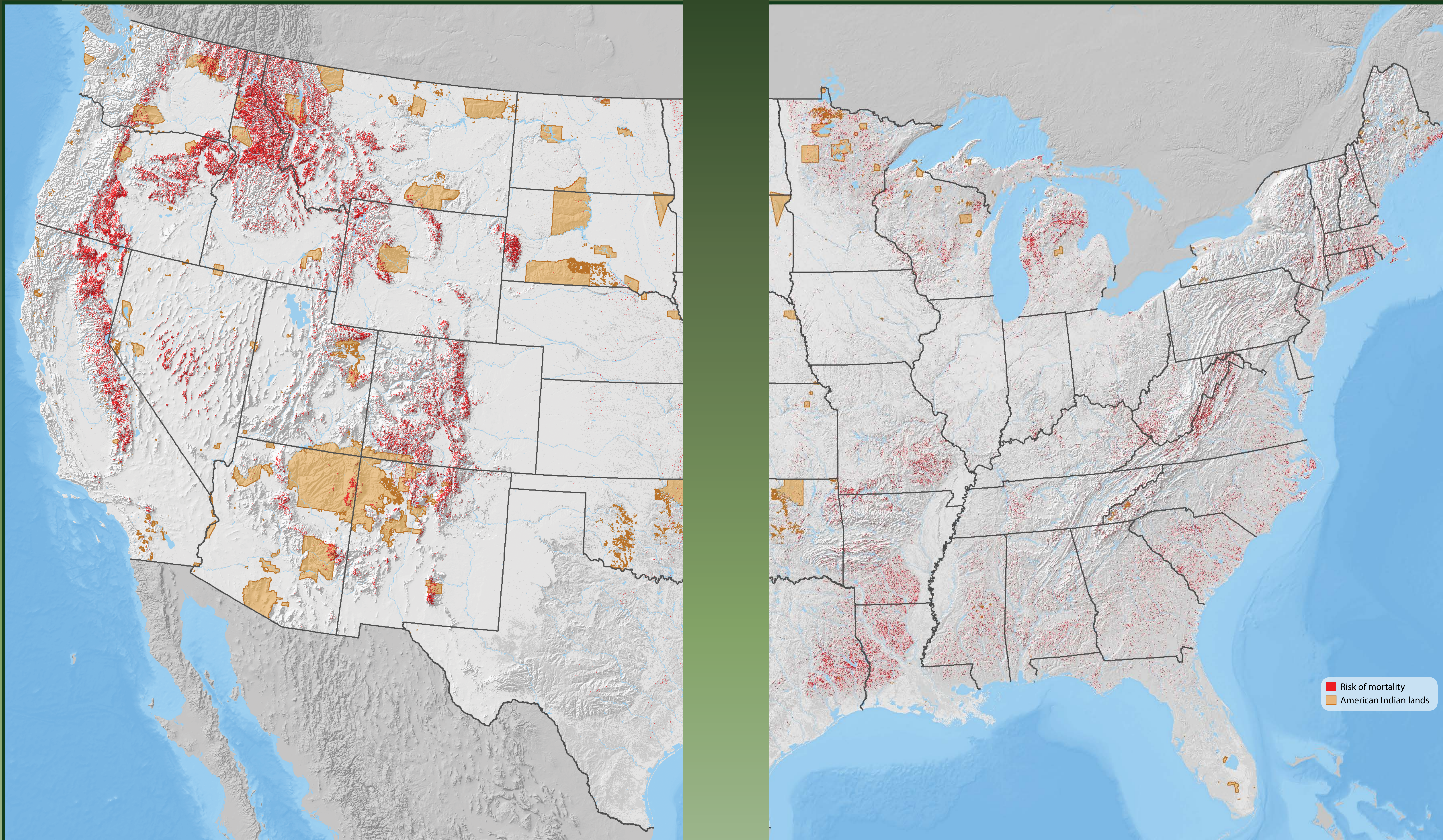


TABLE 2

AGENT	BA Losses (Millions of Sq. Feet)
BARK BEETLES (TOTAL)	**3337.3**
Mountain pine beetle	708.1
Southern pine beetle	647.5
Engraver beetles [*Ips* spp.][1]	580.2
Spruce beetle	536.4
Douglas-fir beetle	457.8
Western pine beetle	165.9
Fir engraver	159
Jeffrey pine beetle	28.2
Western balsam bark beetle	22.7
Eastern larch beetle	19.9
Roundheaded pine beetle	11.6
DECLINES (TOTAL)	**1425.9**
Oak decline and gypsy moth	1109.8
Maple decline	202.5
Aspen and cottonwood decline	101.3
Yellow-cedar decline	12.3
DISEASES (TOTAL)	**1156.6**
Root diseases—all[2]	1117.3
Stem rot	18.8
Fusiform rust	17.7
Bur oak blight	2.8
EXOTICS (TOTAL)	**840.5**
Emerald ash borer	255.2
Balsam woolly adelgid	121.7
Hemlock woolly adelgid	102.5
Beech bark disease	93.6
Sudden oak death	58.3
Dutch elm disease	49.2
Winter moth	45.9
White pine blister rust	34.8
Oak wilt	33
Sirex woodwasp	23.7
Laurel wilt	22.1
Asian longhorned beetle	0.4
Goldspotted oak borer	0.1

AGENT	BA Losses (Millions of Sq. Feet)
DEFOLIATORS (TOTAL)	**422.4**
Eastern spruce budworm	233.9
Western spruce budworm	115.8
Forest tent caterpillar	28.7
Douglas-fir tussock moth	28.1
Jack pine budworm	15.9
OTHER (TOTAL)	**45.2**
Dwarf mistletoes[3]	44.3
Spruce aphid	0.9
HAWAIIAN PESTS[4]	
Ohia rust	N/A
Koa wilt	N/A
Myoporum thrips	N/A
Erythrina gall wasp	N/A

[1]Group includes Arizona fivespined ips, eastern fivespined ips, northern spruce engraver, pine engraver, pinyon ips, sixspined ips, small southern pine engraver, and three western species without common names, *Ips latidens*, *Ips knausi* and *Ips integer*.

[2]Group includes annosus, armillaria, laminated root rot, and Port-Orford-cedar root diseases.

[3]Group includes American, Douglas-fir, hemlock, larch, limber pine, pineland, and pinyon dwarf mistletoes.

[4]Host BA loss layers were not created for Hawaiian pests and pathogens.

TABLE 3

AGENT	Thousands of Acres by Forest Service Region								
	R1	R2	R3	R4	R5	R6	R8	R9	R10
BARK BEETLES									
Douglas-fir beetle	2369	406	240	1115	-	577	-	-	-
Eastern larch beetle	-	-	-	-	-	-	-	170	234
Engraver beetles [*Ips* spp.]	-	569	1033	1341	10	-	tr*	-	-
Fir engraver	1	-	-	3	79	85	-	-	-
Jeffrey pine beetle	-	-	-	1	7	tr	-	-	-
Mountain pine beetle	2921	2799	4	1568	791	815	-	-	-
Southern pine beetle	-	-	-	-	-	-	1832	4	-
Spruce beetle	110	1298	138	154	-	23	-	-	848
Western balsam bark beetle	-	1	-	4	-	-	-	-	-
Western pine beetle	7	14	5	61	240	152	-	-	-
DECLINES									
Aspen and cottonwood decline	7	237	1	76	tr	-	5	38	-
Maple decline	-	-	-	-	-	-	tr	173	-
Oak decline and gypsy moth	1	10	-	-	-	-	2955	3581	-
DISEASES									
Fusiform rust	-	-	-	-	-	-	6	-	-
Root diseases—all	1903	312	12	1	tr	47	170	134	-
EXOTICS									
Asian longhorned beetle	-	-	-	-	-	-	-	tr	-
Balsam woolly adelgid	6	-	-	26	-	112	-	19	-
Beech bark disease	-	-	-	-	-	-	47	126	-
Dutch elm disease	13	164	-	-	-	-	18	158	-
Emerald ash borer	29	2	-	-	-	-	66	618	-
Goldspotted oak borer	-	-	-	-	5	-	-	-	-
Hemlock woolly adelgid	-	-	-	-	-	-	1	43	-
Laurel wilt	-	-	-	-	-	-	105	-	-
Oak wilt	-	-	-	-	-	-	31	183	-
Sudden oak death	-	-	-	-	128	30	-	-	-
White pine blister rust	1	tr	-	tr	tr	tr	-	-	-
Winter moth	-	-	-	-	-	-	-	201	-
DEFOLIATORS									
Eastern spruce budworm	-	-	-	-	-	-	-	242	-
Forest tent caterpillar	6	-	-	-	-	-	-	1025	-
Jack pine budworm	-	-	-	-	-	-	-	448	-
HAWAIIAN AGENTS									
Erythrina gall wasp	-	-	-	-	12	-	-	-	-
Koa wilt	-	-	-	-	53	-	-	-	-
Myoporum thrips	-	-	-	-	61	-	-	-	-

* In all instances, tr (trace) refers to values less than 500 acres.

TABLE 4

STATE	Risk Area (1000 acres)	Treed Area (1000 acres)	State Area (1000 acres)	% of State with Trees	% of Treed Acres at Risk
Idaho	7,680	27,777	53,484	52%	28%
Rhode Island	143	635	696	91%	23%
Montana	7,645	36,244	94,105	39%	21%
Oregon	6,723	37,396	62,128	60%	18%
South Dakota	832	4,700	49,353	10%	18%
Colorado	5,358	32,563	66,620	49%	16%
Wyoming	2,758	17,390	62,600	28%	16%
Connecticut	399	3,093	3,184	97%	13%
Massachusetts	609	4,946	5,199	95%	12%
California	5,697	47,237	101,218	47%	12%
New Mexico	2,363	23,587	77,818	30%	10%
Washington	2,702	27,827	43,279	64%	10%
Louisiana	1,613	20,213	30,013	67%	8%
Nevada	1,288	16,710	70,759	24%	8%
West Virginia	1,054	15,094	15,507	97%	7%
Virginia	1,621	23,696	25,926	91%	7%
South Carolina	1,190	18,436	19,831	93%	6%
New Hampshire	363	5,799	5,930	98%	6%
Arkansas	1,630	26,424	34,035	78%	6%
Michigan	1,810	30,624	37,214	82%	6%
Alaska	9,519	170,082	420,048	40%	6%
Minnesota	1,492	28,582	54,002	53%	5%
Utah	1,358	26,299	54,335	48%	5%
Missouri	1,376	29,959	44,611	67%	5%
Vermont	264	5,767	6,153	94%	5%
Arizona	1,146	25,487	72,959	35%	4%
New Jersey	187	4,363	4,851	90%	4%
Wisconsin	1,088	26,772	35,909	75%	4%
North Carolina	1,138	29,119	31,626	92%	4%
Mississippi	1,029	26,508	30,516	87%	4%
Alabama	1,177	31,101	33,063	94%	4%
Maine	726	20,055	20,841	96%	4%
Hawaii	77	2,151	4,142	52%	4%
New York	972	28,384	31,132	91%	3%
Georgia	1,035	35,217	37,652	94%	3%
Oklahoma	531	22,163	44,736	50%	2%
Kentucky	464	21,177	25,862	82%	2%
Tennessee	514	23,697	26,972	88%	2%
Maryland	110	5,246	6,638	79%	2%
North Dakota	89	4,248	45,247	9%	2%
Nebraska	143	7,230	49,506	15%	2%
Pennsylvania	510	26,444	28,992	91%	2%
Texas	1,854	97,489	169,463	58%	2%
Kansas	154	9,987	52,657	19%	2%
Indiana	160	12,004	23,157	52%	1%
Illinois	168	13,278	36,058	37%	1%
Ohio	200	17,057	26,405	65%	1%
Florida	265	30,238	36,326	83%	1%
Iowa	67	9,348	36,014	26%	1%
Delaware	3	918	1,285	71%	<0.5%
District of Columbia	0	36	44	81%	0%

IMPACTS ON INDIVIDUAL TREE SPECIES

For the next 15 years (2013–2027), redbay, whitebark pine, limber pine, and lodgepole pine will likely continue to decline due to pests and pathogens (USDA 2012). Estimated BA losses for these most-at-risk species could range from 40% for lodgepole pine to 90% for redbay (**TABLE 5**, pages 38-39). Although average projected BA losses are expected to be less than 30% each for ash, beech, and hemlock, local impacts may be much higher. For example, in Michigan vast areas have lost nearly 100% of green, white, and black ash due to emerald ash borer. Similarly, hemlock woolly adelgid feeding has removed large tracts of eastern and Carolina hemlock from the Appalachian Mountains.

REDBAY (*Persea borbonia*)

Our models predict that over 90% of the redbay BA in the United States will die in the next 15 years.

The entire range of redbay, a relative of avocado, is at risk due to a recently introduced disease called "laurel wilt." Redbay and other tree species in the family Lauraceae are susceptible. The disease, caused by a fungus (*Raffaelea lauricola*), is introduced into redbay trees by the small, non-native, redbay ambrosia beetle (*Xyleborus glabratus*). The fungus interferes with the tree's water translocation mechanism and causes trees to wilt. Laurel wilt has caused widespread and severe levels of mortality in the southeastern coastal plain. This mortality is expected to continue as this beetle spreads unabated throughout the entire redbay range.

Redbay grows along the edge of streams, springs, and swamps from eastern Texas to southern Virginia. It has evergreen, aromatic, leathery leaves, dark blue fruit hanging on into winter, and reddish bark. Native Americans found a host of medicinal uses for this small-to-medium-sized tree. Inhabitants of the South often used its fine-grained, highly polished wood as trim for boats and ships.

WHITEBARK PINE (*Pinus albicaulis*)

Our models estimate BA losses for whitebark pine approaching 60% over the next 15 years as a result of mountain pine beetle and white pine blister rust.

Whitebark pine is highly vulnerable to the combined effects of white pine blister rust, mountain pine beetle, fire suppression, and climate change. Indeed, in 2011 the U.S. Fish and Wildlife Service (2011) found it warranted being listed as a "Threatened or Endangered" species. Many land management agencies have called for actions and strategies to address the threats (Keane et al. 2012), and such management is seen as necessary to ensure the survival of this ecologically important and often long-lived species.

Whitebark pine is a keystone species, meaning that its importance in ecosystem function is large relative to its abundance. It is also a foundation species, and its presence exerts significant controls on the ecological community structure. Whitebark pine seed is an important food source for birds, small mammals, and bears. Aided by Clark's nutcracker for seed dispersal, whitebark pine quickly establishes itself after disturbance (e.g., fire) and is important in curtailing soil erosion, maintaining snowpack, and providing wildlife habitat and biodiversity. It exists in the western United States primarily at high elevations in a variety of habitat types, mostly on public lands.

LIMBER PINE (*Pinus flexilis*)

Basal area losses in limber pine are estimated to exceed 40% over the next 15 years, primarily due to mountain pine beetle and secondarily to the combination of white pine blister rust and dwarf mistletoe.

Given limber pine's wide adaptability, its vulnerability to climate change and mountain pine beetle is lower than that of other high-elevation, five-needle pines over much of its range.

Limber pine exists over very broad geographic and elevation ranges; it is found at both upper and lower elevation tree-lines (and elevations in between) and is distributed from southern California to South Dakota and from Mexico to British Columbia. It is a drought-tolerant species widely adapted to a variety of habitat types, frequently found co-existing with other species, such as aspen, ponderosa pine, lodgepole pine, and bristlecone pine. Occupying a variety of ecological niches, limber pine is an important pioneer species and is a climax species on harsh (xeric or high-elevation) sites (Keane et al. 2011). Like whitebark pine, limber pine seed is important in the ecology of birds and mammals, thus contributing to the maintenance of biodiversity across a variety of habitats.

LODGEPOLE PINE (*Pinus contorta*)

We estimate BA loss due mountain pine beetle and dwarf mistletoe to approach 40% over the next 15 years.

While the risk of loss of lodgepole pine remains high, it is unlikely that lodgepole pine forests are at risk of extirpation as a result of these agents or other disturbances, such as wildfire or climate change. Although these latter two disturbances are often associated with mountain pine beetle outbreaks (e.g., climate as a contributing factor and wildfire as a subsequent event), neither are likely to contribute to long-term widespread losses of lodgepole pine forests except, perhaps, at population margins, where future climates may affect the post-disturbance re-establishment potential of lodgepole pine.

Lodgepole pine is a widespread species, ranging from the southern to northern Rockies, the Sierras, and southeast Alaska, and existing in both pure and mixed-species stands. It is fire-adapted and has co-evolved with the mountain pine beetle, a native bark beetle, which has killed vast amounts of lodgepole pine trees over large areas in recent years (USDA 2012).

The proportion of projected host BA loss for redbay, whitebark pine, limber pine, lodgepole pine, and hemlock, summarized by watershed is shown in **FIGURES 23–27** (pages 40–44). The proportion of potential host lost is calculated by summing the host BA losses for all risk agents that affect each host in each watershed; the BA host loss is then divided by the total host BA to determine the proportion of host BA that may be lost in the next 15 years. Watersheds containing each tree species are then grouped within the following classes: 0% (little or no host BA loss), 1–4% loss, 5–14% loss, 15–24% loss, and 25–100% loss.

Continued, page 45

TABLE 5

HOST SPECIES Agent (maximum mortality rate)[1]	Loss Rate[2]
WESTERN SOFTWOODS	
Whitebark pine	**58%**
Mountain pine beetle (80–85%)	
White pine blister rust (25–30%)	
Limber pine	**44%**
Dwarf mistletoe (5%)	
Mountain pine beetle (20–80%)	
White pine blister rust (10–20%)	
Lodgepole pine	**39%**
Dwarf mistletoe (2%)	
Mountain pine beetle (25–85%)	
Ponderosa pine	**28%**
Dwarf mistletoe (8%)	
Engraver beetles [*Ips* spp.] (5–40%)	
Mountain pine beetle (10–80%)	
Root diseases (10–30%)	
Roundheaded pine beetle (5–25%)	
Western pine beetle (5–60%)	
Pinyon pines (5 species)	**27%**
Dwarf mistletoe (3%)	
Engraver beetles [*Ips* spp.] (35–70%)	
Jeffrey pine	**26%**
Jeffrey pine beetle (40%)	
Root diseases (30%)	
Grand fir	**25%**
Balsam woolly adelgid (15%)	
Douglas-fir tussock moth (20%)	
Fir engraver (10–25%)	
Root diseases (32%)	
Western spruce budworm (5%)	
Engelmann spruce	**23%**
Root diseases (15%)	
Spruce beetle (80%)	
Western spruce budworm (3%)	
Western white pine	**23%**
Mountain pine beetle (50–60%)	
White pine blister rust (30%)	
Port-Orford-cedar	**22%**
Root diseases (50–95%)	
Subalpine fir	**21%**
Balsam woolly adelgid (30–50%)	
Root diseases (24–43%)	
Western balsam bark beetle (10–60%)	
Western spruce budworm (5%)	
White spruce	**21%**
Northern spruce engraver (25%)	
Root diseases (8%)	
Spruce beetle (40%)	

See footnotes, page 39

HOST SPECIES Agent (maximum mortality rate)[1]	Loss Rate[2]
Sugar pine	**19%**
Mountain pine beetle (10–30%)	
Mountain pine beetle (10–30%)	
White fir	**18%**
Douglas-fir tussock moth (13–20%)	
Fir engraver (25–80%)	
Western spruce budworm (5%)	
Sitka spruce	**18%**
Spruce aphid (2%)	
Spruce beetle (40%)	
Stem rot (2.4%)	
Tamarack [3]	**17%**
Eastern larch beetle (50%)	
Douglas-fir	**15%**
Douglas-fir beetle (5–60%)	
Douglas-fir tussock moth (20%)	
Dwarf mistletoe (5%)	
Root diseases (18–52%)	
Western spruce budworm (5%)	
Mountain hemlock	**11%**
Root diseases (30%)	
Coulter pine	**10%**
Western pine beetle (60%)	
Alaska yellow-cedar	**10%**
Yellow-cedar decline (21%)	
California red fir	**9%**
Fir engraver (20%)	
Southwestern white pine	**7%**
Mountain pine beetle (5–70%)	
White pine blister rust (10%)	
Grand fir and Douglas-fir	**5%**
Root diseases (25–30%)	
Western spruce budworm (20%)	
Western hemlock	**5%**
Dwarf mistletoe (6%)	
Stem rot (2.4%)	
Rocky Mountain bristlecone pine	**4%**
White pine blister rust (10%)	
Western red cedar	**3%**
Root diseases (11%)	
Grand fir and white fir	**2%**
Fir engraver (60%)	
Root diseases (30%)	
Spruce / fir (17 species)	**2%**
Root diseases (15–25%)	
Pacific silver fir	**1%**
Balsam woolly adelgid (30%)	
Western larch	**<0.5%**
Dwarf mistletoe (3%)	

TABLE 5, cont.

HOST SPECIES Agent (maximum mortality rate)[1]	Loss Rate[2]
WESTERN HARDWOODS	
Tanoak	**24%**
Sudden oak death (60%)	
California live oak	**11%**
Goldspotted oak borer (50%)	
Sudden oak death (30%)	
Quaking aspen	**9%**
Aspen & cottonwood decline (25–30%)	
Live oak	**7%**
Oak wilt (50%)	
Bur oak	**3%**
Bur oak blight (25%)	
California black oak	**1%**
Goldspotted oak borer (50%)	
Sudden oak death (30%)	
Canyon live oak	**<0.5%**
Goldspotted oak borer (15%)	
EASTERN SOFTWOODS	
Balsam fir	**27%**
Balsam woolly adelgid (35%)	
Spruce budworm (50%)	
Jack pine	**22%**
Jack pine budworm (70%)	
Root diseases (50%)	
Tamarack [3]	**17%**
Eastern larch beetle (50%)	
Southern pines (group 1) (6 species)	**13%**
Southern pine beetle (35%)	
Pitch pine	**7%**
Southern pine beetle (35%)	
Eastern and Carolina hemlock	**6%**
Hemlock woolly adelgid (40%)	
Eastern white pine	**5%**
Root diseases (50%)	
Southern pine beetle (25%)	
White pine blister rust (15%)	
Spruce (8 species)	**5%**
Spruce budworm (30%)	
Red pine	**5%**
Root diseases (50%)	
Southern pines (group 2) (3 species)	**4%**
Root diseases (35%)	

HOST SPECIES Agent (maximum mortality rate)[1]	Loss Rate[2]
Longleaf pine	**4%**
Root diseases (25%)	
Southern pine beetle (25%)	
Fir (9 species)	**3%**
Root diseases (25%)	
Southern pines (group 3) (8 species)	**2%**
Ips engraver beetles (5%)	
Sirex pines (10 species)	**<0.5%**
Sirex woodwasp (5%)	
Southern pines (group 4) (2 species)	**<0.5%**
Fusiform rust (40%)	
EASTERN HARDWOODS	
Redbay	**90%**
Laurel wilt (98%)	
Ash (8 species)	**27%**
Emerald ash borer (50%)	
American elm	**20%**
Dutch elm disease (30–50%)	
Red oaks (13 species)	**19%**
Oak decline (70%)	
Oak wilt (15–80%)	
White oaks (10 species)	**19%**
Oak decline (60%)	
American beech	**18%**
Beech bark disease (70%)	
Sugar maple	**14%**
Asian longhorned beetle (30%)	
Maple decline (50%)	
Cottonwood (6 species)	**3%**
Aspen and cottonwood decline (50%)	
Aspen (2 species)	**2%**
Forest tent caterpillar (40%)	
Sassafras	**1%**
Laurel wilt (50%)	
Oaks (24 species)	**1%**
Winter moth (50%)	
Paper birch	**<0.5%**
Root diseases (22%)	
Red maple	**<0.5%**
Asian long-horned beetle (40%)	

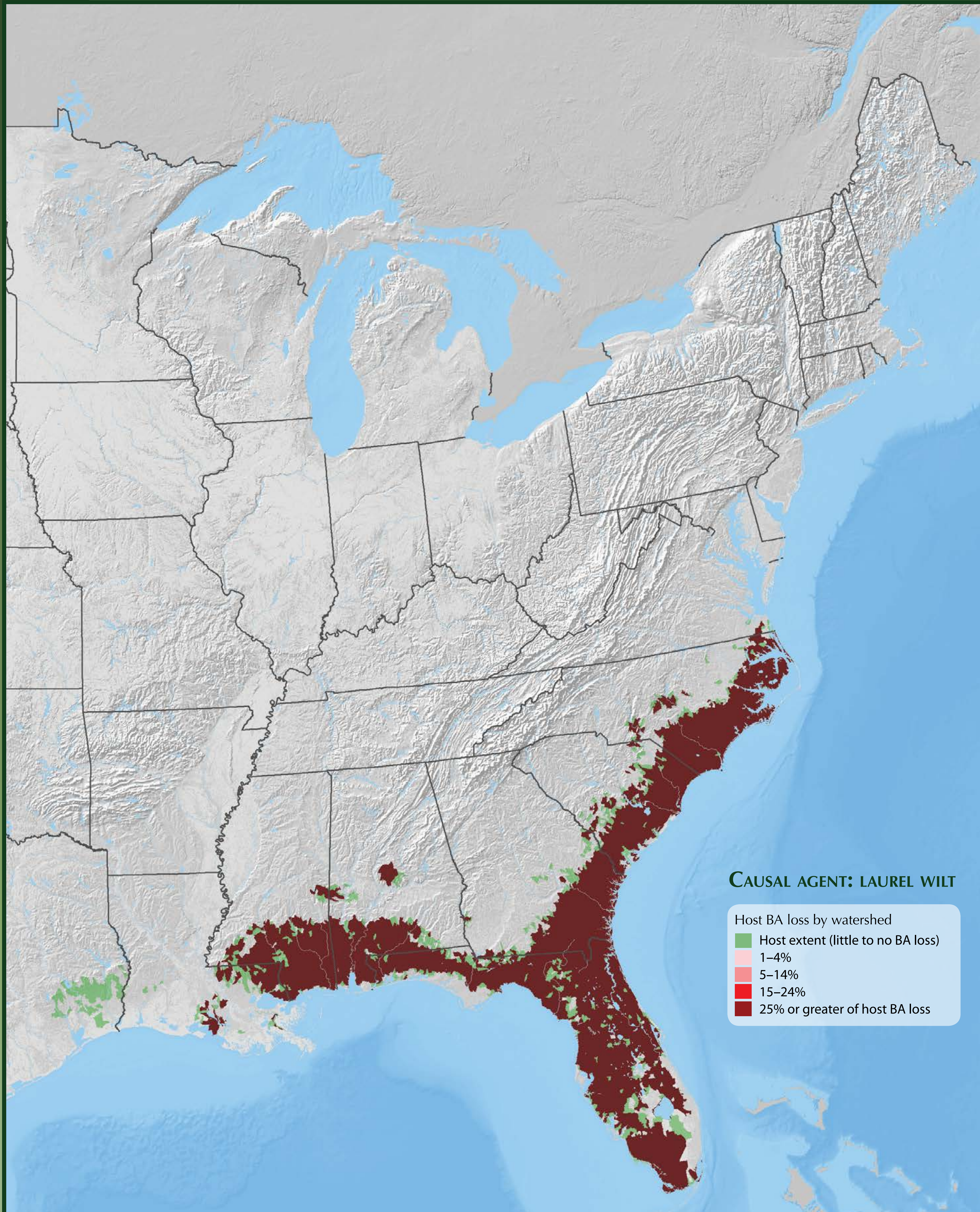
[1]Maximum mortality rate is the range of maximum allowable host mortality rates across the suite of agent-host-specific models.

[2]Estimated BA mortality rates are the average across the entire host tree species' extent regardless of whether the agent was modeled across that host tree species' entire range.

[3]Eastern larch beetle in tamarack was modeled in both Alaska and the eastern United States; both of its listings here reflect the nationwide mortality rate estimate.

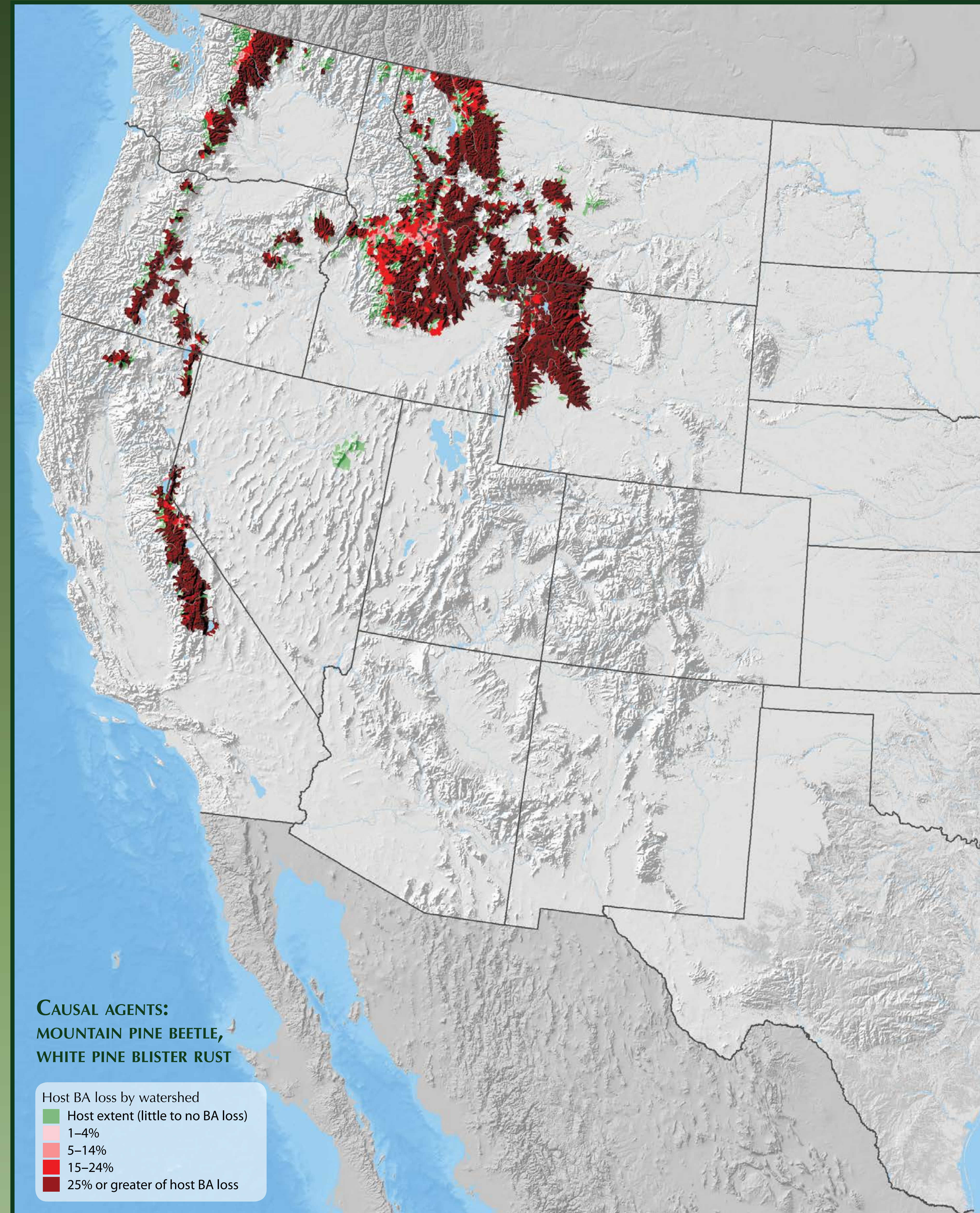
Percentage of Redbay Basal Area Loss

FIGURE 23



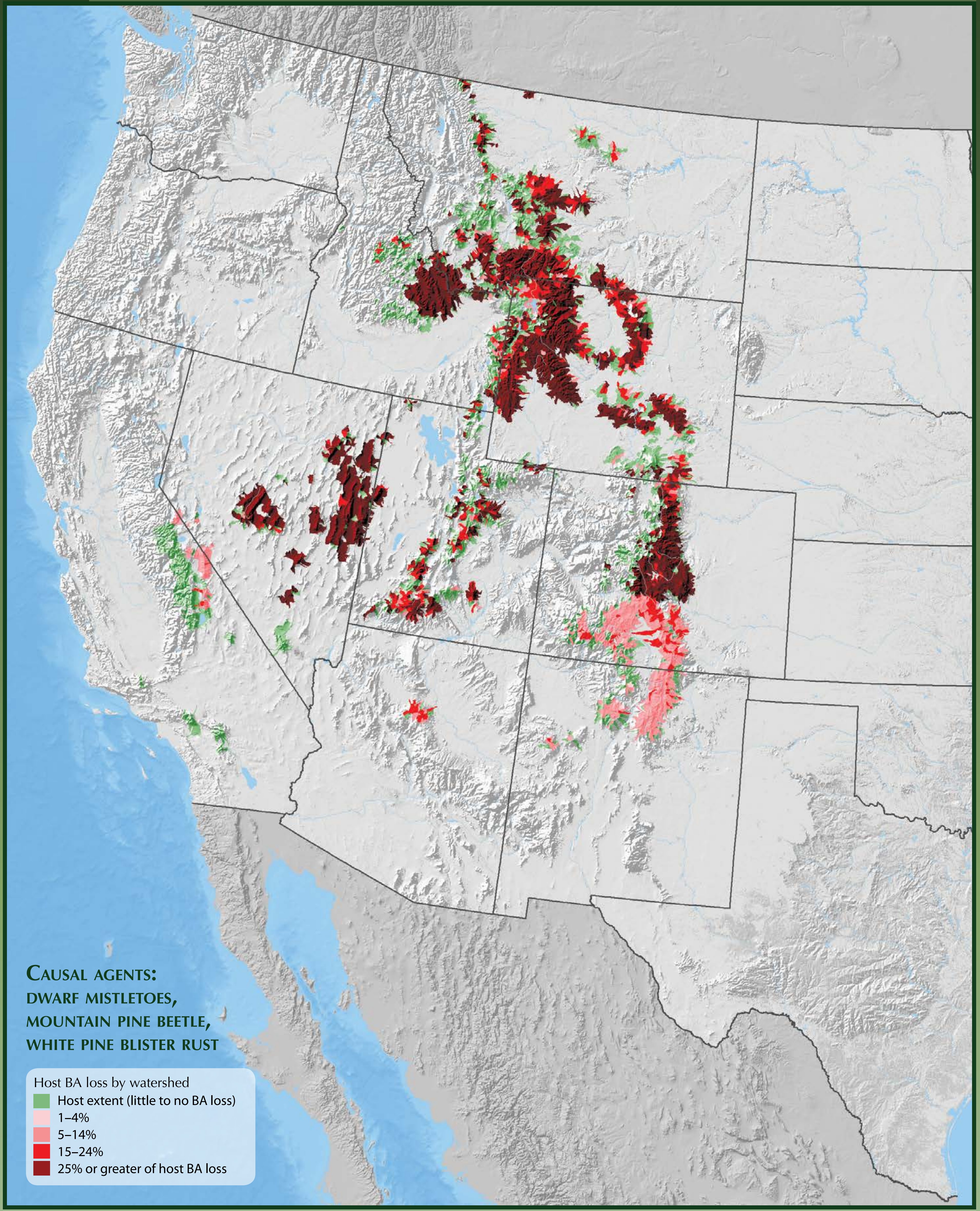
Percentage of Whitebark Pine Basal Area Loss

FIGURE 24



Percentage of Limber Pine Basal Area Loss

FIGURE 25



Percentage of Lodgepole Pine Basal Area Loss

FIGURE 26

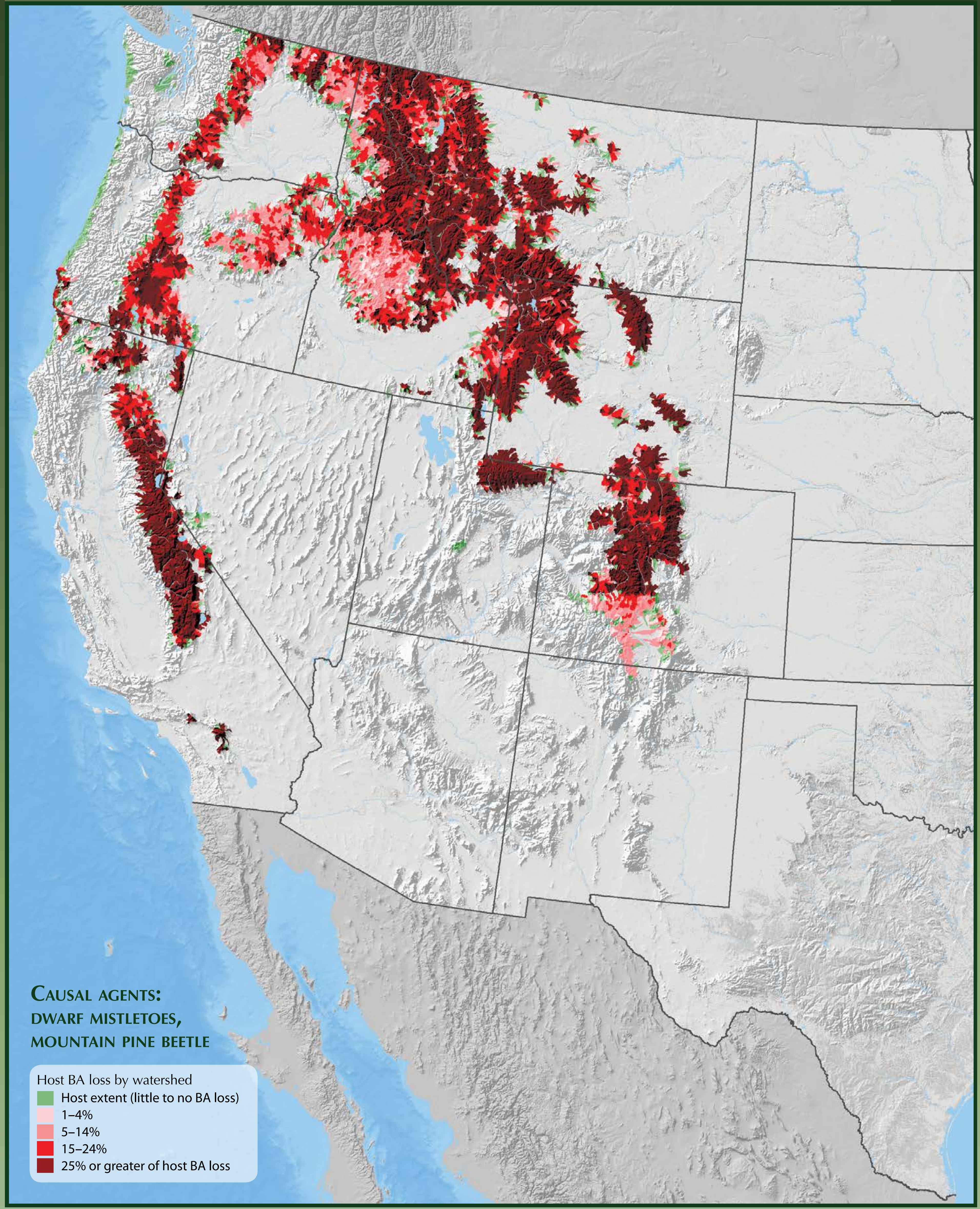
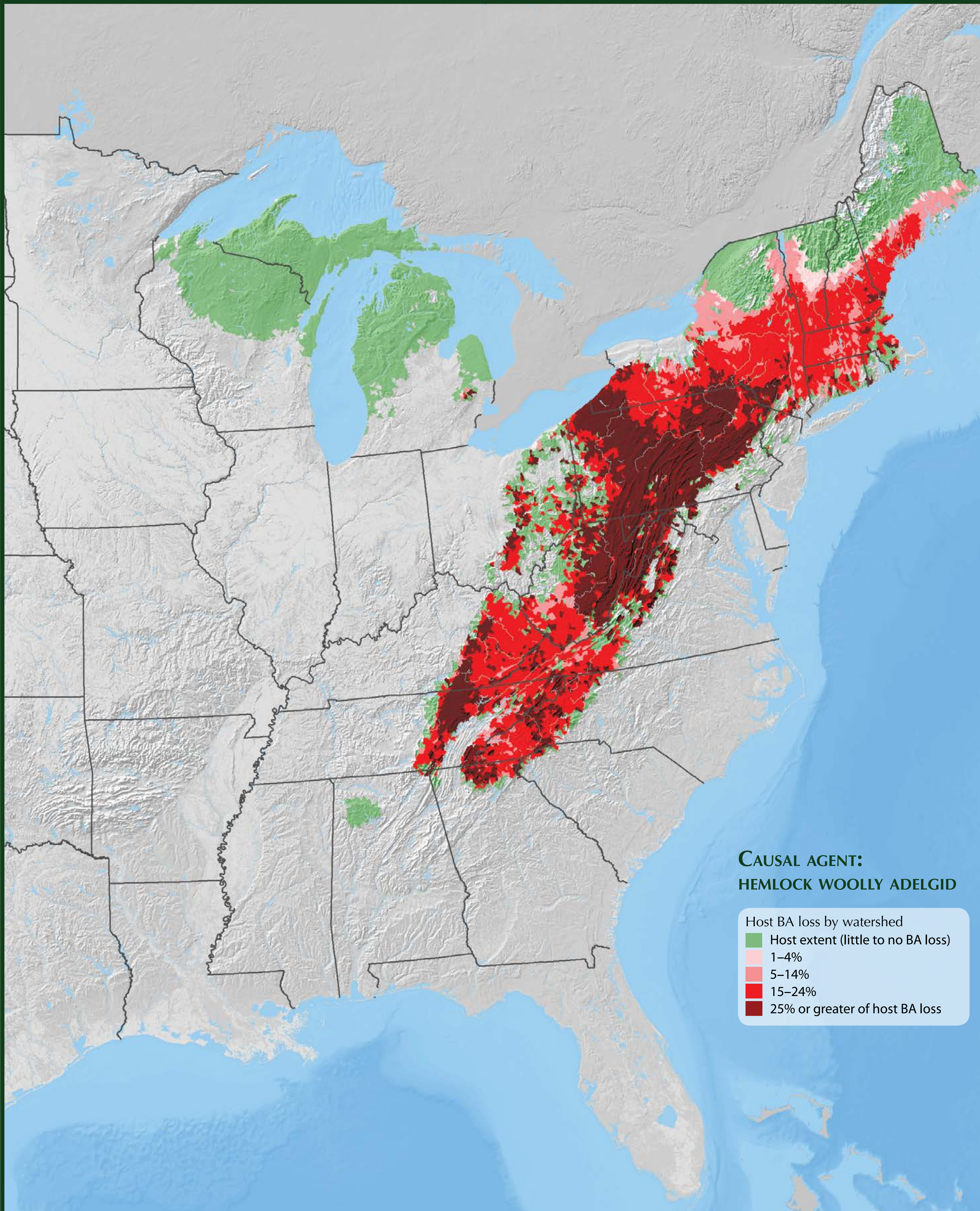


FIGURE 27



SIGNIFICANT IMPROVEMENTS IN DATA COVERAGE

Hawaii was not included in the 2006 risk assessment; however—and despite the lack of modeled forest parameter data—risk models for Hawaii were constructed for the 2012 assessment. But unlike the models for the coterminous United States and Alaska, risk models for Hawaii do not yield any estimates of BA loss.

In the 2006 NIDRM, many older FIA plots were used to acquire the necessary spatial coverage to generate interpolated surfaces that reasonably depict natural variation of forest parameter distributions. A number of gaps in FIA plot network coverage have subsequently been filled. There are still gaps in forest parameter coverage for national parks, some wilderness areas, sparsely tree-covered regions (e.g., the Great Plains), and urban areas.

In 2012, with the improvement in host modeling methods, we significantly enhanced forest parameter information across regions that previously relied on generalized renditions of host distribution. Despite these improvements, our remotely sensed modeling techniques produce less-reliable depictions of host extent in sparsely treed areas relative to more heavily forested areas, which are well-covered by the FIA plot network.

HAWAII

Today, only 5% of Hawaii's indigenous dry forest ecosystem remains intact. Beginning with the arrival of the first Polynesians and continuing through the first European contact in the 18th century up to today, housing and urban development, agriculture, and introduced species have displaced much of Hawaii's native vegetation.

Isolated by thousands of miles of ocean, the unique forests of Hawaii evolved from the extremely rare introduction of plants via wind, birds, or flotation. Initial changes began when the Polynesians first arrived sometime between 300 and 800 CE, bringing with them a handful of useful plants and, more significantly, seed-eating rats and land clearing practices. Following European contact, changes in vegetation greatly accelerated with the introduction of countless plant and ungulate species, as well as more intensive development.

Today, non-native plants make up the majority of Hawaii's lowland vegetation, with intact, native forests occurring in higher elevations where non-native plants have not yet supplanted the native species. Indeed, a visitor to the islands might never set eyes on a native Hawaiian plant. This wholesale replacement of native vegetation by exotic species continues in Hawaii at an alarming rate.

What little remains of Hawaii's dry forests naturally occurs on leeward areas at lower elevations. Fire-prone, invasive grasses aggressively spread into these areas and prevent native plant establishment, leading to a destructive grass-fire cycle, after which grasses quickly replace woody vegetation. Due to the co-location of dry lowland forests and Hawaii's ports of entry, these areas are more susceptible to introduction and establishment of non-native forest pests.

The bulk of remaining native forests occurs in more isolated, high-elevation, high-rainfall areas of the state. However, these forests are not impervious to invasion by alien plants. Many horticultural and forestry species have "jumped the fence" and are now threatening the last tracts of native forest. Strawberry guava, miconia, and Himalayan ginger are just a few of the most aggressive plants that thrive in the cool, wet, upland habitats of Hawaii and quickly out-compete native trees. No risk models representing non-native plants were included in the 2012 assessment; in order to provide a complete picture of native tree mortality, future risk and hazard assessments should address the impacts of invasive, non-native plants.

In addition to introduced plants, ungulates continue to destroy native Hawaiian forests. Hawaiian plants are not adapted to grazing, trampling, and rooting by mammal species, which were entirely absent from the native Hawaiian biota (except for a single bat species). In addition, ungulates promote the spread of invasive plants by serving as seed dispersers and by disturbing the forest floor. Pigs, goats, sheep, and various deer species all degrade forest areas where they have not been excluded by fencing and active control programs.

Although invasive plants and ungulates have been the primary focus of forest conservation efforts in Hawaii, insect and disease pests continue to pose significant risks to native forest species. Recent introductions (such as the erythrina gall wasp, ohia rust, and Myoporum thrips) demonstrate Hawaii's vulnerability to pest and pathogen introductions. Introduction of exotic forest pests is facilitated by a high level of domestic imports (including 90% of Hawaii's food) and the economically vital visitor industry. Once established, these pests and pathogens are difficult to control; prevention, therefore, is paramount.

Local and regional forest health specialists identified four insect and disease pests that have a significant impact on Hawaii's forests: Myoporum thrips, erythrina gall wasp, koa wilt, and ohia rust (**FIGURE 28**, page 46).

Myoporum thrips (*Klambothrips myopori)*

The initial infestation of naio, *Myoporum sandwicense*, by Myoporum thrips, *Klambothrips myopori*, in Hawaii was reported in March 2009. Surveys are ongoing to determine the extent of its distribution on the island of Hawaii, where naio mortality has been observed. This thrips causes leaf curling and gall-like symptoms on infested plants, with high levels of infestation resulting in plant mortality. The loss of naio, a native, ecologically important species, would be particularly biologically detrimental where the plant is a key component of critical habitat for the palila, *Loxioides bailleui*, a federally-listed endangered species of honeycreeper on Mauna Kea.

Erythrina gall wasp (*Quadrastichus erythrinae)*

The erythrina gall wasp was first detected on Oahu in April 2005. Once introduced, this pest spread to all of the main Hawaiian Islands within six months, resulting in chronic defoliation and mortality of thousands of endemic wiliwili, *Erythrina sandwicensis*, an important tree species in Hawaii's remaining lowland dry forests, recognized as one of the most endangered habitats in Hawaii. Erythrina gall wasps are very small, about the size of a typed comma; consequently, host injury (severe galling of multiple tissue types) is generally detected prior to the observation of adult wasps. Plant vigor declines from sequential defoliation, and mortality may be observed in one to two years.

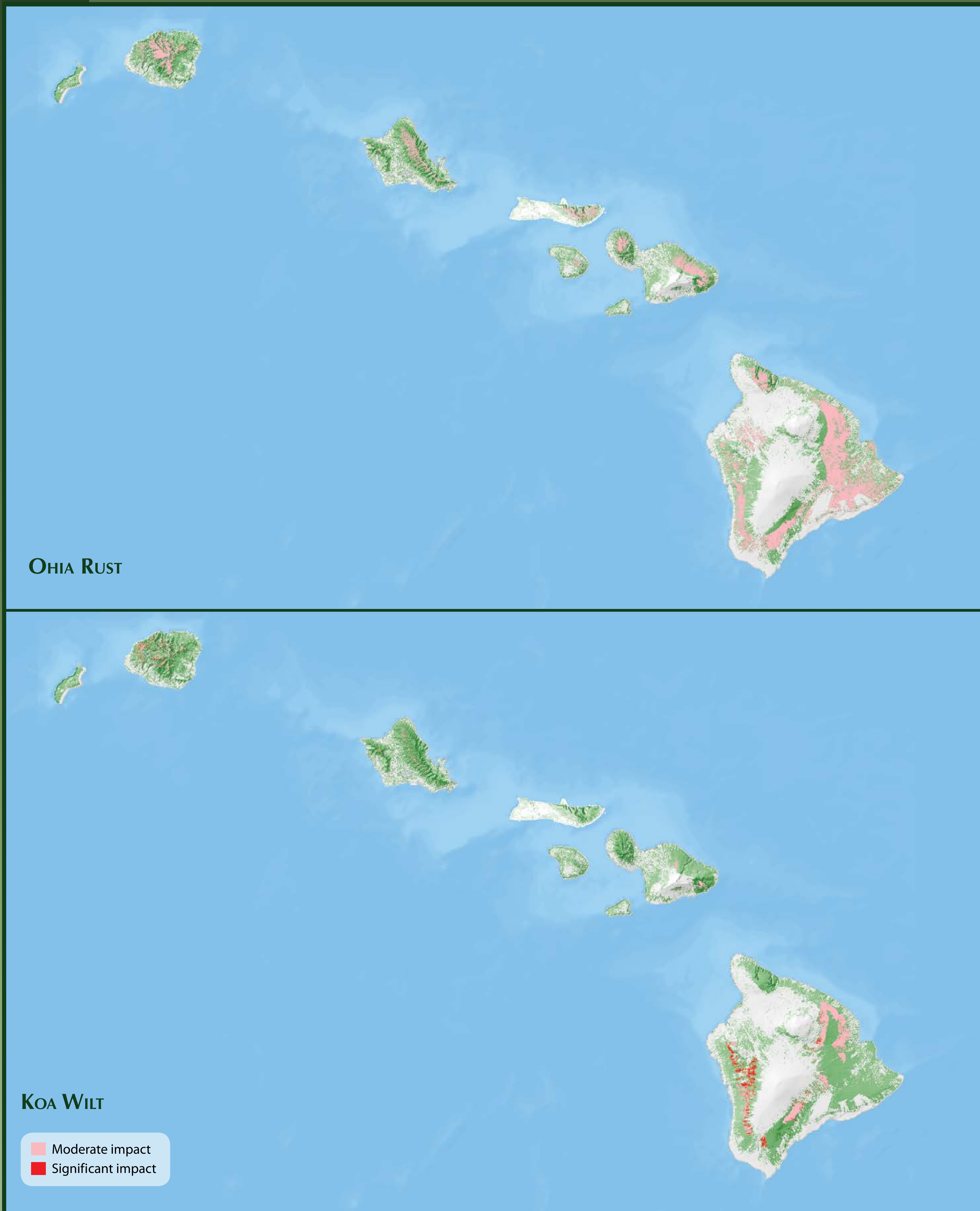
Koa wilt (*Fusarium oxysporum* f. sp. *koae*)

Koa wilt, a vascular disease, has been found on the islands of Hawaii, Maui, Oahu, and Kauai. It is caused by the fungus *Fusarium oxysporum* f. sp. *koae*, which is now commonly found in soils of the Hawaiian Islands and can kill trees of all ages. The fungus enters the roots and then colonizes the main stem's conductive tissue. Water supply to leaves is cut off within infected trees, resulting in yellowing of leaves and crown wilt symptoms. Many plantation failures and high mortality rates of young trees have been observed.

Continued, page 48

Areas of Hawaii Likely to be Impacted by Ohia Rust and Koa Wilt

FIGURE 28



Areas of Hawaii Likely to be Impacted by Myoporum Thrips and Erythrina Gall Wasp

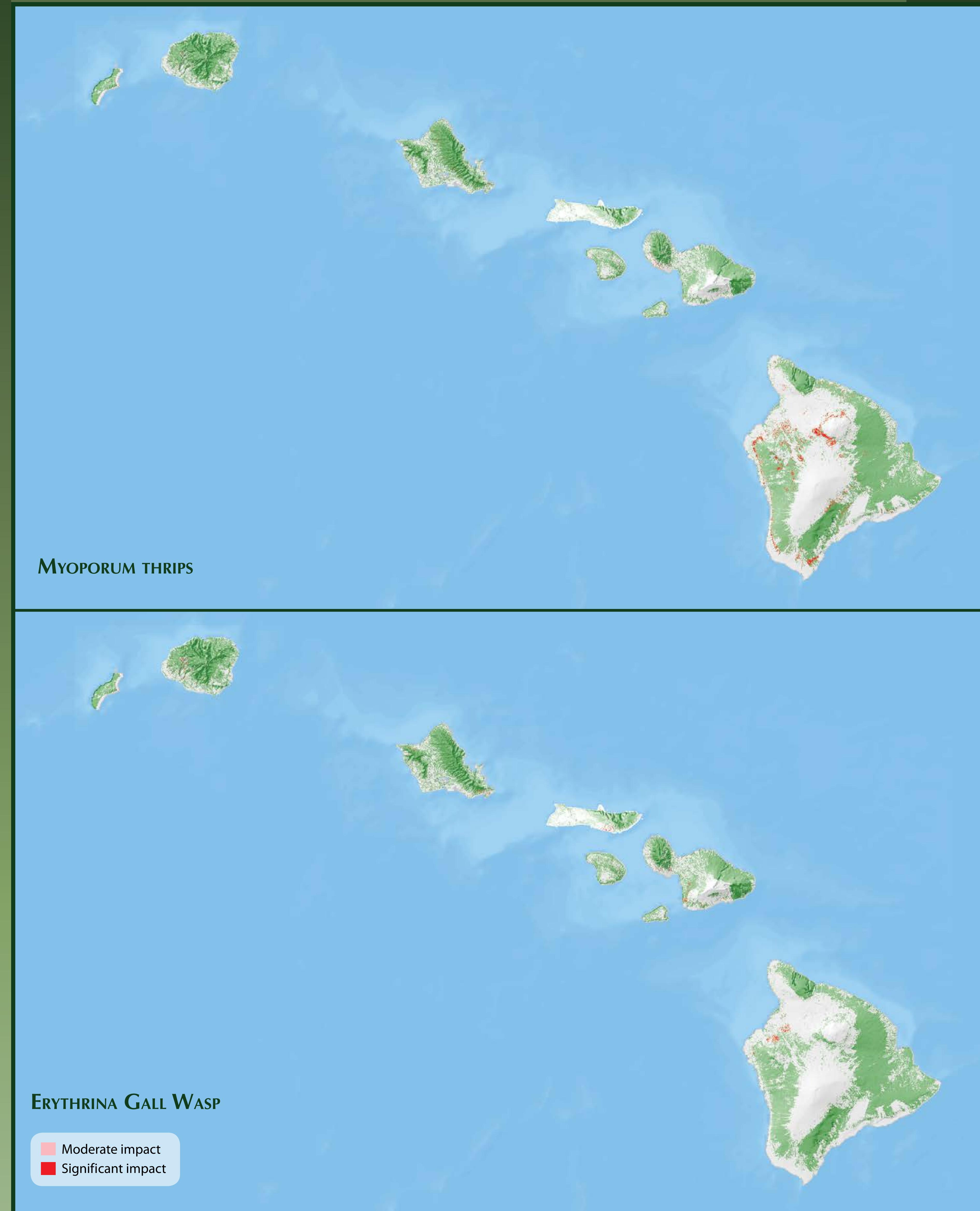


TABLE 6

Ohia rust (*Puccinia psidii*)

Ohia rust, also known as guava rust, eucalyptus rust, and myrtle rust, is caused by the fungus *Puccinia psidii*, which was first detected in Hawaii in 2005. It occurs on all of the major islands and affects a large range of native and non-native plants in the Myrtaceae. The rust infects new foliage, and in some host's reproductive tissues and green stems. Ohia (*Metrosideros polymorpha*) is an endemic tree that makes up most of the remaining native forest in Hawaii and is mildly susceptible to the rust. Although the rust does not cause dieback in mature trees, it can impact seedlings and hinder regeneration.

GREAT PLAINS

Most of the treed area of the Great Plains and adjacent prairies is located in riparian areas, along the edges of farmland, and around homesteads. Although this region is lightly forested, riparian forests, woodlots, and windrows play a critical role in protecting soil and water resources. We did not include these areas in the 2006 risk assessment due to the lack of FIA plots to account for them; by design we modeled risk only within the extent of forested areas. We derived the extent of forest from a national forest type dataset developed by the FIA and the Forest Service Remote Sensing Applications Center (RSAC) (Ruefenacht et al. 2008).

In 2012, we did not limit the extent of risk models to the distribution of forest areas as defined by Ruefenacht et al. (2008). Rather, we included any areas where the presence of trees was recorded. This greatly improves the representation of treed areas and potential risk throughout the Great Plains. Because many of the tree species and forest types along riparian areas are similar to their eastern counterparts and contain some of the same agents, relevant eastern models, such as emerald ash borer, aspen, cottonwood, oak declines, and Dutch elm disease, were used for the Great Plains area and modified as necessary (**TABLE 6**).

TABLE 6 Top mortality agents by rank for treed areas within the Great Plains and adjacent prairies

AGENT NAME	BA LOSSES (Millions of Sq. Feet)
Oak decline and gypsy moth	31.8
Dutch elm disease	5.9
Emerald ash borer	4.5
Bur oak blight	2.3
Aspen and cottonwood decline	2.1

We were unable to model certain tree and forest parameters for non-native species, such as ponderosa and Austrian pine, planted as windbreaks and around homesteads. Thus, we were not able to model the risk to these unique treed areas for key pests of concern such as diplodia tip blight, dothistroma needle blight, and pine wilt.

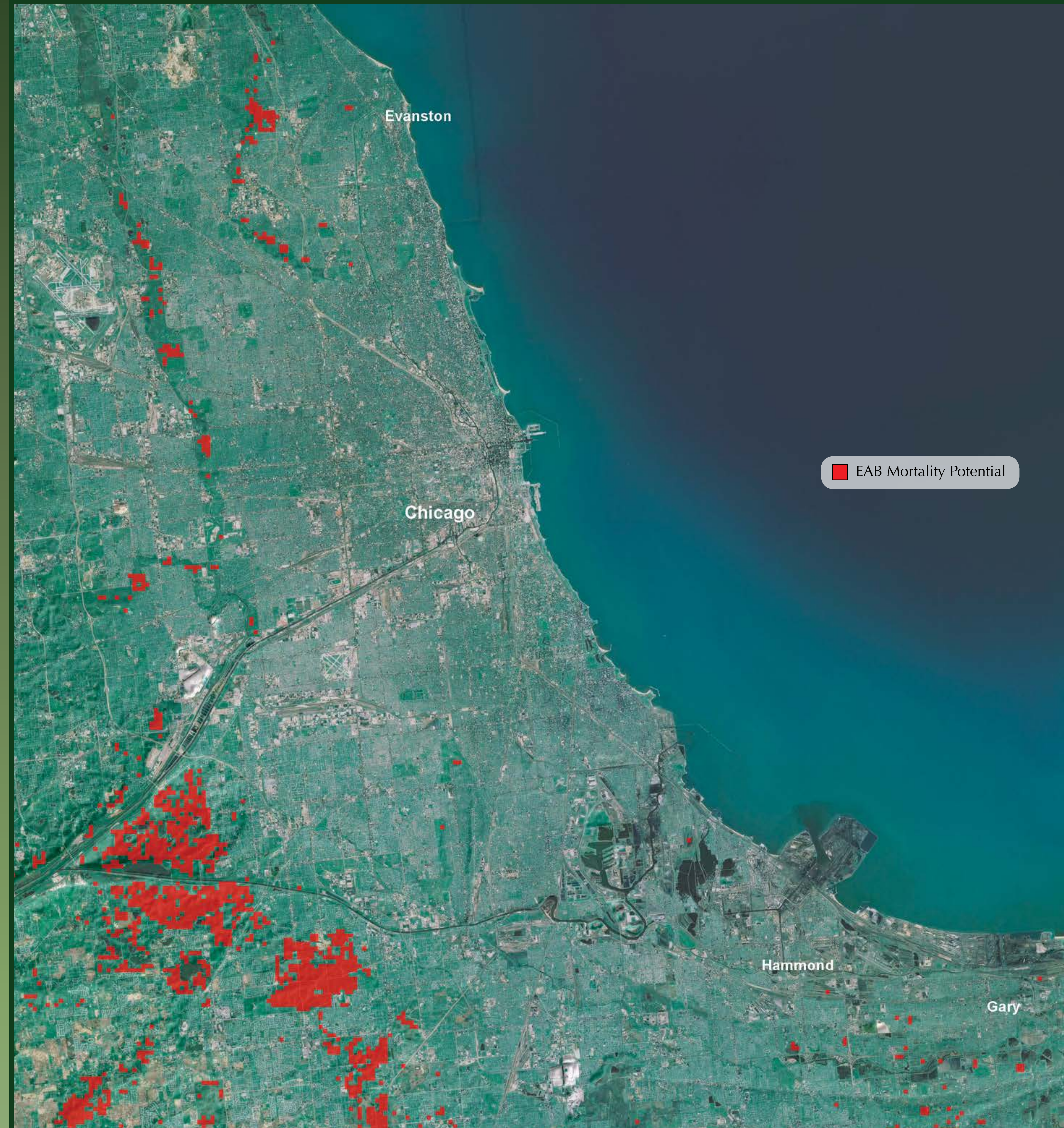
URBAN AREAS

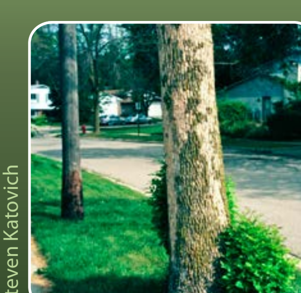
There are numerous social, ecological, and economic benefits of urban forests (Nowak et al. 2010), and it is important to assess the threats to them. Factors similar to those that inhibited our ability to properly model risk to the Great Plains in 2006 also apply to our ability to model risk to urban areas. Native insects, such as mountain pine beetle, can and do cause extensive damage in many urban areas (Ellig 2008). Introduction and establishment of exotic and invasive forest pests, such as Asian longhorned beetle and emerald ash borer, often begin in urban areas (**FIGURE 29**, page 49). Once established exotic and invasive forest pests can move into the wildland-urban interface and impact and spread through native forests. For the 2012 NIDRM, we greatly improved upon our ability to conduct host mapping in urban areas. Although we still do not have adequate forest inventory plots in urban areas, our host maps do render urban forests in a more representative way. Because of this, our individual risk models do run across the rural-urban forest continuum

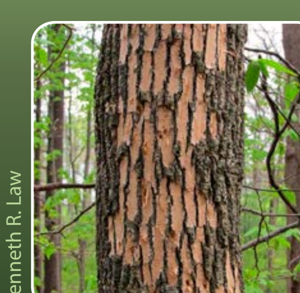
NATIONAL PARKS

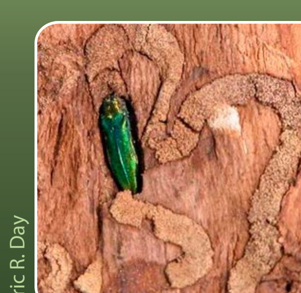
The improved resolution and coverage of the host layers provide an opportunity to generate risk maps at a scale useful for resource planning and management purposes in many of our National Parks. With the enhanced resolution we were able to estimate the proportion of most-at-risk tree species across National Parks such as Yellowstone and the Great Smoky Mountains. In Yellowstone, we estimate that 46% of whitebark pine basal area could be lost due to white pine blister rust and mountain pine beetle. In the Great Smoky Mountains 18% of hemlock and 26% of beech could be lost due to hemlock woolly adelgid and beech bark disease. Mountain pine beetle is the most destructive risk agent in Yellowstone with a 35% potential loss of the park's total BA. In the Great Smoky Mountains, oak decline is the greatest hazard with potential losses of 31% of the park's oak resource and 9% of its total BA. These mortality estimates by agent are combined to develop the overall composite risk of mortality (**FIGURES 30, 31**, pages 52, 53). A summary of mortality for the most significantly impacted national parks and national forests is provided in **TABLES 7** and **8**. Spreadsheets listing information for all national forests and parks, including details on impacts from individual agents, are available from the NIDRM 2012 website http://www.fs.fed.us/foresthealth/technology/nidrm2012.shtml. ♦

FIGURE 29



Steven Katovich


Kenneth R. Law


Eric R. Day


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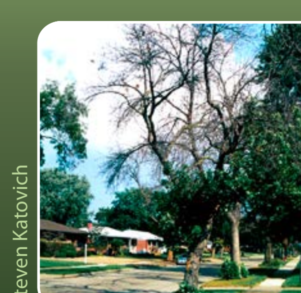


TABLE 7

NATIONAL PARK SERVICE UNIT*	Treed area (1000 acres)	% treed	BA loss (1000 sq. ft.)	% BA loss	BA loss rate (sq. ft. per acre)	Risk area (1000 acres)	% of treed area at risk
ALASKA							
Wrangell-St. Elias National Preserve	1928	40%	15,985	16%	8	375	19%
Lake Clark National Preserve	700	50%	3,954	17%	6	234	33%
Denali National Park	1587	34%	4,259	12%	3	183	12%
Wrangell-St. Elias National Park	1066	13%	6,559	16%	6	147	14%
Yukon-Charley Rivers National Preserve	1843	73%	4,863	7%	3	70	4%
Katmai National Park	728	20%	3,699	17%	5	60	8%
Lake Clark National Park	544	21%	2,057	9%	4	41	8%
INTERMOUNTAIN							
Yellowstone National Park	1768	80%	33,830	40%	19	450	25%
Glacier National Park	871	86%	6,666	19%	8	110	13%
Rocky Mountain National Park	209	78%	5,044	33%	24	62	30%
Grand Canyon National Park	470	39%	3,668	18%	8	56	12%
Grand Teton National Park	191	61%	2,107	26%	11	37	19%
Canyon de Chelly National Monument	85	92%	1,155	21%	14	20	24%
Great Sand Dunes National Preserve	38	92%	1,120	31%	29	12	32%
John D. Rockefeller, Jr. Memorial Parkway	23	99%	380	28%	16	8	32%
MIDWEST							
Ozark National Scenic Riverway	82	100%	1,229	14%	15	12	14%
Sleeping Bear Dunes National Lakeshore	56	80%	722	16%	13	10	17%
Buffalo National River	93	99%	1,253	13%	14	8	9%
Pictured Rocks National Lakeshore	65	88%	764	11%	12	6	9%
Voyageurs National Park	152	74%	525	6%	3	5	3%
Wind Cave National Park	21	62%	201	37%	9	5	23%
Missouri National Recreation River	37	54%	90	13%	2	5	13%
NATIONAL CAPITOL							
Chesapeake and Ohio Canal National Historic Park	20	98%	134	10%	7	1.6	8%
NORTHEAST							
Shenandoah National Park	193	100%	3,957	16%	20	43	22%
Saint Croix National Scenic River	91	93%	556	13%	6	12	13%
Cape Cod National Seashore	20	49%	230	28%	12	7	35%
Delaware Water Gap National Recreation Area	68	99%	768	12%	11	7	10%
New River Gorge National River	70	100%	1,107	11%	16	5	7%
Acadia National Park	38	97%	592	14%	16	3	8%
PACIFIC WEST							
Yosemite National Park	689	92%	20,958	28%	30	286	41%
Kings Canyon National Park	318	69%	8,134	29%	26	120	38%
Sequoia National Park	328	81%	10,430	24%	32	98	30%
Crater Lake National Park	168	92%	5,303	18%	32	32	19%
Lassen Volcanic National Park	104	97%	2,470	23%	24	28	27%
Great Basin National Park	75	97%	872	13%	12	5	7%
North Cascades National Park	399	80%	1,047	3%	3	4	1%
Hawai'i Volcanoes National Park	62	17%	n/a	n/a	n/a	3	4%
SOUTHEAST							
Great Smoky Mountains National Park	516	100%	7,763	12%	15	41	8%
Blue Ridge Parkway	90	100%	1,213	12%	13	8	9%
Mammoth Cave National Park	52	100%	750	10%	15	4	8%
Cumberland Gap National Historical Park	25	100%	524	14%	21	3	14%
Big South Fork National River and Recreation Area	123	100%	1,471	11%	12	2	2%

*% *treed* = treed area/total unit area. The *BA loss rate* (sq. ft. per acre) uses treed area as its basis.

TABLE 8

NATIONAL FOREST*	Treed area (1000 acres)	% treed	Total BA loss (1000 sq ft)	BA loss rate	BA loss rate (sq ft per acre)	Area at risk (1000 acres)	% of treed area at risk
Northern (Region 1)							
Nez Perce	2,210	98%	87,662	38%	40	1,339	61%
Lolo	2,599	99%	67,082	36%	26	1,198	46%
Clearwater	1,731	100%	55,254	31%	32	884	51%
Flathead	2,522	98%	46,786	28%	19	835	33%
Beaverhead	1,780	87%	48,014	39%	27	770	43%
Gallatin	2,103	91%	35,287	29%	17	683	32%
Kaniksu	1,707	98%	50,183	26%	29	673	39%
Kootenai	2,097	99%	48,432	24%	23	664	32%
Lewis and Clark	1,892	95%	34,570	27%	18	602	32%
Bitterroot	1,536	97%	31,463	34%	20	589	38%
Coeur d'Alene	801	100%	30,299	37%	38	541	68%
Rocky Mountain (Region 2)							
Black Hills	1,461	96%	46,293	54%	32	786	54%
San Juan	1,948	94%	63,781	32%	33	706	36%
Rio Grande	1,694	91%	50,443	36%	30	489	29%
Pike	1,189	93%	36,877	37%	31	470	40%
Gunnison	1,671	92%	52,208	30%	31	442	26%
Roosevelt	1,046	97%	24,736	32%	24	384	37%
San Isabel	1,107	86%	32,134	33%	29	383	35%
Southwestern (Region 3)							
Carson	1,487	93%	33,864	29%	23	442	30%
Santa Fe	1,534	96%	28,553	26%	19	426	28%
Intermountain (Region 4)							
Toiyabe	3,443	78%	40,669	20%	12	731	21%
Payette	2,357	97%	20,796	21%	9	458	19%
Salmon	1,619	91%	20,931	24%	13	419	26%
Bridger	1,519	87%	27,126	31%	18	419	28%
Ashley	1,140	85%	31,129	35%	27	345	30%
Targhee	1,468	88%	16,768	23%	11	338	23%
Pacific Southwest (Region 5)							
Modoc	1,743	88%	32,005	32%	18	675	39%
Lassen	1,333	97%	44,180	28%	33	651	49%
Sierra	1,317	93%	47,380	27%	36	480	36%
Tahoe	1,199	99%	31,494	18%	26	353	29%
Plumas	1,379	99%	34,569	18%	25	320	23%
Pacific Northwest (Region 6)							
Fremont	1,651	96%	37,594	31%	23	906	55%
Deschutes	1,815	98%	38,564	25%	21	763	42%
Umatilla	1,493	99%	29,861	29%	20	701	47%
Whitman	1,536	98%	32,476	26%	21	695	45%
Winema	1,094	99%	30,796	27%	28	563	51%
Wallowa	885	83%	15,563	30%	18	470	53%
Malheur	1,273	98%	20,189	24%	16	460	36%
Southern (Region 8)							
George Washington	1,746	99%	40,405	21%	23	522	30%
Eastern (Region 9)							
Mark Twain	2,881	97%	39,716	16%	14	398	14%
Manistee	1,284	97%	16,150	19%	13	342	27%

*% *treed* = treed area/total unit area. The *BA loss rate* (sq. ft. per acre) uses treed area as its basis.

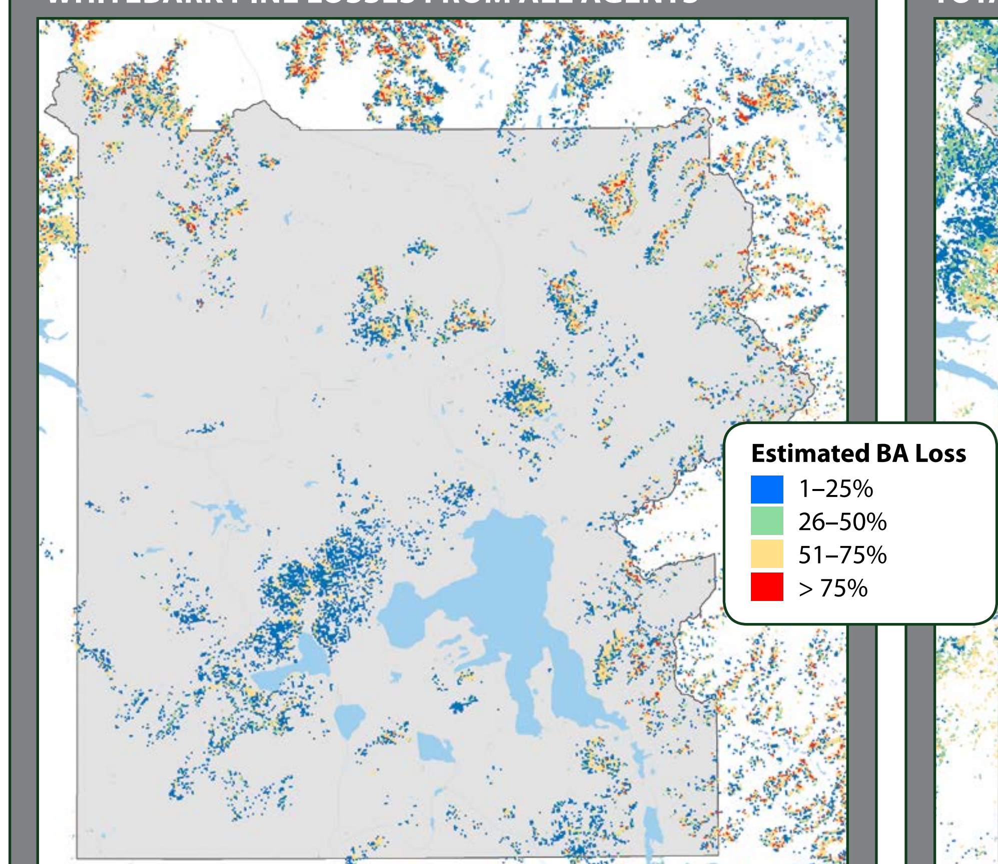
Overall Risk

TREE SPECIES*	Host's % of Total BA	BA per Acre on Host Extent	Host BA Loss Rate
Lodgepole pine	65.2%	43.6	51.8%
Whitebark pine	3.0%	10.7	46.3%
Douglas-fir	2.3%	16.2	20.9%
Engelmann spruce	11.9%	16.7	15.1%
Subalpine fir	15.1%	15.6	14.8%
Limber pine	0.2%	4.4	27.7%
Quaking aspen	0.01%	2.8	12.5%
ALL TREE SPECIES**		**48.1**	**39.8%**

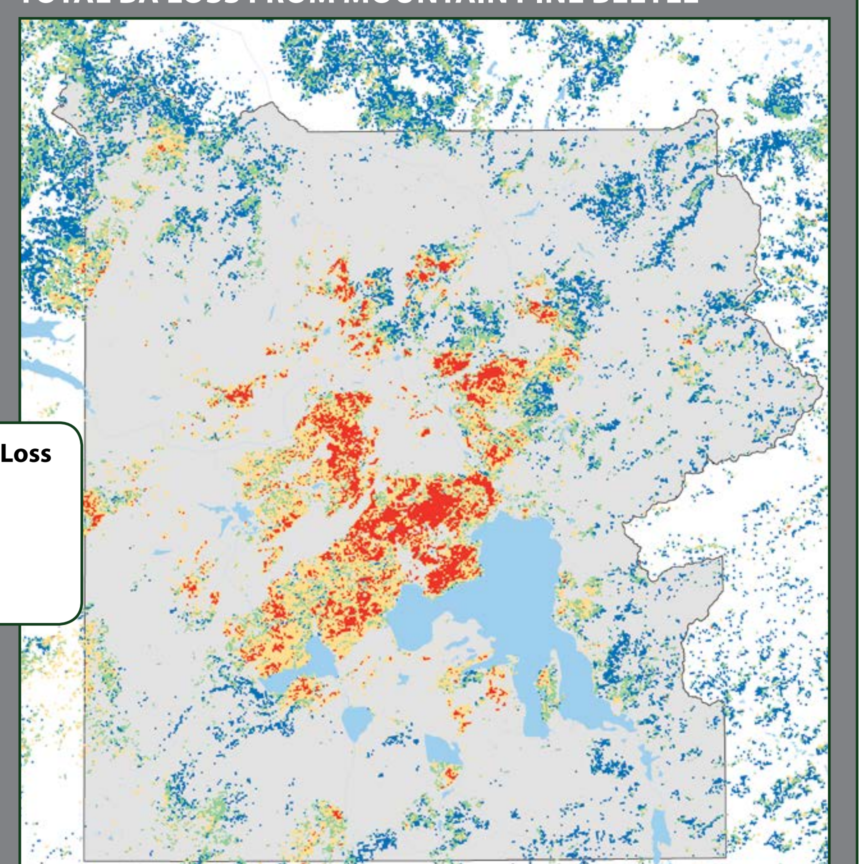
* Table only shows species with modeled BA losses.
** BA per Acre uses treed area as its basis. Host BA Loss uses total BA (all host tree species) as its basis.

PEST OR PATHOGEN (All numbers are rounded)	Host's % of Total BA	Host BA Loss Rate	Total BA Loss Rate
Mountain pine beetle	68.5%	51.0%	34.9%
Root diseases	52.5%	2.9%	1.5%
Spruce beetle	11.9%	9.2%	1.1%
Balsam woolly adelgid	15.1%	4.8%	0.7%
Western spruce budworm	29.3%	1.4%	0.4%
Western balsam bark beetle	15.1%	2.2%	0.3%
Douglas-fir beetle	2.3%	13.1%	0.3%
White pine blister rust	3.2%	7.1%	0.2%
Dwarf mistletoes	67.8%	0.1%	0.1%
Aspen / cottonwood decline	0.01%	8.0%	<0.05%
IMPACT FROM ALL AGENTS			**39.8%**

Whitebark Pine Losses from All Agents

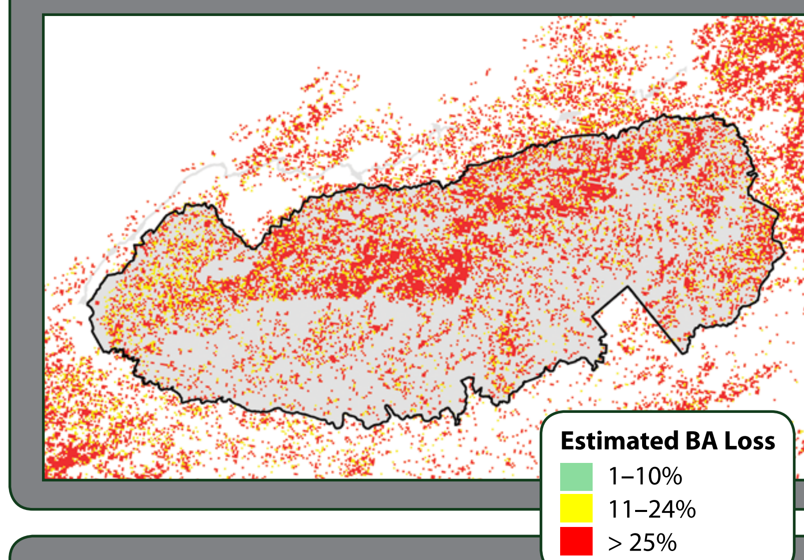


Total BA Loss from Mountain Pine Beetle

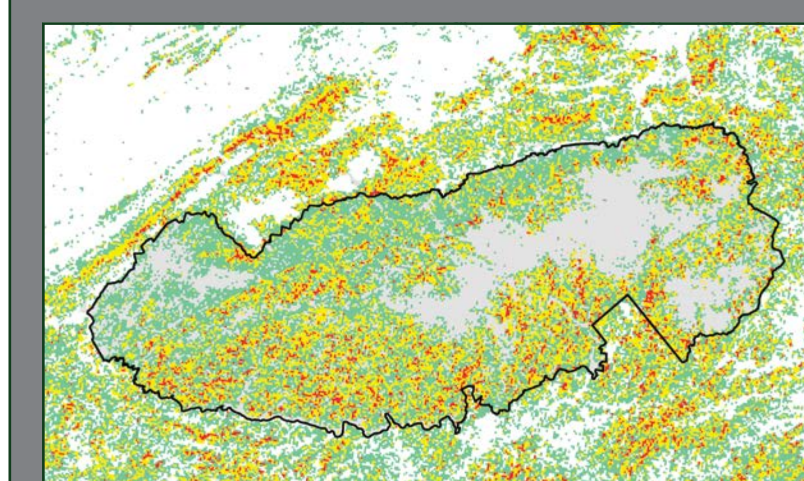


Overall Risk

Host Loss from Hemlock Woolly Adelgid



Host Loss from Oak Decline



TREE SPECIES*	Host's % of Total BA	BA per Acre on host extent	Host BA Loss Rate
Red oak spp.	14.9%	23.7	34.1%
White oak spp.	13.7%	25.4	27.7%
American beech	2.9%	12.1	26.3%
Hemlock spp.	6.4%	13.6	18.1%
Eastern white pine	3.0%	16.5	9.4%
Ash spp.	0.4%	5.1	18.8%
Southern pines (9 species)	5.6%	22.9	1.9%
Sassafras	0.2%	3.4	8.7%
Sirex pines (10 species)	2.6%	14.2	1.6%
ALL TREE SPECIES**		**130.8**	**11.5%**

* Table only shows species with modeled BA losses.
** BA per Acre uses treed area as its basis. Host BA Loss uses total BA (all host tree species) as its basis.

PEST OR PATHOGEN (All numbers are rounded)	Host's % of Total BA	Host BA Loss Rate	Total BA Loss Rate
Oak decline	28.5%	30.8%	8.8%
Hemlock woolly adelgid	6.4%	18.2%	1.2%
Beech bark disease	2.9%	26.2%	0.8%
Southern pine beetle	5.6%	7.5%	0.4%
Ips spp.	5.6%	1.9%	0.1%
Emerald ash borer	0.4%	18.9%	0.1%
Oak wilt	14.9%	0.5%	0.1%
Root diseases	9.9%	0.6%	0.1%
Sirex woodwasp	2.6%	1.7%	<0.05%
Laurel wilt	0.2%	4.0%	<0.05%
IMPACT FROM ALL AGENTS			**11.5%**

Apart from host parameters, climate data are the most significant type of criteria used in NIDRM models (**TABLE 1**, page 4).

Climate is generally defined as the average weather conditions of an area. In a broad sense, climate integrates a suite of dynamic environmental factors surrounding biotic communities, including the composition of the atmosphere, the temperature and moisture content of the air and soil, and the timing and severity of extreme weather events. In a narrower sense, climate can be characterized, at least in part, via metrics such as average temperature and moisture content (precipitation) for a region over a period of time.

Forest climates exert significant pressures on the population structure and dynamics of forest pest agents and their hosts, and on the relationships between agents and hosts. The concentration of atmospheric carbon dioxide (CO_2) affects plant photosynthetic rates and tissue quality, which in turn has cascading effects throughout the ecosystem's food chain. Atmospheric pollutants can significantly affect soil chemistry in ways that can be either beneficial or detrimental to plants. Temperature is extremely important in controlling biotic metabolic rates and exerts strong influence over plant, insect, and pathogen development and reproductive rates. Timing, duration, and severity of cold conditions influence plant and insect cold-hardiness, phenology, and survivorship. Ecosystem moisture content strongly regulates a community's productivity and, together with temperature, dictates moisture stress (drought) status, which in turn significantly affects the potential severity of insect and disease outbreaks. Severe weather events can cause widespread mortality of trees.

Many of the relationships between climate and forest pests are well-understood and documented. For example, drought stress is long-recognized as contributing to the severity of many bark beetle outbreaks; precipitation and humidity affect the spread of foliage and root diseases; and the population dynamics of many insects is influenced by climatic trends. Although many of these climate-pest relationships have been elucidated by forest ecologists, many others are poorly understood.

An abundant body of scientific research suggests that we can expect significant shifts in many climate variables over the coming decades. Leading the way in summarizing climate research is the Intergovernmental Panel on Climate Change (IPCC), whose data have been made available via the Program for Climate Model Diagnosis and Intercomparison (PCMDI) Climate Model Intercomparison Project 3 (CMIP3) (https://esg.llnl.gov:8443/index.jsp). According to the IPCC's Fourth Assessment Report (AR4) (AR4; IPCC 2007), by the end of the 21st century North America is *very likely* to have experienced an increase in average temperature of approximately 4° C. While less certain, projections for precipitation over the next century indicate wetter conditions in some areas (e.g., the Northeast), drier conditions in others (e.g., the Southwest), and generally dryer summers throughout the coterminous United States.

As discussed above, the 2012 NIDRM draws on historical (1971–2000) climate datasets for risk-model criteria (see Forest Host-Tree Species Parameter Development, page 5). Therefore, risk model outputs assume that climate over the next 15 years will be more or less commensurate with historical climate levels. To the extent that this is not the case, that instead climate over the next 15 years may be significantly different than the 1971–2000 "climate normal" period, it is important to consider the possible effects of a climate-altered future in our estimation of risk.

We did not perform a comprehensive, future, climate-effects analysis as part of the 2012 NIDRM assessment; however, for some agents we conducted a preliminary analysis of the possible effects of future climate on forest-pest risk. Our analysis represents an introductory attempt to understand the importance of climate on various agent-host relationships, and to demonstrate the degree to which the individual NIDRM models can capture the effects of future climate.

Of the 186 models that comprise NIDRM, 85 (78 in the coterminous US) use one or more climate criteria as "drivers" of risk (**TABLE 9**). That some risk models neglected to include climate drivers should not be interpreted as an indication that climate is not an important driver in any particular agent-host relationship. Future climate datasets were not available during model development, and the idea of conducting future climate analysis had not been formally developed; thus, we did not consider future climate, per se, when we designed the individual pest and pathogen models.

Our procedures for simulating future climate effects consisted simply of deriving projected future climate datasets (details provided below) and using them in place of historically based climate data. We did not attempt to adjust or amend 2012 NIDRM models to better account for climate drivers. We then re-ran the standard 2012 NIDRM models through RMAP using the future climate datasets. As a result, our analyses reflect future climate effects as predicted by only the subset of models that explicitly use climate criteria. Comparing the standard NIDRM results with the results from runs using future climate provides insights into how future climate may affect agent-host relationships, and also helps us evaluate our models, thereby allowing us to build better models in the future. We present results from two individual models.

FUTURE CLIMATE DATASETS

Future climate datasets were obtained from the Forest Service Rocky Mountain Research Station (Coulson et al. 2010). Datasets include down-scaled (5 arc minute postings–approximately 7-kilometer resolution) estimates of monthly climate variables for all months of the 21st century for the coterminous United States. Data were not available for Alaska and Hawaii. Variables include estimates for average monthly and annual maximum temperature (Tmax), minimum temperature (Tmin), average temperature (Tavg), precipitation (PPT), and potential evapotranspiration (PET). Data are expressed both as *deltas,* representing a change from historical (1971–2000) averages, and as future estimates per se, (i.e., as an estimate of the metric itself [e.g., PPT], derived by applying the delta to the historical average metric at each location). The available data are derived from CMIP3-published data and represent output from a number of different general circulation models run under different CO_2 emission scenarios. We used data from the Canadian Centre for Climate Modeling and Analysis, Third Generation Coupled Global Climate Model Version 3.1 medium resolution: emission scenario A1B (http://www.cccma.ec.gc.ca/data/cgcm3/cgcm3.shtml). A discussion of the datasets and the downscaling procedures can be found in Joyce et al. (2011).

AGENT	HOST(S)	Number of models	CLIMATE CATEGORY*		
			Drought	Precip.	Temp.
Aspen decline	Quaking aspen	2	yes (1)	no	yes (1)
Balsam woolly adelgid	Balsam fir, grand fir, subalpine fir	4	no	no	yes
Blight	Bur oak	1	yes	no	no
Douglas-fir beetle	Douglas-fir	1	yes	no	no
Fir engraver	California red fir, grand/white fir spp.	5	yes (5)	yes (4)	no
Goldspotted oak borer	California black oak, California live oak, canyon live oak	3	yes	no	no
Hemlock woolly adelgid	Eastern hemlock, Carolina hemlock	1	no	no	yes
Engraver beetles [*Ips* spp.]	Ponderosa pine, southern pines, pinyon spp.	7	yes (7)	yes (2)	no
Jeffrey pine beetle	Jeffrey pine	1	yes	no	no
Mountain pine beetle	Limber pine, lodgepole pine, ponderosa pine, sugar pine, whitebark pine	6	yes (5)	yes (1)	no
Root disease	Grand/white/Douglas-fir spp., subalpine fir, fir spp., mountain hemlock, Jeffrey pine, ponderosa pine, western red cedar	12	no	yes (11)	yes (12)
Roundheaded pine beetle	Ponderosa pine	3	yes	no	no
Sudden oak death	California black oak, California live oak, tanoak	6	no	yes	yes
Western balsam bark beetle	Subalpine fir	6	yes	no	no
Western pine beetle	Coulter pine, ponderosa pine	9	yes	no	no
Western spruce budworm	Grand/Douglas-fir spp.	1	no	yes	yes
White pine blister rust	Limber pine, Rocky Mountain bristlecone pine, sugar pine, western white pine, whitebark pine, eastern white pine	9	no	yes (8)	yes (8)
Winter moth	Oak spp.	1	no	no	yes

* The number of models using criteria from the climate category is shown in parentheses.

For this analysis, climate data projections representing the 15-year period, 2012–2026 were used. Temperature and precipitation deltas averaged over this period were applied to their corresponding NIDRM historical climate data-layers to derive future estimates (both annual and monthly) for Tmax, Tmin, Tavg and PPT. The future monthly estimates of PET and PPT data (for each month in the 15-year period) were used to derive projected, 15-year, drought-index and drought-frequency data layers using methods similar to those used to generate the standard historically based NIDRM drought layers (Koch et al. in press). All available climate datasets were resampled to a 240-meter resolution for inclusion within RMAP.

FUTURE CLIMATE PREDICTIONS

Our future climate datasets exhibit slight but significant shifts in temperature and precipitation, relative to the historical datasets. Our mean annual temperature (MAT) dataset indicates increased temperatures throughout the coterminous United States (**FIGURE 32**). Our mean annual precipitation (MAP) dataset indicates decreased precipitation in much of the Interior West and Southwest, and increased amounts in most of the Pacific Northwest and areas east of the Mississippi (**FIGURE 33**). The future drought layers indicated significantly greater frequency of drought (data not shown). How all of these trends translate into levels of risk to trees from insect and pathogen agents depends upon what specific climate variable(s) are used to model risk, and the magnitude of the variable(s) relative to the levels that constitute risk. We present two examples, armillaria root disease in the west and hemlock woolly adelgid in the east, to demonstrate how subtle shifts in one or two climate variables can result in changes in modeled risk and mortality.

Armillaria Root Disease (genus *Armillaria*)

One NIDRM root disease model in the Pacific Northwest represents Armillaria root disease in grand fir and Douglas-fir hosts, and represents three ecoregions occupying parts of northeast Oregon and southeast Washington. This model utilizes two climate variables, MAP and MAT, in addition to two forest-parameter variables and a soil drainage index. In this model, the risk-response curves for MAP and MAT dictate increasing risk as the variable increases above a threshold, plateaus at some point, and then decreases as the variable continues to increase. The plateau levels (range of values where risk remains maximized) for MAP are ~ 35–50 inches of precipitation per year, and for MAT, ~ 42–45° F.

Modeled basal area (BA) mortality from this model under future climate *varies* relative to mortality under historical climate, with mortality rates increasing in some locations and decreasing in other locations (**FIGURE 34A**). This varied response reflects the variable nature of the risk-response curves and the distributions of MAP and MAT. Areas of decreasing mortality under future climate generally fall in locations where MAT is transitioning to temperatures higher than those corresponding to the plateau of the risk-response curve (i.e. greater than ~ 45° F) (**FIGURE 34B**). Areas with increasing mortality are generally in locations where future MAP is increasing within the upward portion of the risk-response curves (i.e between 21 and 35 inches of MAP/yr.; **FIGURE 34C**).

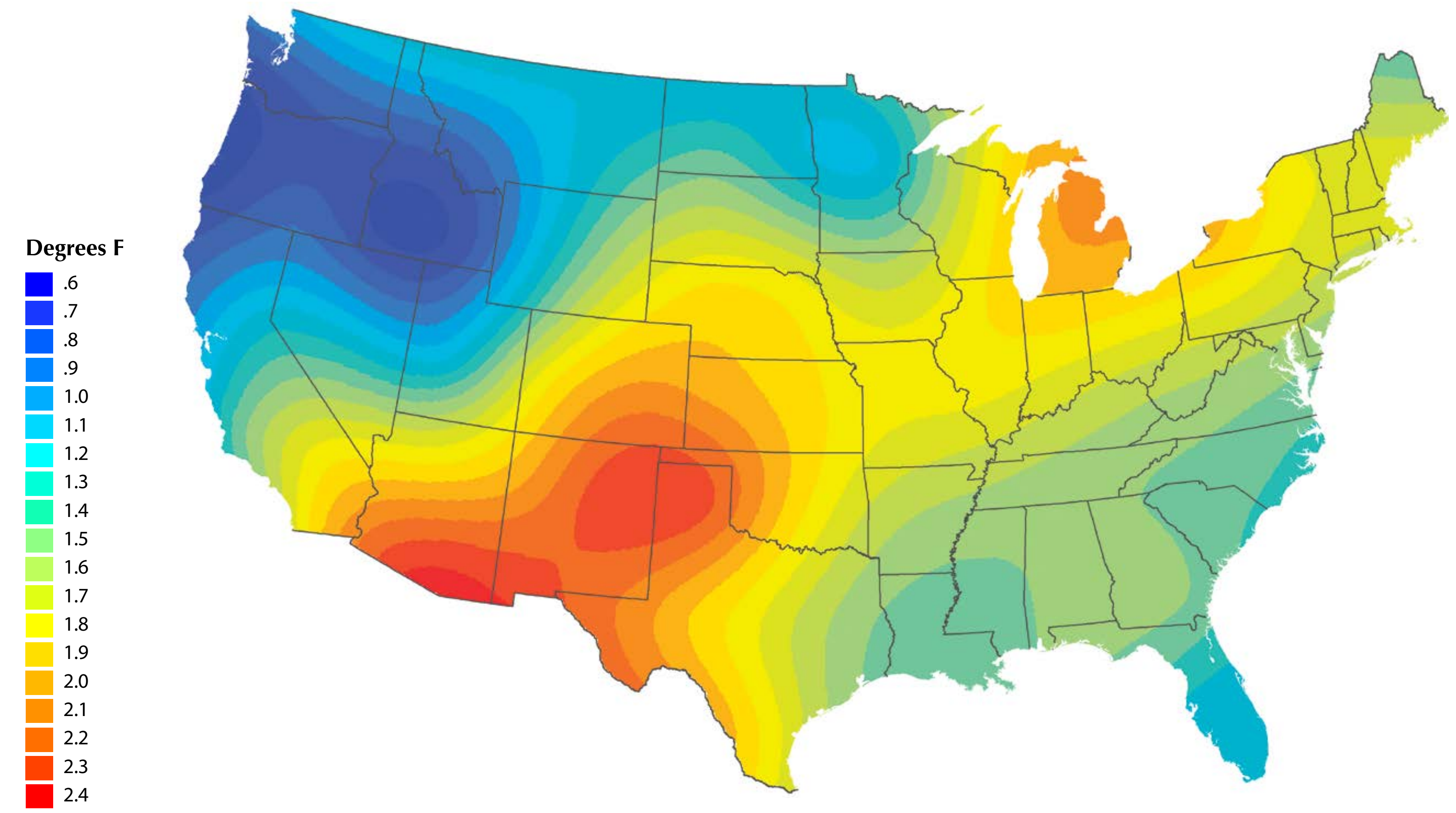


FIGURE 32 Estimated increase in mean annual temperature

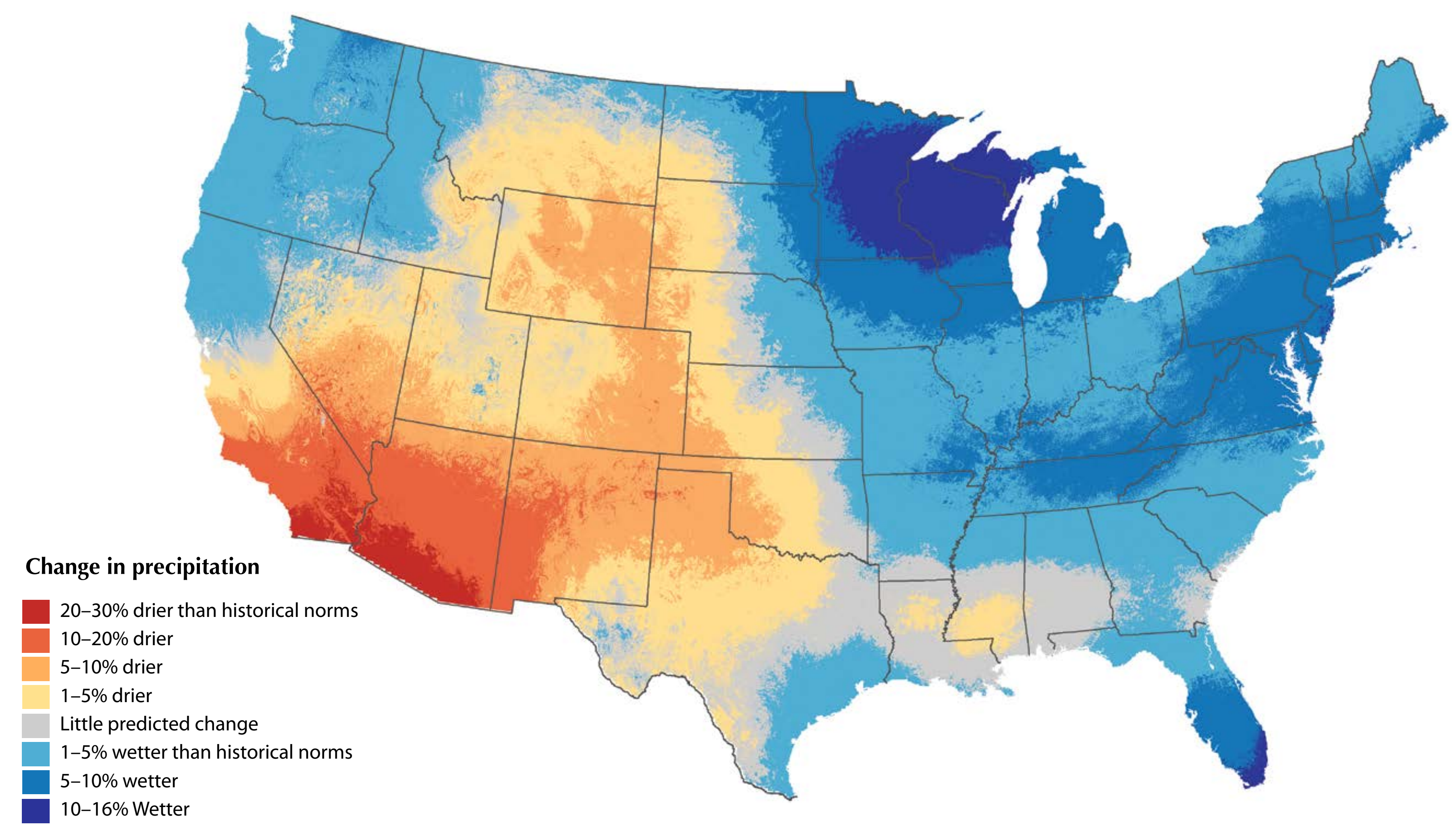
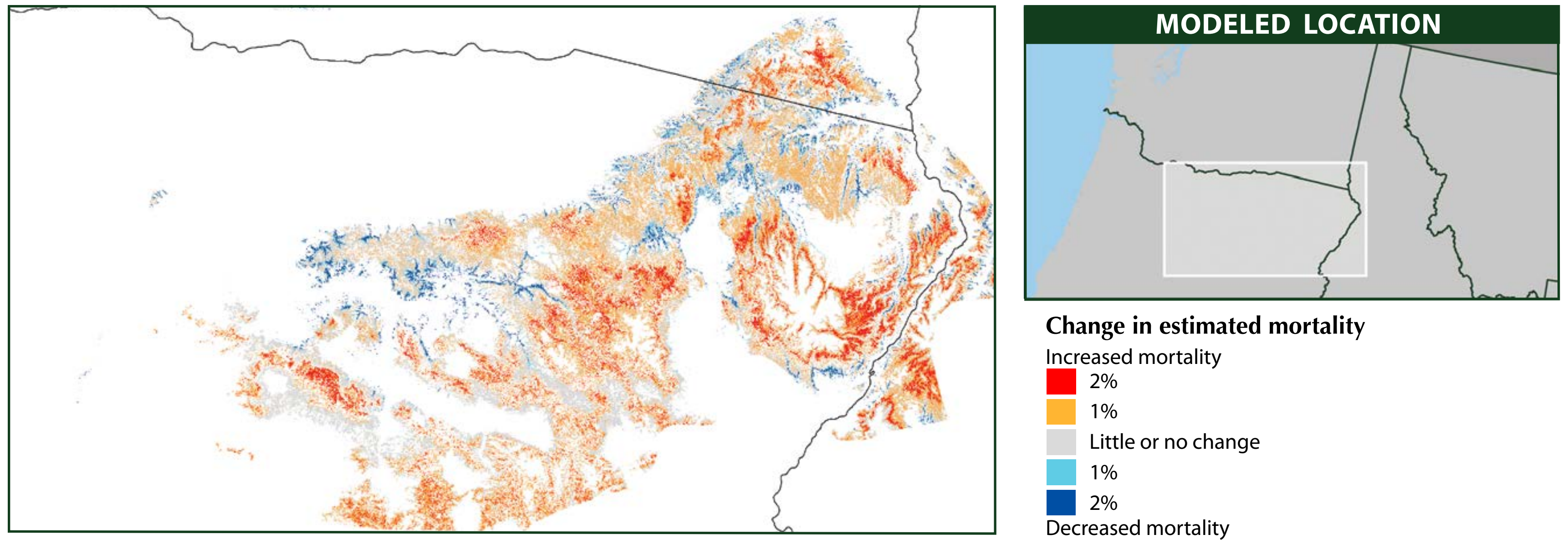
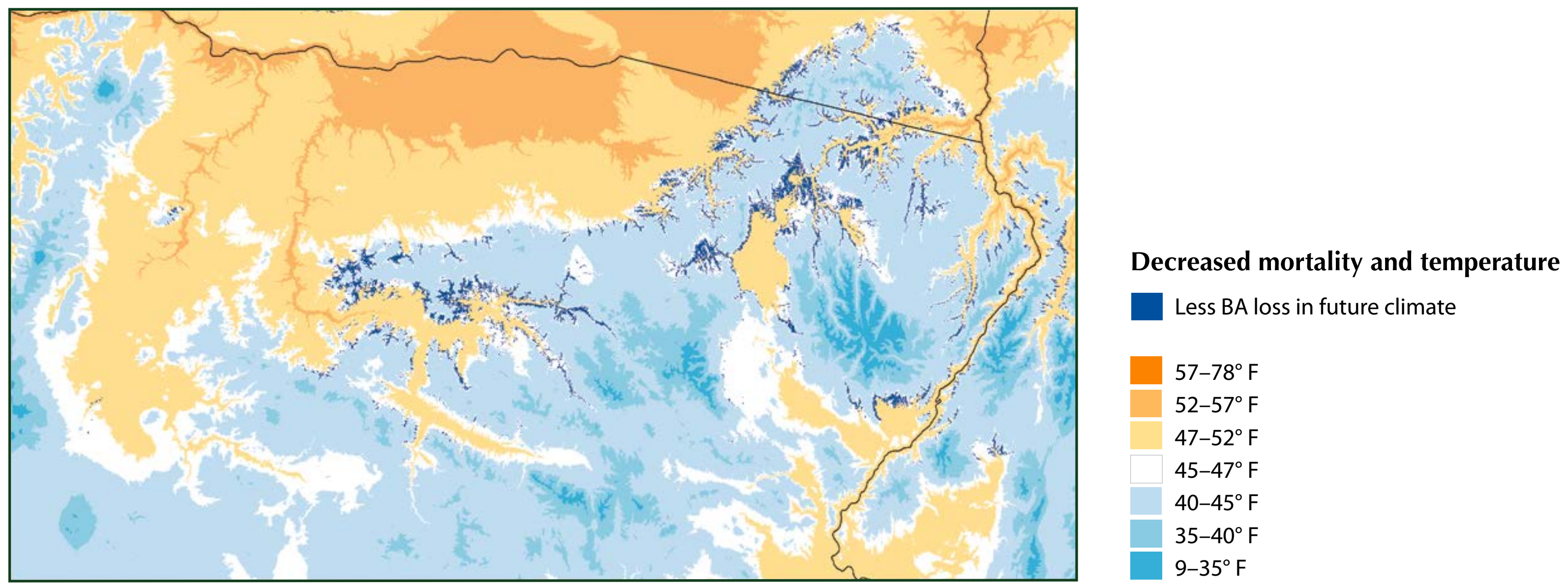


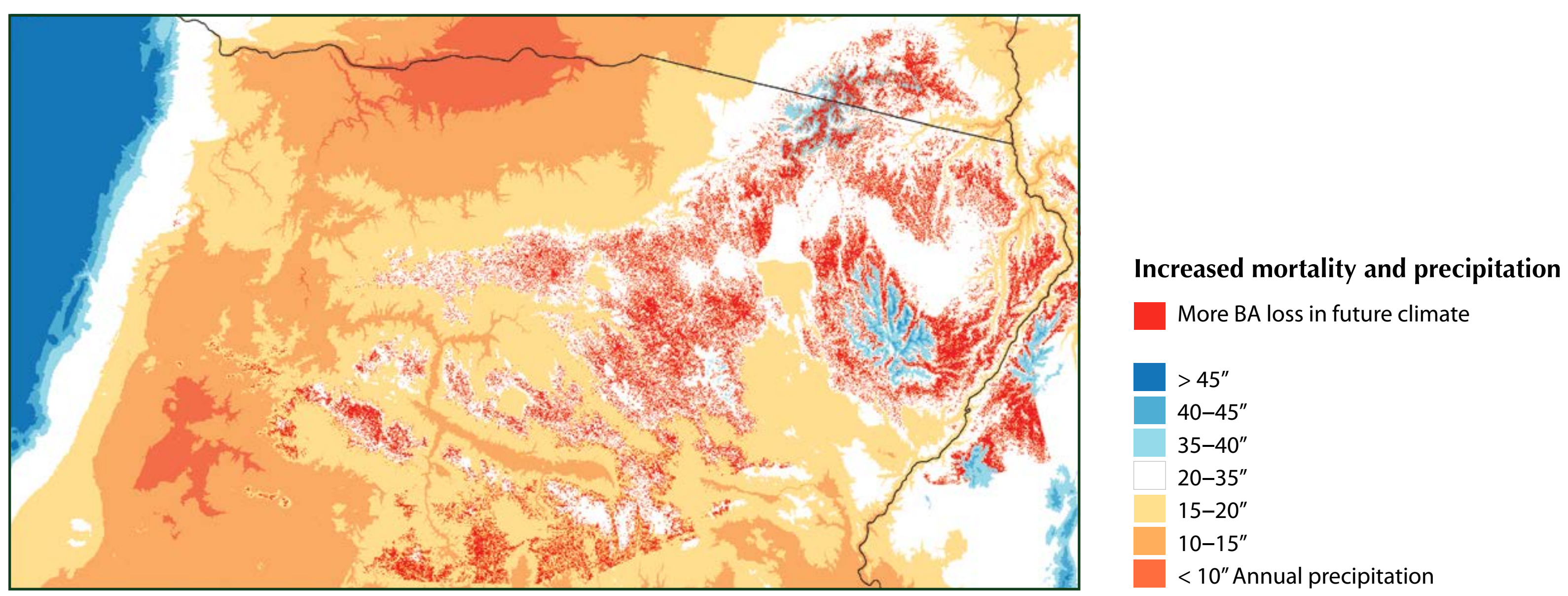
FIGURE 33 Estimated change in mean annual precipitation



A Change in modeled mortality from Armillaria root disease (ARD)
Percent BA mortality (future climate) minus % BA mortality (historical). Hosts are grand fir and Douglas-fir.



B Future MAT and areas of decreased mortality from ARD
Blue pixels represent areas modeled as having less mortality from ARD under future climate relative to historical climate. White areas represent the future climate scenario 45–47° F MAT.



C Future MAP and areas of increased mortality from ARD
Red pixels represent areas modeled as having more mortality from ARD under future climate relative to historical climate. White areas represent the 20–35 inch MAP band.

Hemlock Woolly Adelgid (*Adelges tsugae*)

The NIDRM model for hemlock woolly adelgid (HWA) in hemlock species in the Northeast utilizes one climate criterion, January Tmin (**FIGURE 35**), along with two forest-parameter layers and an HWA range distribution layer. It was run in 24 ecoregions. The model's risk-response curve for January Tmin dictates that risk begins at ~ 10° F, and increases as temperature increases, reaching a maximum near 15° F.

Projected BA mortality in hemlock from HWA under future climate *increases* (overall) relative to the standard NIDRM run, with individual pixel changes (future climate mortality rate minus historical climate mortality rate) ranging from 0–5% BA. This follows from the January Tmin never being lower in any location in the future climate dataset relative to the historical dataset (data not shown). Bands of increased mortality fall in areas where the future climate January Tmin is in the 10–15° range (**FIGURE 35**).

The two examples above (ARD and HWA) demonstrate a contrasting set of agents and risk-response types. HWA is an exotic agent from the eastern United States, which had a unidirectional response to one climate variable. Armillaria root disease is an agent native to the western United States, which had a varied response to two climate variables. These two responses typify those seen across the suite of NIDRM models that use climate criteria to estimate risk and mortality (**TABLE 9**, page 56).

As for the other NIDRM models utilizing climate criteria: Nearly all of the bark beetle models, typically drought-driven, exhibited significant increases in projected mortality rates under future climate. Drought-driven aspen decline models likewise indicated significant increases in mortality in the central and southern portions of the Interior West. Other agents, whose NIDRM models are in part temperature-driven, that exhibit increased mortality under future climate include root diseases, white pine blister rust, balsam woolly adelgid, and western spruce budworm, predominantly in California, the Pacific Northwest, and northern parts of the Interior West.

A number of models predicted decreased levels of mortality under future climate. In the western United States, most of the projected decreases in mortality were attributable to various root disease models that use various temperature and precipitation (annual or seasonal) climate drivers. Sudden oak death in coastal California was projected to be lower in some locations under future climate conditions. Other models exhibiting decreased mortality under future climate include those for bur oak blight in the Midwest, western spruce budworm in Oregon, and white pine blister rust in eastern white pine in the East.

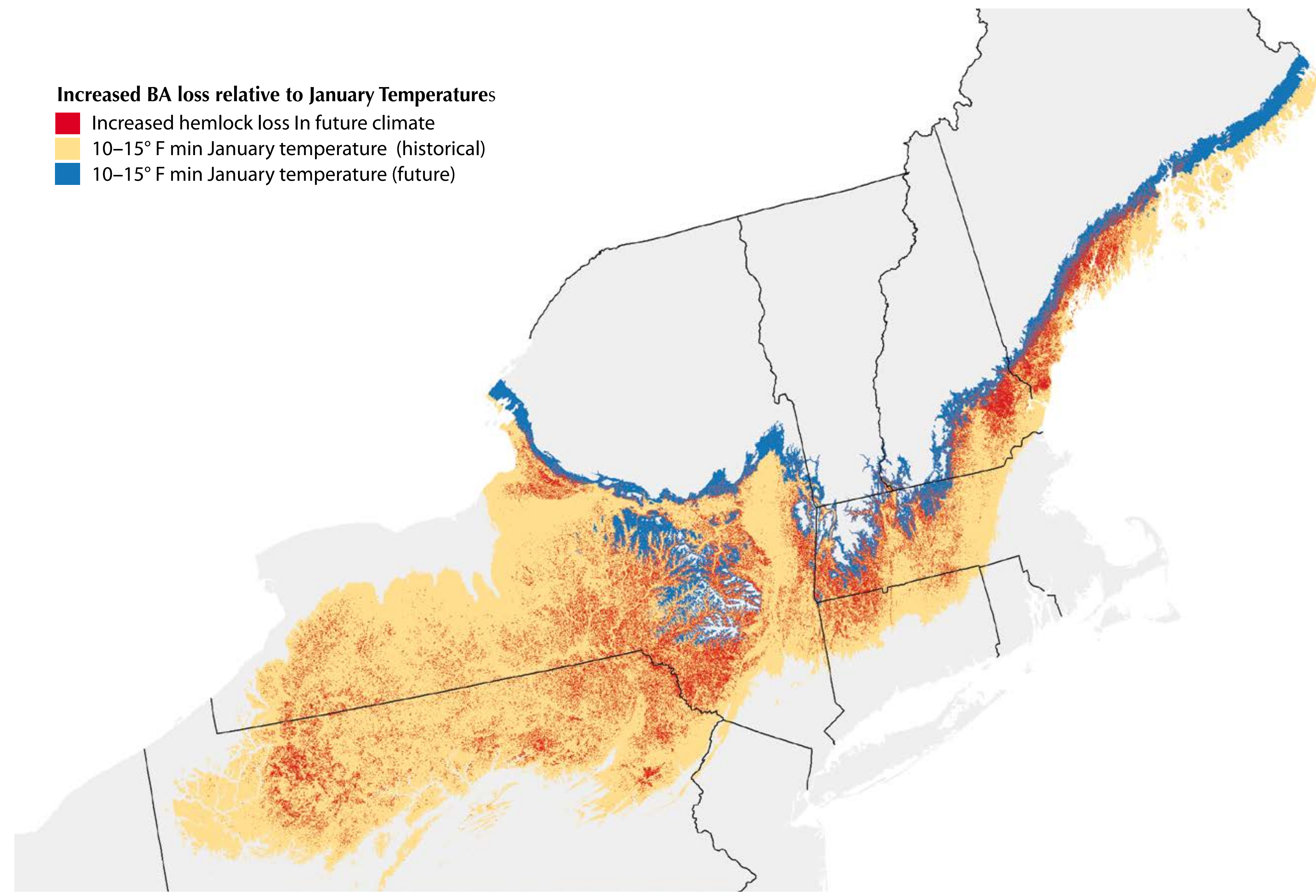


FIGURE 35 January T_{min} and areas of increased mortality from hemlock woolly adelgid (HWA) under future climate*
*Red pixels indicate where BA mortality from HWA in hemlock species increases under warmer future climate relative to the NIDRM model that used historical climate data

The analysis we present here is only a partial assessment of the possible effects of future climate conditions on forest pest dynamics. This assessment demonstrates one approach for performing a climate change analysis via the use of climate-driven models and data from different future-climate scenarios. The projected changes in BA mortality under the future climate scenario reflect a number of modeling constructs and assumptions, including those embodied within the particular future climate dataset(s) used to "drive" the models, as well as the model criteria thresholds used to define risk. Although many NIDRM models use climate criteria as agent-related drivers of mortality, many of the relationships are poorly understood. Further, there are many agent-climate-host relationships that the current suite of NIDRM models fails to capture. Future modeling efforts can bring additional eco-climatological information to bear. For example, phenology models, describing insect developmental rates as a function of variables such as degree-days, together with improved future climate predictions might improve our estimates of the effects of future insect outbreak severity.

Land managers and policymakers now operate in a period of rapidly changing climate. Although predictions about the timing and magnitude of near-future climate changes have inherent uncertainty, it is clear that local future climates will differ from historical norms. All forest risk modeling efforts that seek to provide guidance over medium-term planning horizons (e.g., 10–30 years) will increasingly depend upon the precision and accuracy of future-climate models. To the extent that the RMAP models accurately embody effects of climate drivers on agent-host relationships, and the future climate data we used accurately portray the direction and magnitude of possible climate shifts, these preliminary results indicate that considering future climate clearly matters to our estimation of future risks. We intend to continue to test and apply climate change analyses to the NIDRM results to more fully capture the magnitude and range of possible effects on those results. ♦

Over the last eight years, the NIDRM process has been guided by a philosophy of continuous quality improvement. The 2006 NIDRM focused on bringing FIA inventory data into the analysis and developing a modeling process that was more transparent and repeatable. For the 2012 NIDRM, we maintained those original achievements and redirected some of our effort toward improving the host data maps, automating the modeling process, and improving access to modeling expertise and data.

NIDRM integrates well with a larger system of annual forest pest and pathogen damage information (**FIGURE 36**) and current pest and pathogen range information provided through the Forest Health Protection Mapping and Reporting Portal (http://foresthealth.fs.usda.gov). Forest health managers may want to prioritize remediation efforts by combining NIDRM with insect and disease survey data to target areas with both recent forest pest damage and high hazard ratings. NIDRM host layers and model outputs can inform existing vegetation classification mapping and inventory as well as hazardous fuel reduction efforts. While not designed to predict forest pest and pathogen hazard relative to changing climate, NIDRM is climate-sensitive and outputs can be adjusted to reflect differing climate scenarios.

Ultimately, the 2012 NIDRM is more than a map: It is a strategic hazard assessment with national, regional, and local applications. The goal of NIDRM is to identify landscape-level patterns of potential forest insect and disease activity. This goal is consistent with the FHP philosophy that science-based, transparent methods should be used to allocate management resources across geographic regions and individual pest distributions. In other words: Prioritize investment for areas where both hazard is great and effective treatment can be efficiently implemented. ♦

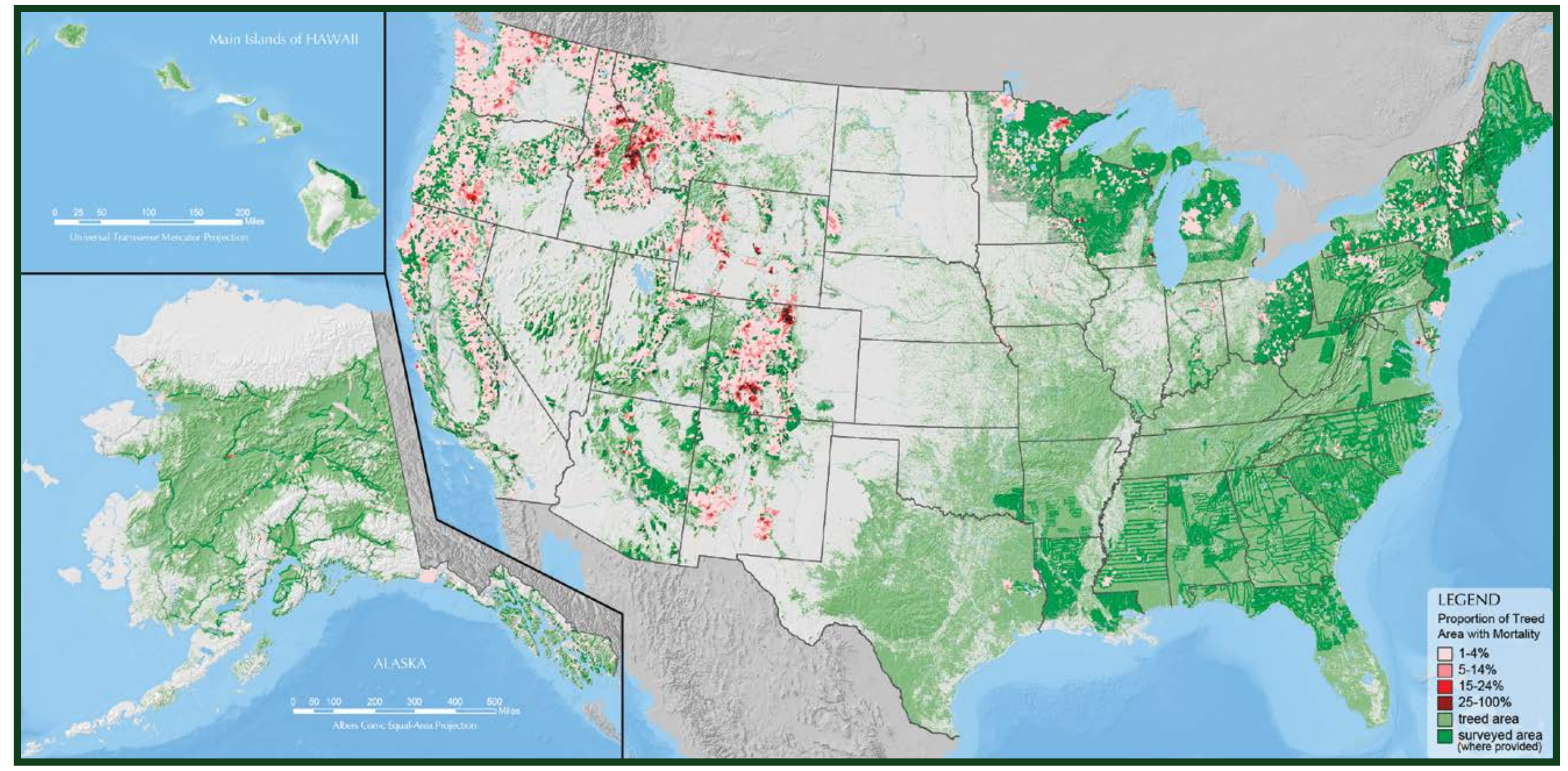


FIGURE 36 2012 National Insect and Disease Survey by watersheds

PAGE	PHOTO CREDIT *(photos shown in order of appearance from left to right)*	DESCRIPTOR AND/OR DESCRIPTION
Sudden oak death, *continued*		
171	Joseph O'Brien, USDA Forest Service, Bugwood.org	Symptoms–Sudden oak death (*ramorum* canker) symptoms on coast live oak
171	Bruce Moltzan, USDA Forest Service, Bugwood.org	Symptoms
171	Joseph O'Brien, USDA Forest Service, Bugwood.org	Symptoms–Tip droop symptom of sudden oak death on tanoak
171	Joseph O'Brien, USDA Forest Service, Bugwood.org	Sign–*P. ramorum* zone lines on coast live oak
Western balsam bark beetle		
172	Javier Mercado, Colorado state University, Bugwood.org	Adult
173	Elizabeth Willhite, USDA Forest Service, Bugwood.org	Damage
173	Scott Tunnock, USDA Forest Service, Bugwood.org	Galleries–The distinctive gallery pattern results from the male excavating a central nuptial chamber from which the several females radiate out to produce their egg galleries
173	Ladd Livingston, Idaho Department of Lands, Bugwood.org	Damage–Trees killed typically have bright red crowns for a year or two after death
173	USDA Forest Service–Ogden Archive, USDA Forest Service, Bugwood.org	Infestation
Western pine beetle		
174	Erich G. Vallery, USDA Forest Service–SRS-4552, Bugwood.org	Adult
175	James Everitt, Bugwood.org	Damage–A still photograph of site in the Davis Mountains of west Texas confirms a stand of dead ponderosa pines killed by western pine beetles
175	Kenneth E. Gibson, USDA Forest Service, Bugwood.org	Damage–Pitch tubes
175	Kenneth E. Gibson, USDA Forest Service, Bugwood.org	Damage–Bark sloughing off of trees
175	William M. Ciesla, Forest Health Management International, Bugwood.org	Damage–Galleries
Western spruce budworm		
176	William M. Ciesla, Forest Health Management International, Bugwood.org	Infestation–Aerial view of defoliation
177	USDA Forest Service, Region 4, Intermountain Archive, USDA Forest Service, Bugwood.org	Adult moth
177	Dave Powell, USDA Forest Service, Bugwood.org	Damage–Mortality. Aldrich Mountains, Bear Valley Ranger District, Malheur National Forest, northeastern Oregon
177	William M. Ciesla, Forest Health Management International, Bugwood.org	Larva(e)
177	David J. Moorhead, University of Georgia, Bugwood.org	Damage
White pine blister rust		
178	Chris Schnepf, University of Idaho, Bugwood.org	Sign–Blister rust sporulating
179	Minnesota Department of Natural Resources (MnDNR) Archive, MnDNR, Bugwood.org	Symptoms
179	USDA Forest Service–Ogden Archive, USDA Forest Service, Bugwood.org	Symptoms
179	John W. Schwandt, USDA Forest Service, Bugwood.org	Sign–Rust sporulating on the bole of an infected tree
179	Ralph Williams, USDA Forest Service, Bugwood.org	Infested stand
180	Susan K. Hagle, USDA Forest Service, Bugwood.org	Symptoms–Stem cankers eventually girdle and kill trees
181	USDA Forest Service, Ogden Archive, USDA Forest Service, Bugwood.org	Sign–Urediospores on *Ribes* spp.
181	Joseph O'Brien, USDA Forest Service, Bugwood.org	Symptoms
181	H.J. Larsen, Bugwood.org	Sign–Close-up view of the aecia of white pine blister rust (*Cronartium ribicola*) on the branch of a pine tree
181	Joseph O'Brien, USDA Forest Service, Bugwood.org	Symptoms–Small "flagged branches"
Winter moth		
182	Dimitrios Avtzis, NAGREF-Forest Research Institute, Bugwood.org	Larva
183	Dimitrios Avtzis, NAGREF-Forest Research Institute, Bugwood.org	Larva(e)
183	Milan Zubrik, Forest Research Institute, Slovakia, Bugwood.org	Adult
183	Dimitrios Avtzis, NAGREF-Forest Research Institute, Bugwood.org	Damage
183	Milan Zubrik, Forest Research Institute, Slovakia, Bugwood.org	Larva
Yellow-cedar decline		
184	Paul E. Hennon, USDA Forest Service, Bugwood.org	Symptoms in southeast Alaska
185	Paul E. Hennon, USDA Forest Service, Bugwood.org	Symptoms in Alaska
185	Paul E. Hennon, USDA Forest Service, Bugwood.org	Symptoms in southeast Alaska

APHIS PPQ Animal and Plant Health Inspection Service, Plant Protection and Quarantine

BA Basal Area

BLM Bureau of Land Management

CART Classification and Regression Tree

CMIP3 Climate Model Intercomparison Project 3

DBH Diameter at Breast Height

DDT NIDRM's Data Development Team

DI Soil Drainage Index

FHM Forest Health Monitoring

FHP Forest Health Protection

FHTET Forest Health Technology Enterprise Team

FIA Forest Inventory and Analysis

GIS Geographic Information System

IDW Inverse Distance Weighting

MAP Mean Annual Precipitation

MAT Mean Annual Temperature

MDT NIDRM's Model Development Team

MODIS Moderate Resolution Imaging Spectroradiometer

NDVI Normalized Difference Vegetation Index

NIDRM National Insect and Disease Risk Map

NA Northeast Area (Forest Service: State and Private administrative unit for northeastern states)

NLCD National Land Cover Data

NOAA National Oceanic and Atmospheric Association

NOAA-NCDC National Oceanic and Atmospheric Association National Climate Data Center

NRCS Natural Resources Conservation Service

PET Potential Evapotranspiration

PI Productivity Index

PRISM Parameter-elevation Regressions on Independent Slopes Model

QMD Quadratic Mean Diameter

R1 Region 1 of U.S. Forest Service. (This convention is used for other Forest Service regions; e.g. R8 for Region 8)

RMAP Risk Modeling Application

RMOT Risk Map Oversight Team

RSAC Remote Sensing Applications Center

SDI Stand Density Index

SDL Spatial Data Library (Maintained by FHTET)

STATSGO2 State Soil Geographic database

SSURGO Soil Survey Geographic Database

USDA United States Department of Agriculture

USDI United States Department of Interior

USGS United States Geological Survey

Basal Area (BA) The cross-sectional area of a tree stem, typically measured or estimated at 4.5 feet above the base of the tree, and typically expressed in units of square feet. When expressed on a per-unit-area basis, basal area values provide a representation of tree density. Values for BA cited in this report are expressed on various bases, such as square feet per acre or millions of square feet per watershed.

Cell Size (See **Pixel**)

Diameter at Breast Height (DBH) Tree bole diameter (including bark) at 4.5 feet above the base of the tree.

Drainage Index (DI) An ordinal measure of the long-term natural soil wetness. A GIS surface used as a criterion in several risk models.

Ecoregion A geographic area defined and delineated by climatological and physiographic features and conditions. Models in the 2012 National Insect and Disease Risk Map (NIDRM) are constructed and run within specified ecoregions. Ecoregions are organized hierarchically into four classes or levels, from a coarse to fine scale: Domain, Division, Province, and Section. Ecoregions used in NIDRM are at the Section level.

Endemic Literally "native to a place." In the context of forest disturbance agents, it often describes population reproduction rates (of native pests) that are relatively low, constant, and considered "normal" or "background." (See **Endemic** and **Exotic**)

Epidemic A rate of population growth that is substantially above what is normal or expected. (See **Endemic** and **Exotic**)

Exotic In the context of forest pest agents, exotic describes agents that have moved beyond their natural or historic geographic range(s) as a result of human activity. Exotic pests are sometimes referred to as "introduced." (See **Endemic** and **Epidemic**)

FIA Plot Locations Nationwide plot network on which vegetation and fuels examinations have been conducted by the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service. The number of plots per unit area, and re-measurement dates, vary by state and FIA region. Typically, one plot represents 6000 acres and is re-measured every 5 or 10 years.

Forest Health Monitoring (FHM) An annual, national program of the U.S. Forest Service designed to determine the status, changes, and trends in indicators of forest conditions.

Forest Health Protection (FHP) An organizational unit within the U.S. Forest Service primarily responsible for maintaining forest health by minimizing the spread of established invasive species and lessening the damages caused by native forest insects and diseases.

Forest Inventory and Analysis (FIA) An organizational unit within the U.S. Forest Service that collects, analyzes, and reports information on the status and trends of America's forest resources.

Forest Health Technology Enterprise Team (FHTET) An organizational unit within Forest Health Protection whose mission is to develop and deliver forest health technology services to field personnel in public and private organizations. (See **Forest Health Protection**)

Forest Parameters Attributes, such as basal area, quadratic mean diameter, and stand density index, that are essential to the construction of models used in assembling the 2012 NIDRM composite. These attributes are either components of, or calculated from, FIA plot data. (See **FIA** and **Site Parameters**)

Forest Type A classification, such as a name or label, of a forested area characterizing in a general way the composition of its tree species. Forest types may represent compositions that contain predominantly single species (e.g. loblolly pine), or compositions that contain mixed-species (e.g. Englemann spruce-subalpine fir).

Geographic Information System (GIS) A computer system capable of integrating, storing, editing, analyzing, sharing and displaying geographically referenced information.

Grid (Raster) In a GIS, a geographical representation of an area as an array of equally-sized square cells (pixels) arranged in rows and columns. Each grid cell is referenced by its geographic x,y location and contains one or more attributes (e.g. elevation) characterizing the location represented by the pixel. (See **Pixel**)

Grid Cell (See **Pixel**)

Host Data Gaps Areas where FIA and other plot data sources are lacking within the 2006 NIDRM. Although a few areas are lacking data in western and northern Alaska, remotely sensed data, GIS technologies, and statistical methodologies are used to ensure data gaps do not occur within the forest parameters data layers in the 2012 NIDRM. In the 2006 NIDRM, Host Data Gaps typically occur within national parks, urban areas, and some wilderness areas.

Layer In a GIS, a collection of similar geographic features that represent a particular theme (e.g. roads, streams, or city boundaries) displayed on a map. (See **Surface**)

Mask In a GIS, a spatial dataset (typically a raster) within which analysis, calculations, or other processes are constrained.

Maximum Mortality Rate The maximum realizable basal area mortality rate that can be achieved by a specific risk agent acting on a specific forest host species in a defined area, as shown within a 2012 NIDRM model. The maximum rate is realized when all of a risk model's criteria are evaluated to be at their maximum risk level.

Model (See **Risk Model**)

Mortality Threshold The minimum percentage of basal area loss over an area required to meet the definition of mortality risk. For the 2012 NIDRM, the mortality threshold for mapping risk is defined as 25% or more of the standing live basal area of trees greater than one inch in diameter. (See **Maximum Mortality Risk**)

Multi-Criteria Modeling A modeling process run in a GIS that allows for the combination and weighting of multiple factors to derive a new variable or output metric. It provides a common framework in which to combine dissimilar information in order to produce a single index of evaluation.

Peer Review For the NIDRM project, the peer review process was a formal appraisal conducted by those who were acknowledged to have sufficient expertise to give critical comment and recommendations as to the completeness and accuracy of the 2012 NIDRM report.

Pixel (**Grid Cell**) A discretely uniform unit of area such as 240 meters by 240 meters (pixel size used in the 2012 NIDRM) that represents a portion of the earth's surface. Each pixel has a value assigned to corresponding to a feature or characteristic of that area, such as elevation, temperature, tree species, or soil drainage index.

Quadratic Mean Diameter (QMD) The diameter of a tree having the average basal area, over some unit of area. QMD is derived by taking the square root of the sums of the squared diameters, divided by the number of trees over a given area. Generally, QMD is considered a better metric than a straight arithmetic mean of tree diameters for characterizing average tree size.

Raster (See **Grid**)

Remediation Management actions aimed to ameliorate threats to forest health. For the 2012 NIDRM, the threats are those from insects and diseases, and the modeled scenarios assume that no future remediation will be applied. If remediation is undertaken by federal, state, or other land managers, modeled risks depicted on the 2012 NIDRM may be lowered or eliminated.

Remote Sensing Applications Center (RSAC) An organizational unit within the U.S. Forest Service, Salt Lake City, Utah. RSAC provides assistance to agency field units in applying the most advanced geospatial technology toward improved monitoring and mapping of natural resources.

Resolution A level of precision for grids used in the 2012 NIDRM. (See **Spatial Resolution**)

Risk Modeling Application (RMAP) An ArcGIS-based application built by FHTET allowing users to create multi-criteria risk models against selected datasets and view the results. The application's interface includes a map canvas that allows users to inspect spatial data inputs and outputs. The risk model outputs comprising the 2012 NIDRM were built using RMAP.

Risk Model In the context of the 2012 NIDRM, a set of weighted criteria and associated functions used to derive estimates of risk (on a 0–10 scale) and an associated host basal area mortality rate (15-year) attributable to a specific risk agent (or class of agents) acting on a host species.

Scale The ratio of the distance on a map as related to the true distance on the ground or the pixel size. For the 2012 NIDRM project, the scale of the input linear or polygonal base map features is 1:2,000,000 and the minimum pixel size selected for national display is 240-meter. (See **Pixel**)

Soil Drainage Index (DI) (See **Drainage Index**)

Spatial Resolution A measure of the smallest object that can be represented on the earth's surface by a pixel. (See Pixel and Scale)

Stand Density Index (SDI) A metric reflecting stand stocking levels (i.e. how many trees per unit area), expressed to allow comparisons among differently aged (or sized) stands. Reineke (1933) derived a relationship between tree density (as trees per acre [TPA]) and average tree size (as QMD), finding that TPA is proportional to $(QMD)^{-1.6}$. The SDI is the TPA of a forest stand at a standard QMD, which is usually 10 inches. (See **Quadratic Mean Diameter**)

Surface In a GIS, a geographic attribute represented as a set of continuously distributed data, such that every location on the mapped plane has a value. Typically, surfaces are grids created by interpolating values between known located values. (See **Layer** and **Grid**)

Susceptibility For the 2012 NIDRM, susceptibility is the potential for establishment of a forest pest within a tree species, over a 15-year period. (See **Vulnerability**)

Treed Area A GIS grid, modeled independently of other forest-parameter layers, representing areas having trees at a 240-meter resolution. (See **Grid**)

Vintage In NIDRM, vintage refers to a time period or date, eg., *The vintage (time period, date) of the resultant parameter datasets should be considered as 2002.*

Vulnerability For the 2012 NIDRM, if a forest pest were to become established, vulnerability would be the potential for mortality of a tree species at a given threshold (stated as a percentage) over a 15-year period. (See **Susceptibility**)

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RISKMAP OVERSIGHT TEAM (RMOT)

Team Lead—Borys Tkacz, National Program Manager, FHM

Barbara Burns, VT, Northeast State Representative

Chris Asaro, VA, Southern State Representative

Charles Shaw, Western Wildland Environmental Threat Assessment Center

Danny Lee, Eastern Forest Environmental Threat Assessment Center

Frank J. Krist Jr., FHTET, Data Development Team Leader

Frank Sapio, Director, FHTET

Greg Kujawa, Forest Management, Washington Office

Greg Reams, National Program Manager, Forest Inventory and Analysis (FIA)

Karen Ripley, WA, Western State Representative

Brian Schwind, Remote Sensing Applications Center

Frank Fay, Fire and Aviation Management, Washington Office

Jim Steinman, Northeastern Area (NA)

MODEL DEVELOPMENT TEAM (MDT)

Team Lead—Jim Steinman (NA)

Regional Modeling Leads

Barbara Schultz, entomologist (VT) and Margaret Weeks, pathologist (NA), NA – Northeast FHM Region

Roger Mech, entomologist (MI) and Manfred Mielke, pathologist (NA) NA – Northcentral FHM Region

Sheri Smith, entomologist (R5) and Helen Maffei pathologist (R6) West Coast, Alaska and Hawaii FHM Region

Dan Ryerson (R3-NM) and Holly Kearns, pathologist (R1), Intermountain FHM Region

Dale Starkey, pathologist (R8) and Steve Clarke, entomologist (R8), Southern FHM Region

DATA DEVELOPMENT TEAM (DDT)

Team Leads—Frank J. Krist Jr., GIS and Spatial Analysis Program Manager (FHTET) and Jim Ellenwood Remote Sensing Program Manager (FHTET)

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FHM coordinators

Borys Tkacz – National Program Manager
Jim Steinman – Northeast Region
Dale Starkey- Southern Region
Jeri Lyn Harris – Intermountain Region
Allison Nelson – Western Region (including Alaska and Hawaii)

Reviewers of the Draft Report

Chris Asaro – Virginia Dept. of Forestry
Ron Billings – Texas Forest Service
Pete Budde – National Parks Service
Bob Edmonds – University of Washington
Chris Fettig – Forest Service: Pacific Southwest Research Station
Everett Hansen – Oregon State University
Robert Hauff – Hawaii Dept. of Land and Natural Resources
Jeffrey Hicke – University of Idaho
Louis Iverson – Forest Service: Northern Research Station
Glenn Kohler – Washington Dept. of Natural Resources
Jim Smith – The Nature Conservancy
Richard Sniezko – Forest Service: Dorena Genetic Resource Center
Dale Starkey – FHP

FHP staff who developed RMAP models

Jim Steinman – Northeast Region
Dale Starkey – Southern Region
Daniel Ryerson – Intermountain Region
Holly Kearns – Intermountain Region
Meghan Woods – Western Region (and Hawaii)
Michael Simpson – Western Region
Lia Spiegel – Western Region
Tricia Wurtz – Western Region (Alaska)
Nicholas Lisuzzo – Western Region (Alaska)
Robin Mulvey – Western Region (Alaska)
Loretta Winton – Western Region (Alaska)

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Writer Editors

Chuck Benedict – Cherokee Nations Technologies-FHTET
Mark Riffe – Contractor-FHTET

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FHP

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State partners

Jana Albers (Minnesota Dept. of Natural Resources), Tiffany Arp (South Dakota Dept. of Agriculture), Chris Asaro (Virginia Dept. of Forestry), Aaron Bergdahl (North Dakota Forest Service), Ron Billings (Texas Forest Service), Barbara Burns (Vermont Agency of Natural Resources), Roger Burnside (Alaska Division of Forestry), Randy Chapin (Mississippi Forestry Commission), Andrea Diss-Torrance (Wisconsin Dept. of Natural Resources), Gail Durham (Nevada Division of Forestry), Tom Eckberg (Idaho Dept. of Lands), Todd Edgerton (Virginia Dept. of Forestry), Don Eggen (Pennsylvania Dept. of Conservation), Jeff Eickwort (Florida Division of Forestry), Tivon Feeley (Iowa Dept. of Natural Resources), Rob Flowers (Oregon Dept. of Forestry), Amy Gannon (Montana Dept. of Natural Resources and Conservation), Mark Harrell (Nebraska Forest Service), Rob Hauff (Hawaii Dept. of Land and Natural Resources), Bob Heyd (Michigan Dept. of Natural Resources), Alan Kanaskie (Oregon Dept. of Forestry), Mike Kangas (North Dakota Forest Service), Colleen Keyes (Utah Dept. of Natural Resources), Cynthia King (Hawaii Dept. of Land and Natural Resources), Neal Kittelson (Idaho Dept. of Lands), Les Koch (Wyoming State Forestry Division), Glenn Kohler (Washington Dept.of Natural Resources), Rob Lawrence (Missouri Dept. of Conservation), Kyle Lombard (New Hampshire Division of Forests and Lands), Phil Marshall (Indiana Dept. of Natural Resources), Mike McWilliams (Oregon Dept. of Forestry), Roger Mech (Michigan Dept. of Natural Resources), Jason Moan (North Carolina Forest Service), Danny Norlander (New Mexico Forestry Division), Don Owen (California Dept. of Forestry and Fire Protection), Joe Pase (Texas Forest Service), Chris Pearce (Florida Division of Forestry), Nicole Ricci (Kansas Forest Service), Karen Ripley (Washington Dept.of Natural Resources), Tom Smith (California Dept. of Forestry and Fire Protection), Sky Stephens (Colorado State Forest Service), Dana Stone (Alabama Forestry Commission), Dave Struble (Maine Forest Service), Rob Trickel (North Carolina Forest Service), Julie Yalemar (Hawaii Dept. of Agriculture)

Federal (Other than FHP)

Bud Mayfield (Forest Service: Southern Research Station); Elizabeth LaPoint and Richard McCullough (Forest Service: Northern Research Station -FIA); Lloyd Loope (USGS); Rodney Hart, Jeff Mallory and Carlos Ramirez (Forest Service: Region 5 Remote Sensing Lab)

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FHTET

Nathan Edberg, Contractor, Cherokee Nations Technologies

Jeanine Paschke, Contractor, Cherokee Nations Technologies

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