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.

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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.

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2013–2027
National Insect and Disease Forest Risk Assessment

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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 forest 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 5-year time frame (2012 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 Parch Prioritization Allocation System.

NIDRM products are compiled on a national extent with a 240-meter (approximately 14 acre) 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 “land-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 resolutions—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 conterminous 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.

**Major Hazards**

Collectively, most diseases, bark beetles, and root decline were the leading contributor to the risk of mortality in the conterminous United States, while spruce borer 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 several exotic pests such as mountain pine beetle and engraver beetles (**IP**). 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.fst.fed.us/forestryhealth/nidrm2012.shtml
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2013–2027 National Insect and Disease Forest Risk Assessment
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 conterminous United 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 Buhdurt 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 (FHMD) Program of the Forest Service, Staff from Forest Service FHMD 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 FHMD 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 FHMD 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,
   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...
INTRODUCTION

the core modeling methodology that has been retained from the 2006 NIDRM. We recommended two publications for detailed information on methods and overall processes.


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 widespread 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 period (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 extraordinary 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 units of per year (Smith et al. 2001), 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 larger 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 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).

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.

METHODOLOGY

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.*

*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 maps, 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 supports 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 tables. 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 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, host regions, 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, host type, or in any combination.

Within RMAP, individual tree species serve as insect and disease hosts. Host tree-species parameters, such as BA, S, density hosts, or 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-based 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

<table>
<thead>
<tr>
<th>CRITERIA CATEGORY</th>
<th>% of Model Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter/DBH</td>
<td>66%</td>
</tr>
<tr>
<td>QMD by species or species group</td>
<td>66%</td>
</tr>
<tr>
<td>BA/DBH</td>
<td>63%</td>
</tr>
<tr>
<td>BA by species, species group or total</td>
<td>63%</td>
</tr>
<tr>
<td>S by species, species group, or total</td>
<td>46%</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>40%</td>
</tr>
<tr>
<td>Trees per acre</td>
<td>32%</td>
</tr>
<tr>
<td>Host prevalence</td>
<td>22%</td>
</tr>
<tr>
<td>Host-prevalence per county</td>
<td>22%</td>
</tr>
<tr>
<td>Climate</td>
<td>17%</td>
</tr>
<tr>
<td>Slope</td>
<td>17%</td>
</tr>
<tr>
<td>Elevation</td>
<td>10%</td>
</tr>
<tr>
<td>Aspect</td>
<td>10%</td>
</tr>
<tr>
<td>Curvature, position index</td>
<td>10%</td>
</tr>
<tr>
<td>Other</td>
<td>10%</td>
</tr>
</tbody>
</table>

### Methods

#### Host Tree-Host 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 Ellen Wood (Ellen Wood et al. 2014).

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 coarser resolution than the commonly occurring species associations. For example, the “Northern Hardwood” association might be made up of white ash, hackberry, 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 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 utilize 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 site type, individual tree pine species can often be distinguished more precisely.

The previous versions of NIDRM utilized coarse resolutions of forest host maps. The 2000 NIDRM employed a national forest-type map developed at a 240,000:1 scale (Lewis 2002). The map category had broad definitions, which did not allow for modeling individual pest species. The 2016 NIDRM utilized an Inverse Distance Weighting (IDW) interpolation of FIA plot data to produce a 1-kilometer resolution surface 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 resampled to a 240-meter resolution prior to forest pest and pathogen model development in RMAP.

Unlike spatial surface modeling employed in the IDW, 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/absence of tree species as measured over 50,000 FIA plot locations. To describe in simple terms the difference between the 2006 surfaceing 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 of climate models with thematic attributes such as slope, aspect, and imagery characteristics. The predictive model generated from this overlay analysis is then used to model (predict) ponderosa pine BA in our host layers by 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 Guisan 2002). Nearly all species distribution models 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 a measure of the amount of space that is occupied by that species on a site; and the dominance of a species is an indication of how well it competes with other tree species on a site.
Climate

Often, climate variables are significant for modeling individual tree species extents. Because climate is a broad characterization of conditions for 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 were used as predictor layers for host parameters surfaces and as stand-alone climate criteria for NIDRM modeling.

Using the ANUSPLIN application (Hutchinson 1991) and techniques developed by Rohto (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 contiguous United States and the other for Alaska. For the contiguous 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 1,197 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, Rohto'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 Rohto 2006).

Soils

Two components of soils are significant in forest type mapping: water holding capacity and productivity (Sehrt et al. 2009). However, current metrics available from the NRCS, such as available water holding capacity (AWC), do not adequately describe natural soil moisture. 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 Schertl et al. (2009). The DI is a number that ranges from 0 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 more exacting data requirements.

FIGURE 6

Overview of individual tree species parameter development

FIGURE 6 - Overview of individual tree species parameter development

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 6: 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 south-eastern 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) (Rohto and Pinson 2003). FIA subplots were used in the forest parameter modeling to improve the precision of the parameter samples. Sub-plots were linked to the FLADB 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 (Torr 2009a, 2009b). Sub-plot locations were determined based upon the calculated magnetic declination and the plot design using an equidistant-azimuthal projection from the plot center.
Methods

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, “…a 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 Sec5, version 2.06. The model derived from Sec5 was converted to a raster surface using the RSAC Cubist/See5 toolset (Ruefenacht et al. 2008). We consider this layer a geospatial representation of tree area, and it was utilized as a subsequent mask for all other host layers. The minimum density that can be measured on an FIA subplot 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 (Rolins and Frame 2006), and the NLCD canopy closure layer (Homer 2004). Host presence maps were then reviewed for accuracy by local foresters and forest health experts. Local experts also provided hand-digitized polygons depicting areas of host presence and density.

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 tree 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 within 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...
Methods

Included to the off-site incomplete representation of FIA annualized panels. Though not annualized, inventories in Nevada, Wyoming, and 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 2012 NIDRM dataset was utilized in key portions of Colorado, Utah, and Wyoming to account for census and pine beetle mortality. Building upon techniques developed by Hargrove et al. (2012), a linear regression model was performed on the stock of the approximate 2012 to 2011 FIA estimate. Due to the frequency and nature of the FIA inventory, recent mortality is under-represented in FIA estimates.

The adjustment process for the coterminous United States utilized a MODIS phenology dataset (2001–2010) from the NASA’s Ecosystems (Hargrove et al. 2009, McKellip et al. 2010) and the FHTET Pest Portal Forest Disentanglement Mapper (FDM) (http://foresthealth.fs.fed.us/FHTET Pest Portal Forest Disentanglement Mapper) (Hargrove et al. 2009, McKellip et al. 2010). The NASA’s Ecosystems 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 census and pine beetle mortality. Unlike adjustments for the coterminous United States, the growth and mortality adjustment for Alaska was limited to forest-related mortality. Input for fire-related mortality was taken from the Monitoring Trends in Burn Severity (MTBS) archive (Eidenshonk 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 (Burn Severity-landscape-level loss), Low (25% loss); Moderate (50% loss); and Severe (75% loss). The 30-meter dataset was up-scaled to 240-meter resolution by multiplying the 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 pests-host composition, quadratic mean diameter (QMD), and trees per acre (A1 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 patches for the 2012 NIDRM, over 600 layers representing various characteristics important to understanding risk agent behavior were included in the SDI, for use in RMAP. This includes monthly and an annual climate parameters, pest and pathogen ranges, land use, soil characteristics, topography, vegetation, and plant hardiness zones among others. Several of these layers were discussed in detail in the previous section and are grouped in A1 Table 1 by general category.

Drought layers were not used to model the forest host surfaces; however, drought was a key criterion of many of the NIDRM models and merits further explanation. Drought index and frequency data layers were retrieved from PRISM climate data (www.prism.oregonstate.edu) consisting of precipitation and temperature grids for every month from January 1885 to October 2009. From the temperature grids, together with the annual monthly temperature departure index, 240-meter cell values were derived. From PET and precipitation grids, a dimensionless monthly moisture index (scaled between -1 and 5) was composed for each grid cell. 15-day and 30-day moving averages of these 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-year were derived from the drought index departure scores and classified into drought event parameters datasets a 2012 time-stamp. The final tree growth and mortality model used the host layers as this adjustment represented in Figure B1, page 6.

As with the coterminous United States, Alaska host-parameter layers were derived from ground inventories and imagery datasets that contain information specific to Alaska. This dataset was limited to early summer and late summer, with collection dates from 1994 to 2006. Composite photographs 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 1998. Given the lack of coverage, and the lack of the representation, 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 forest-related mortality. Input for fire-related mortality was taken from the Monitoring Trends in Burn Severity (MTBS) archive (Eidenshonk 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 (Burn Severity-landscape-level loss), Low (25% loss); Moderate (50% loss); and Severe (75% loss). The 30-meter dataset was up-scaled to 240-meter resolution by multiplying the 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.

DATA GUIDELINES

We offer two basic guidelines for the appropriate use of information contained in the 2012 NIDRM.

1. Maximum Display Scale - To highlight meaningful patterns of risk and avoid maps that appear pixelated, 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 detail to identify key landscape patterns and patterns of risk and still be zoomed-in close enough to associate blocks of risk with familiar forest landscapes. A 240-meter pixel is approximately 14 acres or 20,000 square feet. The 240-meter pixel size is the default resolution for the 2012 NIDRM, over 600 layers representing various characteristics important to understanding risk agent behavior were included in the SDI, for use in RMAP. This includes monthly and an annual climate parameters, pest and pathogen ranges, land use, soil characteristics, topography, vegetation, and plant hardiness zones among others. These layers were discussed in detail in the previous section and are grouped in Table 1 by general category.

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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/forestry/health/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); watershed-by-the-absolute amount of BA loss are ranked in FIGURES 16 and 17 (pages 21, 24).

NIDRM displays approximately 9.5 million acres at or above the 25%-mortality threshold in Alaska, almost 72 million acres in the conterminous United States, and just under a half a million acres in Hawaii. The combined total of approximately 81 million acres represents about 0.7% of the 1.2 billion acres of modeled treed lands within the United States. Of the combined risk, 64% 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 31). Many of these tribal areas occupy also 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 risk 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 most disease over the next 15 years (TABLE 2, page 14).

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 15; FIGURE 13, page 16). 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 beetle and most disease activity across Region 1 (FIGURE 21, page 25). TABLE 3, page 16), 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, page 14, 16). In addition, a large majority of Region 8 is treed, while east 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 16). The top three risk agents in Idaho and Montana are root disease, Douglas-fir beetle and mountain pine beetle (FIGURE 21, page 10). 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 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 were 16,000, 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.

References/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. Mortality rates for highest risk mortality agents.
Number of mortality risk agents modeled on any given location
17

Number of mortality risk agents modeled on any given location

National 2012 composite insect and disease risk map

Regions

Area at Risk

% of treed area at risk

1 13,181 25.2%
2 7,918 12.1%
3 5,589 7.2%
4 6,166 9.4%
5 5,924 11.4%
6 9,432 14.4%
7 14,061 25.5%
8 11,703 4.1%
9 9,521 5.6%
10 8,321 5.6%

9.5 million acres at risk in Alaska

0.1 million acres at risk in Hawaii

Risk of mortality

Treed areas

Number of agents modeled

1–2
3–4
5–12

Universal Transverse Mercator Projection

Albers Conic Equal-Area Projection

Universal Transverse Mercator Projection

Albers Conic Equal-Area Projection
### Regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Area at Risk (1000 acres)</th>
<th>% of Treed Area at Risk</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>13,381</td>
<td>25.2%</td>
</tr>
<tr>
<td>2</td>
<td>7,918</td>
<td>12.1%</td>
</tr>
<tr>
<td>3</td>
<td>3,509</td>
<td>7.2%</td>
</tr>
<tr>
<td>4</td>
<td>6,166</td>
<td>9.4%</td>
</tr>
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<td>5</td>
<td>5,924</td>
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</tr>
<tr>
<td>10</td>
<td>9,521</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

**71.7 million acres at risk in the coterminous United States**
**Percentage of Treed Area at Risk by Watershed — Alaska and Hawaii**

*Figure 15*

- Little to no risk
- 1–4%
- 5–14%
- 15–24%
- 25% or greater

**Watersheds Ranked by Basal Area Loss Hazard — Alaska and Hawaii**

*Figure 16*

- Host extent (little to no BA loss)
- Bottom 49%
- 50–74%
- 75–95%
- Top 3%—highest estimated BA losses

---

2013–2027 National Insect and Disease Forest Risk Assessment
Watersheds Ranked by Basal Area Loss Hazard

2013–2027 National Insect and Disease Forest Risk Assessment

Host extent (little to no BA loss)
- Bottom 49%
- 50–74%
- 75–95%
- Top 5% - highest estimated BA losses
### Risk by Ownership

<table>
<thead>
<tr>
<th>Ownership</th>
<th>Acres at Risk (Thousands)</th>
<th>% of Treed Land at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest Service administered lands</td>
<td>37,026</td>
<td>19.9%</td>
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<tr>
<td>Other federal lands</td>
<td>4,190</td>
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<td>All other ownerships</td>
<td>30,489</td>
<td>3.9%</td>
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<tr>
<td>Total</td>
<td>71,705</td>
<td>6.9%</td>
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</table>

<table>
<thead>
<tr>
<th>Ownership</th>
<th>Acres at Risk (Thousands)</th>
<th>%  of Treed Land at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest Service administered lands</td>
<td>166,302</td>
<td>19.9%</td>
</tr>
<tr>
<td>Other federal lands</td>
<td>68,375</td>
<td>6.1%</td>
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<tr>
<td>All other ownerships</td>
<td>785,176</td>
<td>3.9%</td>
</tr>
<tr>
<td>Total</td>
<td>1,039,553</td>
<td>6.9%</td>
</tr>
</tbody>
</table>
**Treed Acres (Thousands)**
- Forest Service administered lands: 14,557
- Other federal lands: 91,537
- All other ownerships: 65,987
- 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%

**Major Risk Agents Contributing to the 2012 NIDRM — Alaska and Hawaii**
1. Eastern larch beetle, spruce beetle
2. Spruce beetle, northern spruce engraver (Ips)
3. Hemlock dwarf mistletoe, yellow cedar decline, stem rot

Agents listed in order of their relative impact, highest to lowest.
Major Risk Agents Contributing to the 2012 NIDRM

1. Douglas-fir beetle, root disease
2. Root disease, Douglas-fir beetle
3. Western spruce budworm, balsam woolly adelgid
4. Root disease, western spruce budworm, Douglas-fir beetle
5. Mountain pine beetle, western pine beetle
6. Spruce budworm
7. Mountain pine beetle, Jeffrey pine beetle
8. Engraver beetles (Ips spp.)
9. Engraver beetles (Ips spp.), western pine beetle
10. Root disease, spruce beetle, Douglas-fir beetle
11. Root disease, spruce beetle
12. Spruce beetle, western spruce budworm
13. Mountain pine beetle
14. Mountain pine beetle, Douglas-fir beetle, spruce beetle
15. Forest tent caterpillar, spruce reaction species, decline, emerald ash borer
16. Aspen/cottonwood/oak decline, emerald ash borer
17. Dutch elm disease, oak decline
18. Southern pine beetle, root disease
19. Jack pine budworm, oak decline, oak wilt
20. Oak decline, jack pine budworm, oak wilt
21. Oak decline, jack pine budworm, maple decline, beech bark disease
22. Eastern spruce budworm, beech bark disease, maple decline
23. Oak decline, winter moth, root disease
24. Oak decline, winter moth, root disease

Agents listed in order of their relative impact, highest to lowest.

Risk of mortality
Treed areas
FIGURE 22

InSECT AND DISEASE RISK ON AMERICAN INDIAN LANDS

2013–2027 National Insect and Disease Forest Risk Assessment

Risk of mortality
American Indian lands
<table>
<thead>
<tr>
<th>AGENT</th>
<th>BA Losses (Millions of Sq. Feet)</th>
<th>AGENT</th>
<th>BA Losses (Millions of Sq. Feet)</th>
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<td>Ohia rust</td>
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<td>Bench bark disease</td>
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<td>Dutch elm disease</td>
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<tr>
<td>Goldspotted oak borer</td>
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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.

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

Group includes American, Douglas-fir, hemlock, larch, limber pine, pine, and pinyon desert mistletoes.

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

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<thead>
<tr>
<th>AGENT</th>
<th>Thousands of Acres by Forest Service Region</th>
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<tr>
<td><strong>BARK BEETLES</strong></td>
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</tr>
<tr>
<td>Douglas-fir beetle</td>
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<tr>
<td>Eastern larch beetle</td>
<td></td>
</tr>
<tr>
<td>Engraver beetles (ps sp.)</td>
<td></td>
</tr>
<tr>
<td>Spruce beetle</td>
<td></td>
</tr>
<tr>
<td>Jeffrey pine beetle</td>
<td></td>
</tr>
<tr>
<td>Mountain pine beetle</td>
<td></td>
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<tr>
<td>Southern pine beetle</td>
<td></td>
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<tr>
<td>Spruce beetle</td>
<td></td>
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<tr>
<td>Western balsam bark beetle</td>
<td></td>
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<tr>
<td>Western pine beetle</td>
<td></td>
</tr>
<tr>
<td><strong>DECLINES</strong></td>
<td></td>
</tr>
<tr>
<td>Aspen and cottonwood decline</td>
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</tr>
<tr>
<td>Maple decline</td>
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</tr>
<tr>
<td>Oak decline and gypsy moth</td>
<td></td>
</tr>
<tr>
<td><strong>DISEASES</strong></td>
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<tr>
<td>Fusiform rust</td>
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<td>Root diseases—all</td>
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</tr>
<tr>
<td><strong>EXOTICS</strong></td>
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</tr>
<tr>
<td>Asian longhorned beetle</td>
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<td>Balsam wooly adelgid</td>
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<td>Beech bark disease</td>
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<tr>
<td>Dutch elm disease</td>
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<tr>
<td>Emerald ash borer</td>
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<td>Goldspotted oak borer</td>
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<td>Hemlock wooly adelgid</td>
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<tr>
<td>Laurel wilt</td>
<td></td>
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<tr>
<td>Oak wilt</td>
<td></td>
</tr>
<tr>
<td>Sudden oak death</td>
<td></td>
</tr>
<tr>
<td>White pine blister rust</td>
<td></td>
</tr>
</tbody>
</table>
| * In all instances, tr (trace) refers to values less than 500 acres.
### 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 whitebark 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 avocados, is at risk due to a recently introduced disease called “laurit wilt.” Redbay and other tree species in the family Lauraceae are susceptible. The disease, caused by a fungus (Fusarium ananatis), 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. Laurit wilt has caused widespread and severe levels of mortality in the southeastern coastal plains. 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. Habitats of the South often used to fine-grained, polished wood is 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 warranting listing 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. Added by Clark’s nutcracker for seed dispersal, whitebark pine quickly establishes itself after disturbance (e.g., fire) and is important in curbing 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.

### Lodgepole Pine (Pinus Contorta)

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 drought/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 (sage 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.

### Results/Discussion

Continued, page 45
<table>
<thead>
<tr>
<th>HOST SPECIES</th>
<th>Agent (maximum mortality rate)</th>
<th>Loss Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>WESTERN SOFTWOODS</td>
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<tr>
<td>Whitebark pine</td>
<td>Mountain pine beetle (90–100%)</td>
<td>30%</td>
</tr>
<tr>
<td>White pine</td>
<td>White pine blister rust (25–30%)</td>
<td>20%</td>
</tr>
<tr>
<td>Limber pine</td>
<td>Dwarf mistletoe (1%)</td>
<td>1%</td>
</tr>
<tr>
<td>Mountain pine beetle (20–30%)</td>
<td>20%</td>
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</tr>
<tr>
<td>White pine blister rust (10–20%)</td>
<td>10%</td>
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<tr>
<td>Lodgepole pine</td>
<td>Dwarf mistletoe (1%)</td>
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<td>Ponderosa pine</td>
<td>Dwarf mistletoe (1%)</td>
<td>1%</td>
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<td>Mountain pine beetle (10–40%)</td>
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<td>Pinyon pines (5 species)</td>
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<tr>
<td>Root diseases (10%)</td>
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<tr>
<td>Fe engraver (10–25%)</td>
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<td>Root diseases (3%)</td>
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<td>Western spruce budworm (3%)</td>
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<td>Western white pine</td>
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<tr>
<td>Port-Oxford-cedar</td>
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<td>Root diseases (90–95%)</td>
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<td>Spruce beetle (40%)</td>
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</tbody>
</table>

See footnotes, page 19
**Percentage of Redbay Basal Area Loss**

**Host BA loss by watershed**
- Host extent (little to no BA loss)
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of host BA loss

**Causal agent: Laurel wilt**

**Percentage of Whitebark Pine Basal Area Loss**

**Host BA loss by watershed**
- Host extent (little to no BA loss)
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of host BA loss

**Causal agents:**
- Mountain pine beetle
- White pine blister rust
Causal agents:
- Dwarf mistletoes
- Mountain pine beetle
- White pine blister rust

Host extent (little to no BA loss)
- 1-4%
- 5-14%
- 15-24%
- 25% or greater of host BA loss

Host BA loss by watershed
- Host extent (little to no BA loss)
- 1-4%
- 5-14%
- 15-24%
- 25% or greater of host BA loss
SIGNIFICANT IMPROVEMENTS IN DATA COVERAGE

Hawaii was not included in the 2006 risk assessment; however—and despite the lack of modelled forest parameter data—risk models for Hawaii were constructed for the 2012 assessment. But unlike the models for the conterminous 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-refinable depictions of host extent in sparsely treed areas relative to more heavily forested areas, which are well-covered by the FIA plot network.

CAUSAL AGENT: HEMLOCK WOOLLY ADDELID

Host BA loss by watershed

<table>
<thead>
<tr>
<th>Host extent (little to no BA loss)</th>
<th>BA loss by watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4%</td>
<td>Host extent (little to no BA loss)</td>
</tr>
<tr>
<td>5-14%</td>
<td>Host extent (little to no BA loss)</td>
</tr>
<tr>
<td>15-24%</td>
<td>Host extent (little to no BA loss)</td>
</tr>
<tr>
<td>25% or greater of host BA loss</td>
<td>Host extent (little to no BA loss)</td>
</tr>
</tbody>
</table>

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 forest flora 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 species, with intact, native forests occurring in higher elevations andland clearing practices. Following European contact, changes in vegetation greatly accelerated with the introduction of countless plant species, with intact, native forests occurring in higher elevations and

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 occur 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 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, prevent, or remove.

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 (Klarnothrips myopori)

The initial introduction of this pest, Myoporum sandwicense, by Myoporum thrips, Klarnothrips myopori, in Hawaii was reported in March 2009. Surveys are ongoing to determine the extent of its distribution on the island of Hawaii, where native mortality has been observed. This thrips causes leaf curling and gall-like symptoms on infested plants, with high levels of infection 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, Loxia calloptera, a federally-listed endangered species of honeycreeper on Maui 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. koaerum)

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. koaerum, 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 wilting symptoms. Many plantation failures and high mortality rates of young trees have been observed.
**Areas of Hawaii Likely to be Impacted by Ohia Rust and Koa Wilt**

**Ohia Rust**
- Moderate impact
- Significant impact

**Koa Wilt**
- Moderate impact
- Significant impact

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

**Myoporum Thrips**
- Moderate impact
- Significant impact

**Erythrina Gall Wasp**
- Moderate impact
- Significant impact
Ohia rust (Puccinia psidii)

Ohia rust, also known as guava rust, cayudaputrus 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 stigmas. 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, woodlands, 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 plans 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 aspen, cottonwood, oak declines, and Dutch elm disease, were used for the Great Plains area and modified as necessary (TABLE 6).

**URBAN AREAS**

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 33% potential loss of the park’s total BA. These mortality estimates by agent are combined to develop the overall composite mortality estimates for the Great Smoky Mountains (FIGURES 29, page 49). Once established exotic and invasive forest pests can move into the wildland urban interface and impact 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.

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

<table>
<thead>
<tr>
<th>AGENT NAME</th>
<th>LOSSES (Millions of Sq. Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak decline and gypsy moth</td>
<td>31.8</td>
</tr>
<tr>
<td>Dutch elm disease</td>
<td>5.9</td>
</tr>
<tr>
<td>Emerald ash borer</td>
<td>4.5</td>
</tr>
<tr>
<td>Bar oak blight</td>
<td>2.3</td>
</tr>
<tr>
<td>Aspen and cottonwood decline</td>
<td>2.1</td>
</tr>
</tbody>
</table>

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, dobsonula needle blight, and pine wilt.
### Northern (Region 1)

<table>
<thead>
<tr>
<th>Park Name</th>
<th>Treated Area (1000 acres)</th>
<th>% Treated</th>
<th>Total BA Loss (1000 sq ft)</th>
<th>BA Loss Rate (sq ft per acre)</th>
<th>Area at Risk (1000 sq ft)</th>
<th>% of Treated Area at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nez Perce</td>
<td>2,210</td>
<td>98%</td>
<td>67,662</td>
<td>38%</td>
<td>40</td>
<td>1,339 (61% )</td>
</tr>
<tr>
<td>Lolo</td>
<td>2,599</td>
<td>99%</td>
<td>67,062</td>
<td>36%</td>
<td>26</td>
<td>1,198 (46% )</td>
</tr>
<tr>
<td>Clearwater</td>
<td>1,711</td>
<td>99%</td>
<td>55,234</td>
<td>31%</td>
<td>32</td>
<td>884 (51% )</td>
</tr>
<tr>
<td>Flathead</td>
<td>2,522</td>
<td>98%</td>
<td>46,786</td>
<td>28%</td>
<td>19</td>
<td>835 (53% )</td>
</tr>
<tr>
<td>Beaverhead</td>
<td>1,780</td>
<td>87%</td>
<td>46,014</td>
<td>39%</td>
<td>27</td>
<td>770 (43% )</td>
</tr>
<tr>
<td>Galatin</td>
<td>2,105</td>
<td>91%</td>
<td>55,287</td>
<td>29%</td>
<td>17</td>
<td>683 (32% )</td>
</tr>
<tr>
<td>Kake</td>
<td>1,707</td>
<td>98%</td>
<td>50,183</td>
<td>26%</td>
<td>29</td>
<td>673 (39% )</td>
</tr>
<tr>
<td>Kootenai</td>
<td>2,097</td>
<td>99%</td>
<td>46,432</td>
<td>24%</td>
<td>23</td>
<td>664 (32% )</td>
</tr>
<tr>
<td>Lewis and Clark</td>
<td>1,892</td>
<td>95%</td>
<td>34,570</td>
<td>27%</td>
<td>18</td>
<td>602 (32% )</td>
</tr>
<tr>
<td>Bitterroot</td>
<td>1,536</td>
<td>97%</td>
<td>31,463</td>
<td>34%</td>
<td>20</td>
<td>589 (38% )</td>
</tr>
</tbody>
</table>

### Southeast (Region 3)

<table>
<thead>
<tr>
<th>Park Name</th>
<th>Treated Area (1000 acres)</th>
<th>% Treated</th>
<th>Total BA Loss (1000 sq ft)</th>
<th>BA Loss Rate (sq ft per acre)</th>
<th>Area at Risk (1000 sq ft)</th>
<th>% of Treated Area at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracow</td>
<td>1,457</td>
<td>95%</td>
<td>33,664</td>
<td>29%</td>
<td>23</td>
<td>442 (30% )</td>
</tr>
<tr>
<td>Santa Fe</td>
<td>1,534</td>
<td>96%</td>
<td>28,553</td>
<td>26%</td>
<td>19</td>
<td>426 (28% )</td>
</tr>
</tbody>
</table>

### Intermountain (Region 4)

<table>
<thead>
<tr>
<th>Park Name</th>
<th>Treated Area (1000 acres)</th>
<th>% Treated</th>
<th>Total BA Loss (1000 sq ft)</th>
<th>BA Loss Rate (sq ft per acre)</th>
<th>Area at Risk (1000 sq ft)</th>
<th>% of Treated Area at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targhee</td>
<td>3,443</td>
<td>78%</td>
<td>40,669</td>
<td>20%</td>
<td>12</td>
<td>731 (21% )</td>
</tr>
<tr>
<td>Payette</td>
<td>2,357</td>
<td>97%</td>
<td>20,796</td>
<td>21%</td>
<td>9</td>
<td>458 (19% )</td>
</tr>
<tr>
<td>Salmon</td>
<td>1,519</td>
<td>97%</td>
<td>35,141</td>
<td>30%</td>
<td>11</td>
<td>419 (26% )</td>
</tr>
<tr>
<td>Bridger</td>
<td>1,160</td>
<td>99%</td>
<td>12,129</td>
<td>35%</td>
<td>27</td>
<td>345 (30% )</td>
</tr>
<tr>
<td>Ashen</td>
<td>1,488</td>
<td>88%</td>
<td>16,768</td>
<td>23%</td>
<td>11</td>
<td>338 (23% )</td>
</tr>
</tbody>
</table>

### Pacific Southwest (Region 5)

<table>
<thead>
<tr>
<th>Park Name</th>
<th>Treated Area (1000 acres)</th>
<th>% Treated</th>
<th>Total BA Loss (1000 sq ft)</th>
<th>BA Loss Rate (sq ft per acre)</th>
<th>Area at Risk (1000 sq ft)</th>
<th>% of Treated Area at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idaho</td>
<td>578</td>
<td>99%</td>
<td>38,005</td>
<td>18%</td>
<td>18</td>
<td>763 (42% )</td>
</tr>
<tr>
<td>Lassen</td>
<td>1,333</td>
<td>97%</td>
<td>44,180</td>
<td>28%</td>
<td>33</td>
<td>651 (49% )</td>
</tr>
<tr>
<td>Sierra</td>
<td>1,317</td>
<td>95%</td>
<td>47,380</td>
<td>27%</td>
<td>36</td>
<td>480 (30% )</td>
</tr>
<tr>
<td>Tahoe</td>
<td>1,199</td>
<td>99%</td>
<td>21,494</td>
<td>18%</td>
<td>25</td>
<td>333 (21% )</td>
</tr>
<tr>
<td>Plumas</td>
<td>1,379</td>
<td>99%</td>
<td>34,569</td>
<td>18%</td>
<td>25</td>
<td>320 (23% )</td>
</tr>
</tbody>
</table>

### Pacific Northwest (Region 6)

<table>
<thead>
<tr>
<th>Park Name</th>
<th>Treated Area (1000 acres)</th>
<th>% Treated</th>
<th>Total BA Loss (1000 sq ft)</th>
<th>BA Loss Rate (sq ft per acre)</th>
<th>Area at Risk (1000 sq ft)</th>
<th>% of Treated Area at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fremont</td>
<td>1,651</td>
<td>96%</td>
<td>37,594</td>
<td>31%</td>
<td>23</td>
<td>906 (55% )</td>
</tr>
<tr>
<td>Deschutes</td>
<td>1,815</td>
<td>98%</td>
<td>38,554</td>
<td>25%</td>
<td>21</td>
<td>763 (42% )</td>
</tr>
<tr>
<td>Umatilla</td>
<td>1,493</td>
<td>99%</td>
<td>29,661</td>
<td>29%</td>
<td>20</td>
<td>701 (47% )</td>
</tr>
<tr>
<td>Whitman</td>
<td>1,536</td>
<td>98%</td>
<td>32,476</td>
<td>26%</td>
<td>13</td>
<td>495 (26% )</td>
</tr>
<tr>
<td>Wenatche</td>
<td>1,096</td>
<td>99%</td>
<td>30,790</td>
<td>27%</td>
<td>28</td>
<td>553 (31% )</td>
</tr>
<tr>
<td>Walla Walla</td>
<td>885</td>
<td>83%</td>
<td>15,563</td>
<td>30%</td>
<td>18</td>
<td>470 (30% )</td>
</tr>
<tr>
<td>Malheur</td>
<td>1,273</td>
<td>98%</td>
<td>20,189</td>
<td>24%</td>
<td>16</td>
<td>460 (30% )</td>
</tr>
</tbody>
</table>

### Southern (Region 8)

<table>
<thead>
<tr>
<th>Park Name</th>
<th>Treated Area (1000 acres)</th>
<th>% Treated</th>
<th>Total BA Loss (1000 sq ft)</th>
<th>BA Loss Rate (sq ft per acre)</th>
<th>Area at Risk (1000 sq ft)</th>
<th>% of Treated Area at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>George Washington</td>
<td>1,746</td>
<td>99%</td>
<td>40,405</td>
<td>21%</td>
<td>23</td>
<td>522 (30% )</td>
</tr>
</tbody>
</table>

### Eastern (Region 9)

<table>
<thead>
<tr>
<th>Park Name</th>
<th>Treated Area (1000 acres)</th>
<th>% Treated</th>
<th>Total BA Loss (1000 sq ft)</th>
<th>BA Loss Rate (sq ft per acre)</th>
<th>Area at Risk (1000 sq ft)</th>
<th>% of Treated Area at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maine Rock</td>
<td>2,881</td>
<td>97%</td>
<td>39,716</td>
<td>16%</td>
<td>10</td>
<td>384 (14% )</td>
</tr>
<tr>
<td>Mount Hood</td>
<td>1,284</td>
<td>97%</td>
<td>16,150</td>
<td>19%</td>
<td>13</td>
<td>342 (27% )</td>
</tr>
</tbody>
</table>
### Overall Risk

**Tree Species**
- Lodgepole Pine: 65.2% of Total BA, 51.8% Host BA Loss Rate
- Whitebark Pine: 0.9% of Total BA, 34.9% Host BA Loss Rate
- Douglas-fir: 2.3% of Total BA, 20.9% Host BA Loss Rate
- Engelmann Spruce: 4.4% of Total BA, 15.1% Host BA Loss Rate
- Subalpine Fir: 15.1% of Total BA, 14.8% Host BA Loss Rate
- Limber Pine: 0.2% of Total BA, 27.7% Host BA Loss Rate
- Quaking Aspen: 0.0% of Total BA, 12.5% Host BA Loss Rate

**Overall Risk**

- **Red oak spp.** 14.9% of Total BA, 23.7% Host BA Loss Rate
- **White oak spp.** 13.7% of Total BA, 25.4% Host BA Loss Rate
- **American beech** 2.9% of Total BA, 25.9% Host BA Loss Rate
- **Hemlock spp.** 6.4% of Total BA, 13.6% Host BA Loss Rate
- **Eastern white pine** 3.0% of Total BA, 16.3% Host BA Loss Rate
- **Ash spp.** 0.4% of Total BA, 5.1% Host BA Loss Rate
- **Southern pines (9 species)** 5.6% of Total BA, 13.6% Host BA Loss Rate
- **Sassafras** 0.2% of Total BA, 3.4% Host BA Loss Rate
- **Sirex pines (10 species)** 2.6% of Total BA, 1.7% Host BA Loss Rate

**Impact from All Agents**

- **White oak spp.** 46.1% of Total BA, 39.8% Host BA Loss Rate
- **Whitebark Pine** 3.0% of Total BA, 46.3% Host BA Loss Rate
- **Douglas-fir** 2.3% of Total BA, 20.9% Host BA Loss Rate
- **Engelmann Spruce** 11.1% of Total BA, 15.1% Host BA Loss Rate
- **Subalpine Fir** 15.1% of Total BA, 14.8% Host BA Loss Rate
- **Limber Pine** 0.2% of Total BA, 27.7% Host BA Loss Rate
- **Quaking Aspen** 0.0% of Total BA, 12.5% Host BA Loss Rate

### Whitebark Pine Losses from All Agents

**Estimated BA Loss**
- 1–25% 26–50% 51–75% > 75%

### Total BA Loss from Mountain Pine Beetle

**Estimated BA Loss**
- 1–10% 11–24% > 25%

### Host Loss from Hemlock Woolly Adelgid

**Estimated BA Loss**
- 1–25% 26–50% 51–75% > 75%

### Host Loss from Oak Decline

**Estimated BA Loss**
- 1–25% 26–50% 51–75% > 75%
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 (CO₂) 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 are 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; 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 drier summers throughout the conterminous 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 conterminous US) use one or more climate criteria as “drivers” of risk (see 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 conterminous 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 delta, representing a change from historical (1971–2000) averages, and as future estimates per c., 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 CMIP5 published data and represent output from a number of different general circulation models run under different CO₂ 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/cmems5/ cmems5.shml). A discussion of the datasets and the downscaling procedures can be found in Joyce et al. (2011).
For this analysis, climate data projections representing the 15-year period, 2012–2026 were used. Temperature and precipitation shifts 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, Temp, 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, future monthly estimates of PET and PPT data (for each month in the 15-year period). Temperature and precipitation shifts were applied to their corresponding NIDRM climate data-layers to derive future estimates (deltas averaged over the period, 2012–2026 were used). Temperature and precipitation shifts were applied to their corresponding NIDRM climate data-layers to derive future estimates (deltas averaged over the period, 2012–2026 were used). Temperature and precipitation shifts were applied to their corresponding NIDRM climate data-layers to derive future estimates (deltas averaged over the period, 2012–2026 were used). Temperature and precipitation shifts were applied to their corresponding NIDRM climate data-layers to derive future estimates (deltas averaged over the period, 2012–2026 were used).

**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 conterminous 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)

Our 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 indicate 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.

![FIGURE 32 Estimated increase in mean annual temperature](image)

<table>
<thead>
<tr>
<th>Change in precipitation</th>
<th>MAP</th>
<th>MAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>10–20% drier than historical norms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5–10% drier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little predicted change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–5% wetter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5–10% wetter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10–20% wetter</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Hemlock Woolly Adelgid

For hemlock woolly adelgid (FIGURE 34A), the 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 plateaus 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.; 20–35 inches of PPT/yr.; 1.6–2.4° F greater than historical norms).
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 Tmin 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.fed.us). 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.
The Forest Insect and Disease Risk Map Atlas is a stand-alone compendium that includes several maps presented in this report and two maps for each risk agent or agent group examined in this assessment, summarized by watershed. The risk agent maps are arranged in alphabetical order by common name. This atlas serves as a tool and reference guide for resource managers to quickly identify priority and threatened watersheds and their causal agent(s). Watersheds provide a broad overview from which patterns across a large landscape can be identified easily.

The first three sets of maps show composite risk of mortality across all agents. These maps are shown in the main body of the report and are reprinted here for convenient comparison with the individual causal agent maps that complete this atlas. Following the standard pixel-based composite risk map is a watershed summary based on the percentage of total area at risk. The third map ranks watersheds by the cumulative basal area (BA) loss from all agents. Following the composite maps are two tables that summarize the models behind the Risk Maps. Table A (pages 72–73) summarizes the criteria (i.e., drivers for risk) used to model each risk agent or agent group and describes the importance of these criteria. It also lists the maximum realizable mortality rates used in the risk models. The maximum realizable mortality rate is a mortality ceiling assigned to each risk agent model that defines the level (rate) of host BA mortality for the modeled agent that will be attributed to a pixel when all of the risk criteria are at their maximum—i.e., have a risk score of 10 for every criterion (on a 0–10 risk scale, see Krist et al. 2007). The BA mortality rates for risk scores lower than 10 are linearly scaled between 0% and the maximum realizable mortality rate. For example, if the maximum realizable mortality rate is 80%, then pixels having the highest possible risk score of 10 would experience 80% host mortality; pixels having a risk score of 5 would experience a 40% mortality rate, etc. Table B (page 76) provides a crosswalk between the pests and pathogens and their individual tree species hosts, as modeled in the 2012 NIDRM.

We provide two watershed-based maps for each causal agent:

1. **Classification** of watersheds based on the percentage of projected BA loss. Each summarizes the relative impact of each pest or pathogen and allows comparison between watersheds ranging from sparsely to heavily forested.

2. **Ranking** of watersheds by the absolute amount of BA loss. These identify the watersheds where BA loss potential is greatest.

The classification maps are based on the percentage of BA loss, so they are helpful for understanding the relative ecological impact of individual agents on overall stand ecology. In contrast, the ranking maps are useful for identifying those watersheds with the greatest BA losses due to each mortality agent, regardless of how much BA loss is attributed to each pest or pathogen. For example, while the classification maps clearly show that mountain pine beetle is a much more wide-ranging and devastating tree-mortality agent than sires woodwasp, the ranking maps make it easy for the user to identify the watersheds where risk of mortality from each agent is greatest.

The classification maps are calculated by summing the BA loss for each risk agent and the total BA for all tree species in every watershed. The summed BA loss by risk agent is then divided by the total BA to determine the proportion of total BA that may be lost over the next 15 years. Proportions are then grouped within five categories: Host extent but little or no BA loss, 1–4% loss, 5–14% loss, 15–24% loss, and 25–100% loss.

The ranking maps are calculated by summing the BA loss for each risk agent in every watershed. Watersheds with a total of 5 square feet or less of BA loss (per watershed) are set to zero to eliminate noise in the final maps. All watersheds are then grouped and ranked into 100 BA loss classes through an equal-area stretch. The equal-area stretch assigns each watershed to a BA loss class and ensures that a nearly equal number of watersheds occupy each class. Watersheds are assigned to only one of the 100 classes and are not split among classes. Depending upon watershed size, some classes may contain slightly more area than other classes. Finally, the 100 classes are grouped into five categories based on their ranking in the BA loss distribution: Host present with < 5 square feet of BA host loss, 5%–74%, 75%–95%, and the top 5% of most severely impacted watersheds.

The CHARTS presented in the Atlas (page 75) show, by risk agent, the BA loss rate of the most severely impacted watersheds on the ranking maps (i.e., the top 5% category). The ranking maps appear similar in that they depict the same amount of area in each impact category regardless of the agent’s absolute mortality level. Accordingly, we include a magnified version of this chart on all ranking maps to provide context about the overall impact of each pest or pathogen. The Great Plains and its adjacent prairies are lightly forested. When depicted on national maps, it is difficult to differentiate between rankings of the most severely impacted areas and watersheds with little or no loss. Therefore, several key pests projected to impact treed areas of the Great Plains were re-mapped so as to restrict the rankings to only those watersheds within the Great Plains and adjacent prairie ecosystems. Basal area estimates were not calculated for Hawaii. Instead, pest and pathogen maps for Hawaii are presented using 30-meter resolution cells that represent areas at risk due to each agent.
71.7 MILLION ACRES AT RISK IN THE COTERMINOUS UNITED STATES

Risk of mortality
Treed areas
Percentage of Tree Area at Risk by Watershed

Little to no risk
1–4%
5–14%
15–24%
25% or greater
WATERSHEDS RANKED BY BASAL AREA LOSS HAZARD

- Host extent (little to no BA loss)
- Bottom 49%
- 50–74%
- 75–95%
- Top 5%—highest estimated BA losses
### Table 1: Criteria Used to Model Risk Agents and Their Importance in Model Inputs

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight Class</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>low 0–15%</td>
<td>mod</td>
</tr>
<tr>
<td>Host Presence</td>
<td>very high &gt;45–60%</td>
<td>mod</td>
</tr>
<tr>
<td>Climate</td>
<td>extremely high &gt;60%</td>
<td>mod</td>
</tr>
</tbody>
</table>

### Table 2: Tree Species Parameters

<table>
<thead>
<tr>
<th>Tree Species Parameters</th>
<th>Diameter</th>
<th>Basal Area/ Density</th>
<th>Host Presence</th>
<th>Climate</th>
<th>Proximity to Infestation</th>
<th>Physiographic</th>
</tr>
</thead>
</table>

### Table 3: Models

<table>
<thead>
<tr>
<th>Models</th>
<th>Diameter</th>
<th>Basal Area/ Density</th>
<th>Host Presence</th>
<th>Climate</th>
<th>Proximity to Infestation</th>
<th>Physiographic</th>
</tr>
</thead>
</table>

### Notes

- *See footnote, page 73.*
- *Maximum Mortality Rates are the range of maximum allowable host mortality rates across the suite of agent-specific models, by region. For maximum mortality rates by host/agent combination, see Table 5, page 58.
## Host Species Modeled for Each Agent

<table>
<thead>
<tr>
<th>Agent</th>
<th>Host Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian longhorned beetle</td>
<td>Red maple and sugar maple</td>
</tr>
<tr>
<td>Aspen and cottonwood decline</td>
<td>Cottonwood species and quaking aspen</td>
</tr>
<tr>
<td>Balsam woolly adelgid</td>
<td>Balsam, grand, Pacific silver and subalpine fir</td>
</tr>
<tr>
<td>Beech bark disease</td>
<td>American beech</td>
</tr>
<tr>
<td>Bur oak blight</td>
<td>Bur oak</td>
</tr>
<tr>
<td>Douglas-fir beetle</td>
<td>Douglas-fir</td>
</tr>
<tr>
<td>Dutch elm disease</td>
<td>American elm</td>
</tr>
<tr>
<td>Dwarf mistletoes</td>
<td>Douglas-fir, western larch, western hemlock, and the following pines: balsam, limber, ponderosa, tamarack, balsam fir, singleleaf pine, and Arizona pinyon</td>
</tr>
<tr>
<td>Eastern larch beetle</td>
<td>Tamarack (native)</td>
</tr>
<tr>
<td>Eastern spruce budworm</td>
<td>Balsam fir and spruce species</td>
</tr>
<tr>
<td>Emerald ash borer</td>
<td>Ash species</td>
</tr>
<tr>
<td>Engraver beetle (Ips spp.)</td>
<td>White spruce and the following pines: eastern white, loblolly, longleaf, pitch, pond, shortleaf, slash, Virginia, tamarack, singleleaf pine, border pine, Mexican pine, Arizona pine, and ponderosa</td>
</tr>
<tr>
<td>Erythrina gall wasp</td>
<td>Wiliwili</td>
</tr>
<tr>
<td>Fi engraver</td>
<td>California red fir and grand/white fir species</td>
</tr>
<tr>
<td>Forest tent caterpillar</td>
<td>Aspen species</td>
</tr>
<tr>
<td>Fusiform rust</td>
<td>Slash pine and loblolly pine</td>
</tr>
<tr>
<td>Goldspeckled oak borer</td>
<td>California black oak, California live oak, and canyon live oak</td>
</tr>
<tr>
<td>Hemlock woolly adelgid</td>
<td>Eastern hemlock and Carolina hemlock</td>
</tr>
<tr>
<td>Jack pine budworm</td>
<td>Jack pine</td>
</tr>
<tr>
<td>Jeffrey pine beetle</td>
<td>Jeffrey pine</td>
</tr>
<tr>
<td>Koa wilt</td>
<td>Koa</td>
</tr>
<tr>
<td>Laurel wilt</td>
<td>Redbay and sassafras</td>
</tr>
<tr>
<td>Maple decline</td>
<td>Sugar maple</td>
</tr>
<tr>
<td>Mountain pine beetle</td>
<td>Limber, lodgepole, ponderosa, southwestern white, sugar, western white, and whitebark pines</td>
</tr>
<tr>
<td>Myrothecium luteum</td>
<td>None</td>
</tr>
<tr>
<td>Oak decline and gypsy moth</td>
<td>Red oak and oak white species</td>
</tr>
<tr>
<td>Oak wilt</td>
<td>Live oak and red oak species</td>
</tr>
<tr>
<td>Ophi rust</td>
<td>Ophi</td>
</tr>
<tr>
<td>Root diseases</td>
<td>Sitka spruce</td>
</tr>
<tr>
<td>Roundheaded pine beetle</td>
<td>Ponderosa pine</td>
</tr>
<tr>
<td>Saw woodpecker</td>
<td>Shortleaf, slash, pitch, pond, Virginia, jack, red, longleaf, loblolly and Scotch pines</td>
</tr>
<tr>
<td>Southern pine beetle</td>
<td>Eastern white, longleaf, shortleaf, slash, loblolly, pitch, pond, and Virginias pines</td>
</tr>
<tr>
<td>Spruce aphid</td>
<td>Sitka spruce</td>
</tr>
<tr>
<td>Spruce beetle</td>
<td>Engelmann, Sitka, and white spruces</td>
</tr>
<tr>
<td>Stem rot</td>
<td>Sitka spruce and western hemlock</td>
</tr>
<tr>
<td>Sudden oak death</td>
<td>California black oak, California live oak, and tamarisk</td>
</tr>
<tr>
<td>Western balsam bark beetle</td>
<td>Subalpine fir</td>
</tr>
<tr>
<td>Western pine beetle</td>
<td>Coast and ponderosa pines</td>
</tr>
<tr>
<td>Western spruce budworm</td>
<td>Engelmann spruce, Douglas-fir, grand fir, subalpine fir, and white fir</td>
</tr>
<tr>
<td>White pine blister rust</td>
<td>Eastern white, limber, Rocky Mountain bristlecone, southwestern white, sugar, western white, and whitebark pines</td>
</tr>
<tr>
<td>Winter moth</td>
<td>Oak species</td>
</tr>
<tr>
<td>Yellow-cedar decline</td>
<td>Alaska yellow-cedar</td>
</tr>
</tbody>
</table>


2. Group includes Arizona fivespined Ips, eastern fivespined Ips, northern spruce engraver, pine engraver, pinus ips, spruce Ips, small southern pine engraver and three western species without common names: Ips latidens, Ips knausi and Ips integer.


## Basal Area Loss Rates in Watersheds Most Impacted by Each Agent

### Coterminous United States

<table>
<thead>
<tr>
<th>Agent</th>
<th>Basal Area Loss Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian longhorned beetle</td>
<td>25%</td>
</tr>
<tr>
<td>Dwarf mistletoes</td>
<td>20%</td>
</tr>
<tr>
<td>Fusiform rust</td>
<td>15%</td>
</tr>
<tr>
<td>White pine blister rust</td>
<td>10%</td>
</tr>
<tr>
<td>Saw woodpecker</td>
<td>5%</td>
</tr>
<tr>
<td>Bur oak blight</td>
<td>2%</td>
</tr>
<tr>
<td>Goldspeckled oak borer</td>
<td>1%</td>
</tr>
<tr>
<td>Roundheaded pine beetle</td>
<td>0.5%</td>
</tr>
<tr>
<td>Eastern larch beetle</td>
<td>0.25%</td>
</tr>
<tr>
<td>Western balsam bark beetle</td>
<td>0.1%</td>
</tr>
<tr>
<td>Erythrina gall wasp</td>
<td>0.05%</td>
</tr>
<tr>
<td>Fi engraver</td>
<td>0.025%</td>
</tr>
<tr>
<td>Forest tent caterpillar</td>
<td>0.01%</td>
</tr>
<tr>
<td>Fusiform rust</td>
<td>0.005%</td>
</tr>
<tr>
<td>Goldspeckled oak borer</td>
<td>0.0025%</td>
</tr>
<tr>
<td>Engelmann spruce</td>
<td>0.001%</td>
</tr>
</tbody>
</table>

A miniature version of these charts accompanies each of the following maps labeled, “Watershed Ranked by Basal Area Loss Hazard” (Hawaii and Great Plains maps excluded). In the miniature charts, the bar representing the agent depicted in the map is highlighted. The y-axis represents the average basal area mortality rate of the agent’s host tree species in the most severely impacted watersheds (top 5% category). See page 63 for details.

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2. Group includes Arizona fivespined Ips, eastern fivespined Ips, northern spruce engraver, pine engraver, pinus ips, spruce Ips, small southern pine engraver and three western species without common names: Ips latidens, Ips knausi and Ips integer.
Risk Agents for Hawaii

Ohia rust (Puccinia psidii) ........................................ 78
Koa wilt (fusarium oxysporum f. sp. koae) ............... 78
Myoporum thrips (Klambothrips myoporum) ........... 79
Erythrina gall wasp (Quadrastichus erythrinae) ....... 79

Risk Agents for Alaska and the Coterminous United States

Asian longhorned beetle (Anoplophora glabripennis) ... 80
Aspen and cottonwood decline ................................ 82
Aspen and cottonwood decline — Great Plains ........ 84
Balsam woolly adelgid (Adelges piceae) ................. 86, 88
Beech bark disease (Hectria faginata) ..................... 90
Bur oak blight (Tubakia iowensis) .......................... 92
Bur oak blight (Tubakia iowensis) — Great Plains .... 94
Douglas-fir beetle (Dendroctonus pseudotsugae) .... 96
Douglas-fir tussock moth (Orgyia pseudotsugata) .... 98
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Dutch elm disease (Ophiostoma novo-ulmi) — Great Plains 102
Dwarf mistletoes (Arceuthobium spp.) — Alaska .... 104
Dwarf mistletoes (Arceuthobium spp.) ...................... 106
Eastern larch beetle (Dendroctonus simplex) — Alaska 108
Eastern larch beetle (Dendroctonus simplex) ........... 110
Eastern spruce budworm (Choristoneura fumiferana) 112
Emerald ash borer (Agrilus planipennis) ................. 114, 116
Emerald ash borer (Agrilus planipennis) — Great Plains 118
Engraver beetles (Ips spp.) ...................................... 120, 122
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Fir engraver (Scolytus ventralis) .............................. 126
Forest tent caterpillar (Malacosoma disstria) .......... 128
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Goldspotted oak borer (Agrilus auroguttatus) ......... 132
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Jack pine budworm (Choristoneura pinus) ............ 136
Jeffrey pine beetle (Dendroctonus jeffreyi) ............ 138
Laurel wilt (Raffaelea lauricola) .................. 140
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Mountain pine beetle (Dendroctonus ponderosae) .... 144
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Oak decline and gypsy moth — Great Plains ......... 148
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Spruce beetle (Dendroctonus rufipennis) ............... 164
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Western balsam bark beetle (Dypsis melanocephala) 172
Western pine beetle (Dendroctonus brevicornis) .... 174
Western spruce budworm (Choristoneura occidentalis) 176
White pine blister rust (Cronartium ribicola) ........ 178, 180
Winter moth (Operophtera brumata) ................... 182
Yellow-cedar decline ........................................... 184
Ohia rust *Puccinia psidii*

**Modeled host:** ohia

Ohia rust was first detected in Hawaii in 2005. The rust occurs on all the major islands and affects many native and non-native plants in the Myrtaceae family. The rust infects new foliage, and in some hosts it infects the reproductive tissue 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.

Koa wilt *Fusarium oxysporum f. sp. koae*

**Modeled host:** koa

Koa wilt has been found on Hawaii (Big Island), Maui, Oahu, and Kauai. This vascular wilt disease is caused by a fungus that is now commonly found in soils on the Hawaiian Islands and can kill trees of all ages. The fungal pathogen enters the roots and then colonizes the main stem's conductive tissue, resulting in yellowing of leaves and crown wilt. Many plantation failures and high mortality rates of young trees have been observed.

Myoporum thrips *Klambothrips myopori*

**Modeled host:** naio

The initial infestation of naio, a native, ecologically important species, by myoporum thrips in Hawaii was reported in 2009. Surveys are ongoing to determine its extent. This thrips causes leaf curling and gall symptoms on infected plants, with high levels of infestation resulting in plant mortality. The loss of naio would be particularly detrimental where it is a critical habitat component for the palila, *Loxioides bailleui*, a federally endangered species of honeycreeper on Mauna Kea.

Erythrina gall wasp *Quadrastichus erythrinae*

**Modeled host:** wiliwili

The erythrina gall wasp was first detected on Oahu in 2005. Once introduced to Hawaii, the wasp spread across all of the main islands, 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. Plant vigor declines from sequential defoliation and mortality may be observed in one to two years.
Asian longhorned beetle *Anoplophora glabripennis*

**Modeled hosts:** red maple, sugar maple, and other hardwoods

The Asian longhorned beetle is an introduced, destructive, wood-boring pest of maple and other hardwoods. The beetle was first discovered in the United States on trees in Brooklyn, New York, in 1996. Populations now exist in Massachusetts, New Jersey, New York, and Ohio.
Aspen and Cottonwood Decline

Modeled hosts: Cottonwood species and quaking aspen

In various ecosystems in the western United States and Great Plains, aspen and cottonwood stands are declining at an alarming rate. Stem longevity and the associated pathological rotation age seem to be getting shorter. While we know cottonwood and aspen to be short-lived, stand decline seems to be occurring at an increasingly younger stand age. Pest complexes seem to be changing, with the worst impact on hottest and driest areas: low-lying, south-facing slopes.
Aspen and cottonwood decline — Great Plains

Modeled hosts: cottonwood species and quaking aspen

In various ecosystems in the western United States and Great Plains, aspen and cottonwood stands are declining at an alarming rate. Stem longevity and the associated pathological rotation age seem to be getting shorter. While we know cottonwood and aspen to be short-lived, stand decline seems to be occurring at an increasingly younger stand age. Pest complexes seem to be changing, with the worst impact on hottest and driest areas: low-lying, south-facing slopes.
The balsam woolly adelgid is a tiny sucking insect that was introduced into North America from Europe in the mid-1950s. True firs in the United States have no natural defenses against this pest. In some areas, infestations have been so high, true firs have been eliminated entirely from the infested areas.

**Host extent (little to no BA loss)**
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss
The balsam woolly adelgid is a tiny sucking insect that was introduced into North America from Europe in the mid-1950s. True firs in the United States have no natural defenses against this pest. In some areas, infestations have been so high, true firs have been eliminated entirely from the infested areas.

**Balsam woolly adelgid** *Adelges piceae*

**Modeled hosts:** balsam fir, grand fir, pacific silver fir, and subalpine fir

**Host extent (little to no BA loss)**
- 0%–5%
- Bottom 49%
- 50–74%
- 75–95%
- Top 5%–highest estimated BA losses
**Beech Bark Disease** *Nectria faginata*

**Modeled host:** American beech

In the United States, this disease results when the beech scale insect attacks the bark of beech, allowing the introduction of two species of fungi to invade the tree through the wound and cause a canker to be formed. As cankers continue to form, death of the tree can result.

### Host extent (little to no BA loss)
- 3%

### Host extent (little to no BA loss)
- Bottom 49%

### Host extent (little to no BA loss)
- 50–74%

### Host extent (little to no BA loss)
- 75–95%

### Host extent (little to no BA loss)
- Top 5%–Highest estimated BA losses
**Bur oak blight** *Tubakia iowensis*

**Modeled host:** bur oak

As a leafspot fungus that occurs only on bur oaks, this relatively new pest of the upper Midwest. It is associated with early spring rainfall and has been reported since the early 1990s. It is not clear if the pathogen is a recent arrival, or if a shift in climate has made this disease more noticeable.

<table>
<thead>
<tr>
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<tr>
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<tr>
<td>Top 5%–highest estimated BA losses</td>
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</table>
Bur oak blight — Great Plains  
*Tubakia iowensis*

Moded host: bur oak

As a leafspot fungus that occurs only on bur oaks, this relatively new pest of the upper Midwest. It is associated with early spring rainfall and has been reported since the early 1990s. It is not clear if the pathogen is a recent arrival, or if a shift in climate has made this disease more noticeable.
**Douglas-fir beetle**  *Dendroctonus pseudotsugae*

*Modeled host:* Douglas-fir

Douglas-fir beetle is the single most important bark beetle enemy of Douglas-fir. When outbreaks occur, this beetle can kill thousands of seemingly healthy Douglas-fir trees. During outbreaks, groups of trees, ranging from a few to several hundred, can be affected.

<table>
<thead>
<tr>
<th>Host extent (little to no BA loss)</th>
<th>1–4%</th>
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</thead>
</table>

- **Malcolm Furniss**
- **USDA FS Ogden Archive**
- **William M. Ciesla**
- **Sandy Kegley**
The Douglas-fir tussock moth is an important defoliator of true firs, spruces, and Douglas-fir in western North America. Insect outbreaks occur rather suddenly, therefore, considerable effort is made to monitor this insect through the use of a west-wide system of pheromone traps.

*Modeled hosts:* Douglas-fir, grand fir, and white fir

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**Douglas-fir tussock moth** *Orgyia pseudotsugata*

**Host extent (little to no BA loss):**
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

---

**Watersheds ranked by basal area loss hazard:**
- Host extent (little to no BA loss)
- Bottom 49%
- 50–74%
- 75–95%
- Top 5%–highest estimated BA losses

---

2013–2027 National Insect and Disease Forest Risk Assessment
Dutch elm disease is one of the most destructive shade tree diseases in North America. The disease affects American elms—and other elm species to a lesser extent—killing individual branches and, eventually, the entire tree within one to three years.
Dutch elm disease is one of the most destructive shade tree diseases in North America. The disease affects American elms—and other elm species to a lesser extent—killing individual branches and, eventually, the entire tree within one to three years.

**Modeled host:** American elm

**Dutch Elm Disease — Great Plains**

*Ophiostoma novo-ulmi*

- Host extent (little to no BA loss)
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss
Dwarf mistletoes — Alaska *Arceuthobium* spp.

*Modeled host:* western hemlock

Dwarf mistletoes are the most important vascular plant parasites of conifers in the United States. These shrubby, aerial parasites are dispersed by birds or by seed dispersion through explosive fruits. Dwarf mistletoes are obligate parasites, dependent on their host for water, nutrients, and some or most of their food. Pathogenic effects on the host include deformation of the infected stem, growth loss, and increased susceptibility to other pests.
Dwarf mistletoes *Arceuthobium* spp.

**Modelled hosts:** Douglas-fir, western larch, western hemlock, lodgepole pine, limber pine, pinyon pine, and ponderosa pine.

Dwarf mistletoes are the most important vascular plant parasites of conifers in the United States. These shrubby, aerial parasites are dispersed by birds or by seed dispersion through explosive fruits. Dwarf mistletoes are obligate parasites, dependent on their host for water, nutrients, and some or most of their food. Pathogenic effects on the host include deformation of the infected stem, growth loss, and increased susceptibility to other pests.

### Percentage of total basal area loss by watershed

- **1%**
- **5–14%**
- **15–24%**
- **25% or greater of total BA loss**

### Watersheds ranked by basal area loss hazard

- **Host extent (little to no BA loss)**
- **Bottom 49%**
- **50–74%**
- **75–95%**
- **Top 5%–highest estimated BA losses**
The eastern larch beetle is a native North American insect that colonizes the phloem of the main stem, exposed roots, and larger branches of tamarack, or eastern larch. Extensive tree mortality has been reported throughout the range of eastern larch, and beetle outbreaks have been reported from the late 1800s.
The eastern larch beetle is a native North American insect that colonizes the phloem of the main stem, exposed roots, and larger branches of tamarack, or eastern larch. Extensive tree mortality has been reported throughout the range of eastern larch, and beetle outbreaks have been reported from the late 1800s.
**Eastern Spruce Budworm** *Choristoneura fumiferana*

*Modeled hosts: balsam fir and spruce species*

The eastern spruce budworm is one of the most destructive native forest defoliators and is responsible for shaping the stand composition and structure of northern spruce and fir forests in the eastern United States and Canada.
Unequivocally a tree-killer in the United States, the emerald ash borer is by far the most destructive invasive exotic species to have arrived in North America in quite some time.
Unequivocally a tree-killer in the United States, the emerald ash borer is by far the most destructive invasive exotic species to have arrived in North America in quite some time. 

Host extent (little to no BA loss) 
Bottom 49% 
50–74% 
75–95% 
Top 5%—highest estimated BA losses
Uniquely a tree-killer in the United States, the emerald ash borer is by far the most destructive invasive exotic species to have arrived in North America in quite some time.
Engraver beetles *Ips* spp.

**Modeled hosts:** White spruce and the following pines: pinyon, ponderosa, shortleaf, slash, longleaf, loblolly, pitch, pond, Virginia, and eastern white.

Engraver beetles belong to the *Ips* genus of beetles. These beetles are very common throughout the United States, though they only contribute to significant pine tree mortality during periods of drought or other environmental stress.
Engraver beetles (Ips spp.)

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Engraver beetles belong to the *Ips* genus of beetles. These beetles are very common throughout the United States, though they only contribute to significant spruce tree mortality during periods of drought or other environmental stress.

### Host extent (little to no BA loss)
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

### Watersheds Ranked by Basal Area Loss Hazard
- Host extent (little to no BA loss)
- Bottom 49%
- 50–74%
- 75–95%
- Top 5%—highest estimated BA losses
**Fir engraver** *Scolytus ventralis*

**Modeled hosts:** California red fir and grand/white fir species

Fir engravers are tree-killers of true firs, usually attacking pole-sized to saw-timber sized trees. Outbreaks are associated with drought and the presence of root diseases.

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**Percentage of Total Basal Area Loss by Watershed**

- Host extent (little to no BA loss)
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

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**Watersheds Ranked by Basal Area Loss Hazard**

- Host extent (little to no BA loss)
- Bottom 49%
- 50–74%
- 75–95%
- Top 5%—highest estimated BA losses

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*USDA FS Ogden Archive*

*Donald Owen*

*Dave Powell*

*Fred Honing*

*William M. Ciesla*
The forest tent caterpillar is native and may be found throughout the United States and Canada wherever hardwoods grow—from the Pacific Northwest to the South and the upper Midwest, and along the mid-Atlantic states to New England. The favored hosts of this insect are sugar maple, aspen, oaks, water tupelo, sweetgum, blackgum, cottonwood, elms, red alder, and willow.
Fusiform rust *Cronartium quercuum*

**Modeled hosts:** slash pine and loblolly pine

Fusiform rust is a fungus that causes swellings, called galls, on branches and stems of pines. Mortality is greatest on young trees, but the rust galls and cankers deform and weaken older trees as well. The pathogen requires both pine and oak to complete its life cycle.
The goldspotted oak borer is native to oak forests of southeastern Arizona, and a closely related species is found in Central America. Since 2002, the borer is associated with the death of more than 80,000 trees, and this infested area continues to expand as borer populations grow and spread. The borer is not a pest in its native range.

**Host extent**
- Host extent (little to no BA loss)
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

**Watersheds ranked by BA hazard**
- Host extent (little to no BA loss)
- Bottom 49%
- 50–74%
- 75–95%
- Top 5%–highest estimated BA losses

**Modeled hosts:** California black oak, California live oak, and canyon live oak.
Few pests other than chestnut blight and Dutch elm disease have had such a marked effect on eastern forests. Left unchecked, the hemlock woolly adelgid will likely extirpate most of the native hemlock from eastern North America.

Modeled hosts: eastern hemlock and Carolina hemlock
Jack pine budworm is a needle-feeding caterpillar and considered to be the most significant pest of jack pine. Stands older than 45 years, that are growing on very sandy sites and suffering from drought or other stresses, are very vulnerable to damage. Topkill and, ultimately, mortality result when stressed trees are attacked.
**Jeffrey Pine Beetle** *Dendroctonus jeffreyi*

*Modeled host:* Jeffrey pine

The Jeffrey pine beetle kills trees by mining between bark and wood and is the principal bark-beetle enemy of Jeffrey pine. The beetle has economic impacts chiefly in California; it is most destructive in older stands in the timber-producing areas of northeastern California.

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Laurel wilt  *Raffaelea lauricola*

**Modeled hosts:** redbay and sassafras

Laurel wilt is a deadly disease of redbay and other tree species in the Laurel family, such as avocado. The disease is caused by a fungus introduced into host trees by the redbay ambrosia beetle (*Xyleborus glabratus*), a non-native insect. This disease is expected to extirpate redbay from southern forests.
**Maple Decline**

**Modeled host: sugar maple**

More sporadic and less extensive than oak decline, maple decline is associated with drought and harsh site or exposed conditions. Symptoms include slowed radial growth, crown dieback, attack by secondary organisms, and tree mortality.

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The mountain pine beetle is the most important biotic change agent in western forests. This insect has been responsible for contributing to the death of many millions of acres of trees in lodgepole and ponderosa pine forests.

Modeled hosts: limber, lodgepole, ponderosa, southwestern white, sugar, western white, and whitebark pine

Percentage of total basal area loss by watershed

Watersheds ranked by basal area loss hazard
Periods of local and regional occurrences of oak decline have been reported since the early 1900s. Trees weakened from environmental stresses, such as drought, phloem feeders, root pathogens, sucking insects, and defoliators (notably gypsy moth), experience reduced annual growth, canopy dieback, and death.

**Host extent (little to no BA loss)**
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

**Watersheds ranked by basal area loss hazard**
- Bottom 49%
- 50–74%
- 75–95%
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**Oak decline and gypsy moth — Great Plains**

**Modeled hosts:** red oak and white oak species

- Host extent (little to no BA loss) 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

- Bottom 49%
- 50–74%
- 75–95%
- Top 5%–highest estimated BA losses
Oak wilt, *Ceratocystis fagacearum*

**Modeled hosts:** live oak and red oak species

Oak wilt is a vascular disease of oak that can quickly kill a tree. It is caused by the fungus *Ceratocystis fagacearum*. Symptoms vary by tree species but generally consist of leaf discoloration, wilt, defoliation, and death. This fungus spreads overland on the various insect species that fly to surface wounds or through underground root grafting.

- **Host extent (little to no BA loss):** 1–4%
- **5–14%**
- **15–24%**
- **25% or greater of total BA loss**
Root diseases are the most damaging group of diseases affecting forest trees in the United States. Root diseases kill trees, decay wood, slow tree growth, predispose trees to other risk agents, and cause trees to fall or fall over. They impact timber volume, forest composition and structure, ecosystem function, personal safety, and carbon sequestration.
Host extent (little to no BA loss)
Bottom 49%
50–74%
75–95%
Top 5%—highest estimated BA losses

**Root diseases — all**

**Modeled hosts:** spruce and fir species, Douglas-fir, mountain hemlock, Port-Orford-cedar, paper birch, western red cedar, and the following pines: eastern white, jack, Jeffrey, longleaf, ponderosa, red, shortleaf, slash, and loblolly.

Root diseases are the most damaging group of diseases affecting forest trees in the United States. Root diseases kill trees, decay wood, slow tree growth, predispose trees to other risk agents, and cause trees to fall or fall over. They impact timber volume, forest composition and structure, ecosystem function, personal safety, and carbon sequestration.
**Roundheaded Pine Beetle** *Dendroctonus adjunctus*

**Modeled host:** ponderosa pine

This pine pest attacks ponderosa pine, primarily in the southwestern United States. Outbreaks of this beetle, at least in the recent past, are short-lived and sporadic. Damage is typically found on ridgetops and other sites with very dry, sandy soils.

### Host extent

- **Host extent (little to no BA loss)**
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

Watersheds ranked by basal area loss hazard:

- Host extent (little to no BA loss)
- Bottom 49%
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**Sirex woodwasp** *Sirex noctilio*

**Modeled hosts:** shortleaf, slash, longleaf, loblolly, petch, pond, Virginia, jack, red, and Scotch pines

The Sirex woodwasp is a species of horntail native to Europe, Asia, and northern Africa. This invasive species is established in many parts of the world, including Australia, New Zealand, North America, South America, and South Africa, where it can become a significant economic pest of pine. The wasp can attack a wide variety of pine tree species, and stressed trees are those most often attacked.

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**Percentage of Total Basal Area Loss by Watershed**

- Host extent (little to no BA loss)
  - 1–4%
  - 5–14%
  - 15–24%
  - 25% or greater of total BA loss

**Watersheds Ranked by Basal Area Loss Hazard**

- Host extent (little to no BA loss)
  - Bottom 49%
  - 50–74%
  - 75–95%
  - Top 5%—Highest estimated BA losses
The southern pine beetle is the most destructive bark beetle in the eastern United States. Intensively managed forests and active prevention programs have minimized the impact of this potentially explosive pest.

**SOUTHERN PINE BEETLE** *Dendroctonus frontalis*

**Host extent:**
- Host extent (little to no BA loss)
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

**Watersheds ranked by Basal Area Loss Hazard**

- Host extent (little to no BA loss)
- Bottom 49%
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- 75–95%
- Top 5%–Highest estimated BA losses
**Spruce Aphid** *Elatobium abietinum*

*Modeled host:* Sitka spruce

The spruce aphid is thought to have been introduced to North America from Europe. Sitka, Norway, and blue spruce are preferred hosts, but other spruce species might also be attacked.
The spruce beetle is the most significant biotic disturbance agent of mature spruce. Outbreaks of spruce beetles have dramatically changed the structure and composition of North American spruce forests.
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**Modeled hosts:** Sitka spruce, and white spruce

**Host extent:**
- Little to no basal area loss (1-4%)
- 5-14%
- 15-24%
- 25% or greater of total basal area loss

**Watersheds ranked by basal area loss hazard:**
- Host extent (little to no BA loss)
- Bottom 49%
- 50-74%
- 75-95%
- Top 5%—highest estimated BA losses
Stem rot

Modeled hosts: Sitka spruce and western hemlock

Stem rot fungi have a major impact on the forests of Southeast Alaska, where roughly a third of the old-growth timber volume of live trees is affected. These fungi predispose large old trees to bole breakage. Small-scale canopy gaps created by individual tree mortality events serve important ecological functions.
**Sudden Oak Death** *Phytophthora ramorum*

*Modeled hosts:* California black oak, California live oak, and tanoak

Sudden oak death is a tree disease caused by the pathogen *Phytophthora ramorum*. The disease kills some oak species and tanoak, and has had significant effects on forests in California and Oregon.

**Host extent**
- Host extent (little to no BA loss)
- 1–4% BA loss
- 5–14% BA loss
- 15–24% BA loss
- 25% or greater of total BA loss

**Watersheds ranked by basal area loss hazard**
- Host extent (little to no BA loss)
- Bottom 49%
- 50–74%
- 75–95%
- Top 5%–highest estimated BA losses
The western balsam bark beetle is the most conspicuous of a complex of pests which are responsible for high rates of tree mortality in sub-alpine fir stands from New Mexico and Arizona through the northern Rocky Mountains. Typically, infestations are chronic, contributing to high rates of subalpine fir mortality in the West.
**Western pine beetle** *Dendroctonus brevicomis*

**Modeled hosts:** Coulter pine and ponderosa pine

Western pine beetle can be found throughout most of the native range of ponderosa pine and Coulter pine in California. As with most Dendroctonus beetles, this pest breeds in larger trees or in trees that have been stressed by drought, disease, fire, or overly dense conditions.
The western spruce budworm is one of the most destructive forest defoliators in western North America. Outbreaks have occurred from the central Rockies in the United States to the Coast Mountains in British Columbia, Canada, and the panhandle of Alaska.

**Western Spruce Budworm** *Choristoneura occidentalis*

*Modeled hosts:* Engelmann spruce, Douglas-fir, grand fir, subalpine fir, and white fir
White pine blister rust *Cronartium ribicola*

**Host extent** (little to no BA loss)
- 1–4%
- 5–14%
- 15–24%
- 25% or greater of total BA loss

White pine blister rust is probably the most destructive disease of five-needle pines in North America and is a major threat to high-elevation white pines in the western United States. The pathogen is believed to have originated in Asia. By the 1950s it had spread to most of the commercial white pine regions. It became established in Europe as well, after large numbers of highly susceptible American white pines were imported and planted there.
**White pine blister rust** *Cronartium ribicola*

**Modeled hosts:** eastern white, limber, Rocky Mountain bristlecone, southwestern white, sugar, western white, and whitebark pine

White pine blister rust is probably the most destructive disease of five-needle pines in North America and is a major threat to high-elevation white pines in the western United States. The pathogen is believed to have originated in Asia. By the 1950s it had spread to most of the commercial white pine regions. It became established in Europe as well, after large numbers of highly susceptible American white pines were imported and planted there.
Winter moth is an insect pest that was introduced to North America from Europe. It is now established in eastern Canada, British Columbia, New England, and the Pacific Northwest. Various deciduous trees are susceptible, including oaks, maples, basswood, ash, crabapples, apple, blueberry, and certain spruces. Multiple defoliations or interactions with other stressors can lead to tree death.
Yellow-cedar decline

Modeled host: Alaska yellow-cedar

Yellow-cedar decline is not well-understood, but is thought to be associated with root freezing that occurs during very cold weather when the ground is not insulated with snow.
Insect and Disease Forest Risk Assessment

Infestation
Damage – Woodpecker foraging damage due to infestation

Adult – Emerald ash borer
Damage – Mortality
Emerald ash borer larvae and pupae in late winter, early spring. Photo taken in Ann Arbor, MI, 2004

Damage – Ash trees killed after infestation
Damage – Ash killed by EAB in southeastern Michigan

Emerald ash borer adult feeding on an ash leaf

Symptoms – Camphor tree with dieback symptoms caused by laurel wilt

Damage – Staining on the bark surface of coast live oak, resulting from Ips beetle infestation
Damage – Spruce budworm damage

Symptoms – Fusiform rust; stand showing many cankers
Damage – Mortality
Emerald ash borer mortality. Photo taken August 2013

Adult – Fir engraver
Damage – Defoliation
Emerald ash borer infested ash trees along a street in Novi, MI.

Symptoms – Globose galls typical of the pine-oak and pine-pine gall rusts
Damage – Hemlock woolly adelgid
Emerald ash borer larvae in pupal cell within the inner bark

Emerald ash borer adult feeding on an ash leaf

Emerald ash borer adult, in tunnel
Emerald ash borer adult
Emerald ash borer adult

Emerald ash borer adult feeding on an ash leaf

Infestation – Infested with Ips and black turpentine beetles

Adult – Forest tent caterpillar
Damage – Staining on the bark surface of coast live oak, resulting from Ips beetle infestation
Damage – Mortality
Emerald ash borer larvae and pupae in late winter, early spring. Photo taken in Ann Arbor, MI, 2004

Adult – Jack pine budworm
Damage – Mortality
Adult – Jack pine budworm
Emerald ash borer larvae and pupae in late winter, early spring. Photo taken in Ann Arbor, MI, 2004

Friday, 27 March 2020
<table>
<thead>
<tr>
<th>Photo Credits</th>
<th>190</th>
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</thead>
<tbody>
<tr>
<td><strong>Laurel wilt, continued</strong></td>
<td><strong>Laurel wilt, continued</strong></td>
</tr>
<tr>
<td>141</td>
<td>Albert B. Bull/Mayfield, USDA Forest Service, Bugwood.org</td>
</tr>
<tr>
<td>Symptoms—Wilting redbay foliage</td>
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<tr>
<td>141</td>
<td>Ronald F. Billings, Texas Forest Service, Bugwood.org</td>
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<tr>
<td>Symptoms—Redbay trees dying from laurel wilt disease; center tree responding with epicormic sprouting</td>
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<tr>
<td>141</td>
<td>Ronald F. Billings, Texas Forest Service, Bugwood.org</td>
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<td>Symptoms—Redbay trunk with bark removed exposing sapwood with typical black starting caused by laurel wilt disease</td>
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<tr>
<td>141</td>
<td>R. Scott Cameron, Advanced Forest Protection, Inc., Bugwood.org</td>
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<tr>
<td>Symptoms—Redbay mortality on Jekyll island caused by laurel wilt disease</td>
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<td>Maple decline</td>
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<tr>
<td>142</td>
<td>Jason Sherman, VitalTree, Bugwood.org</td>
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<tr>
<td>Damage—Urban tree decline</td>
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<tr>
<td>143</td>
<td>Randy Cy, Greentree, Bugwood.org</td>
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<tr>
<td>Symptoms—Planted maples are on the decline since they were planted in full sun</td>
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<td>Jason Sherman, VitalTree, Bugwood.org</td>
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<td>Damage—Urban tree decline</td>
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<td><strong>Mountain pine beetle</strong></td>
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<tr>
<td>144</td>
<td>Dave Powell, USDA Forest Service</td>
</tr>
<tr>
<td>Damage—Old group of trees killed, Garber Creek area, South Platte Ranger District, Pike National Forest</td>
<td>Damage—Old group of trees killed, Garber Creek area, South Platte Ranger District, Pike National Forest</td>
</tr>
<tr>
<td>145</td>
<td>Whitney Craneshaw, Colorado State University, Bugwood.org</td>
</tr>
<tr>
<td>146</td>
<td>Steven Kotecko, USDA Forest Service, Bugwood.org</td>
</tr>
<tr>
<td>Damage—Pitch tubes. Medicine Bow Mountains, southeast Wyoming</td>
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<td>Ronald F. Billings, Texas Forest Service, Bugwood.org</td>
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<td>Damage—Adult excavating tunnel. Although this tree is still producing pitch, it has been heavily attacked by mountain pine beetle, and this adult beetle is excavating a larval gallery, tunneling the oozing pitch</td>
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<td><strong>Mycorrhizae</strong></td>
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<td>79</td>
<td>University of California Riverside Center for Invasive Species Research</td>
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<td>Nuus trubs, Klambrosip myxopyri</td>
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<td><strong>Oak decline and gypsy moth</strong></td>
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<td>146</td>
<td>USDA Forest Service—Forest Health Protection—St. Paul Archive, USDA Forest Service, Bugwood.org</td>
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<td>Symptoms—oak decline</td>
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<td>147</td>
<td>Tim Tigner, Virginia Department of Forestry, Bugwood.org</td>
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<td>Damage—Late instars feeding on oak foliage</td>
<td>Damage—Late instars feeding on oak foliage</td>
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<td>147</td>
<td>Tim Tigner, Virginia Department of Forestry, Bugwood.org</td>
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<tr>
<td>Infestation—Cherry oak mortality and understory response ensuing defoliation</td>
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<td>147</td>
<td>USDA APHIS PPO Archive, USDA APHIS PPO, Bugwood.org</td>
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<td>Adult—Male Asian gypsy moth visually identical in appearance to regular gypsy moth need DNA analysis to distinguish strains</td>
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<td>147</td>
<td>William M. Grea, Forest Health Management International, Bugwood.org</td>
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<tr>
<td>Infestation—Defoliation of oaks and other broadleaf trees</td>
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<td>148</td>
<td>Joseph O'Brien, USDA Forest Service, Bugwood.org</td>
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<tr>
<td>Moderate to severe decline symptoms in mature red oak</td>
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<td>Tim Tigner, Virginia Department of Forestry, Bugwood.org</td>
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<td>Infestation—Heavy defoliation by larva</td>
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<td>149</td>
<td>William M. Grea, Forest Health Management International, Bugwood.org</td>
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<td>Adult(s)—Female adults and egg masses</td>
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<td>Joseph O'Brien, USDA Forest Service, Bugwood.org</td>
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<td>Symptoms—oak decline</td>
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<td>149</td>
<td>Jon Yochschuk, Bugwood.org</td>
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<td>Gypsy moth caterpillars, Lymantria dispar</td>
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<td><strong>Oak wilt</strong></td>
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<td>150</td>
<td>William M. Grea, Forest Health Management International, Bugwood.org</td>
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<td>Infestation—Oak killed by oak wilt</td>
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<td>151</td>
<td>Joseph O'Brien, USDA Forest Service, Bugwood.org</td>
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<td>Symptoms—expanding oak wilt pocket</td>
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<td>151</td>
<td>Paul A. Matthiessen, USDA Forest Service, Bugwood.org</td>
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<td>Oak wilt, Texas red oak leaf symptoms</td>
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<td>151</td>
<td>Joseph O'Brien, USDA Forest Service, Bugwood.org</td>
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<td>Oak wilt mortality caused by oak wilt</td>
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<td>Paul A. Matthiessen, USDA Forest Service, Bugwood.org</td>
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<td>Oak wilt, Live oak leaf symptoms</td>
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<td><strong>Ohio rust</strong></td>
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<td>78</td>
<td>P. N. Cameron, USDA Forest Service</td>
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<tr>
<td>Ohio rust, Puccinia poiana</td>
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<td><strong>Rout diseases—all</strong></td>
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<td>152</td>
<td>Joseph O'Brien, USDA Forest Service, Bugwood.org</td>
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<tr>
<td>Symptoms—Windthrow caused by Armillaria root rot in a large bur oak on a golf course</td>
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<td>152</td>
<td>Robert L. James, USDA Forest Service, Bugwood.org</td>
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<td>Symptoms—Changes in tree density and clusters of young trees or brush associated with tree mortality are good indicators of root disease</td>
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<td>153</td>
<td>Andry Kucna, National Forest Centre–Slovakia, Bugwood.org</td>
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<td>Symptoms—Root rot</td>
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<td>USDA Forest Service Archive, USDA Forest Service, Bugwood.org</td>
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<tr>
<td>Laminated root disease infestation—yellow shrubs filling gaps caused by conifer mortality</td>
<td>Laminated root disease infestation—yellow shrubs filling gaps caused by conifer mortality</td>
</tr>
</tbody>
</table>
Sudden oak death, continued

171 Joseph O’Brien, USDA Forest Service, Bugwood.org

Symptoms–Sudden oak death (sorumorum canker) symptoms on coast live oaks

171 Bruce Molitan, USDA Forest Service, Bugwood.org

Symptoms

171 Joseph O’Brien, USDA Forest Service, Bugwood.org

Symptoms–Tip drop symptom of sudden oak death on tanoak

171 Joseph O’Brien, USDA Forest Service, Bugwood.org

Sign–P-tannum azalea lives on coast live oak

Western balsam bark beetle

172 Javier Mercado, Colorado-state University, Bugwood.org

Adult

173 Elizabeth Weibel, USDA Forest Service, Bugwood.org

Damage

173 Scott Turnock, 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 Emrich G. Valley, USDA Forest Service–SRS-4552, Bugwood.org

Adult

175 James Everett, 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

176 Kenneth E. Gibson, USDA Forest Service, Bugwood.org

Damage–Pitch tubes

176 Kenneth E. Gibson, USDA Forest Service, Bugwood.org

Damage–Bark sloughing off of trees

176 William M. Civita, Forest Health Management International, Bugwood.org

Damage–Galleries

Western spruce budworm

176 William M. Civita, 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–Aerial view of defoliation

177 William M. Civita, Forest Health Management International, Bugwood.org

Larvae

177 David J. Moorhead, University of Georgia, Bugwood.org

Damage

White pine blister rust

178 Chris Schreep, University of Idaho, Bugwood.org

Sign–Blister rust sporulating

179 Almocosa Department of Natural Resources (WInNR) Archives, NmDNR, Bugwood.org

Symptoms

179 USDA Forest Service–Ogden Archive, USDA Forest Service, Bugwood.org

Symptoms

179 John W. Schwartz, 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 canker eventually girdle and kill trees

180 USDA Forest Service–Ogden Archive, USDA Forest Service, Bugwood.org

Sign–Urediospores on Rikkes spp.

181 Joseph O’Brien, USDA Forest Service, Bugwood.org

Symptoms

181 H.J. Larson, Bugwood.org

Sign–Close-up view of the area 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
Epidemic

Literally "native to a place." In the context of forest health protection, it refers to 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, Province, and Section. Ecoregions used in NIDRM are at the Section level.

Endemic

Literally "native to a place." In the context of forest disease, an endemic pest is one that naturally occurs in the forest and is characterized by naturally occurring periodic outbreaks and typically less severe and less expansive than epidemics. The primary source of endemic pest information for the 2012 NIDRM is the U.S. Forest Service National Insect and Disease Management Program (NIDMP) database. For the 2012 NIDRM, the threats are those from insects and diseases, and the modeled scenarios assume that no forest management 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 operational 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.

Risk Modeling Application (RMAP)

An ArcGIS-based application built by FHETT allowing users to create multi-criteria risk models against selected datums and view the results. The application interface includes a map canvas that allows users to inspect spatial data inputs and outputs. The risk model outputs computing 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 base area mortality scale (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 Grid.
ACKNOWLEDGEMENTS

FHM coordinators
Borry Taoce – National Program Manager
Jim Steinman – Northeast Region
Dale Stanley – Southern Region

Jeff Hicke – University of Idaho

2013–2027 National Insect and Disease Forest Risk Assessment

APPENDIX A: PROJECT MEMBERS AND ACKNOWLEDGEMENTS

RISKMAP OVERSIGHT TEAM (ROMT)

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Chris Asaro, VA, Southern State Representative
Charles Staun, Western wildfire 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
Gong Kajara, Forest Management, Washington Office
Gong Beams, National Program Manager, Forest Inventory and Analysis (FIA)
Karen Ripley, WA, Western State Representative
Brian Schwind, Remote Sensing Program Center
Frank Fay, Fire and Aviation Management, Washington Office
Jim Steinman, Northeastern Area (NA)

ACKNOWLEDGEMENTS

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Roger Mech, entomologist (MI) and Manfred Mielke, pathologist (NA); NA – Northcentral FHM Region
Shen Smith, entomologist (R3) and Helen Mallot pathologist (R6)
West Coast, Alaska and Hawaii FHM Region

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

DATA DEVELOPMENT TEAM (DDT)

Model Development TEAM (MDT)

Team Lead—Jim Steinman (NA)

FHP staff who developed RMAP models
Jim Steinman – Northeast Region
Dale Stanley – Southern Region

Daniel Ryerson – R3 (NM)
Holly Kearns – Intermountain Region
Mike Simpson – Western Region (Alaska)
Lia Spiegel – Western Region
Michael Simpson – Western Region

Data Providers
Arbor Day Foundation
United States Geological Survey
National Oceanic and Atmospheric Administration

Writer Editors
Chuck Benedict – Cherokee Nations Technologies-FHTET
Mark Riffle – Contractor-FHTET

Finally, we would like to thank Lowell Lewis for helping us to get this third installment of NDRMR off the ground.

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State partners
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Federal (Other than FHP)
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University and Non-Profits
Betsy Goodrich (Northern Arizona University), Bill Jacobs (Colorado State University), John Riggin (Mississippi State University), Jim Walia (North Dakota State University), Nick Dudley and Taylor Jones (Hawaii Agriculture Research Center)

FHTET
Nathan Edberg, Contractor, Cherokee Nations Technologies

Jennie Paschke, Contractor, Cherokee Nations Technologies

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