Mapping Risk from Forest Insects and Diseases

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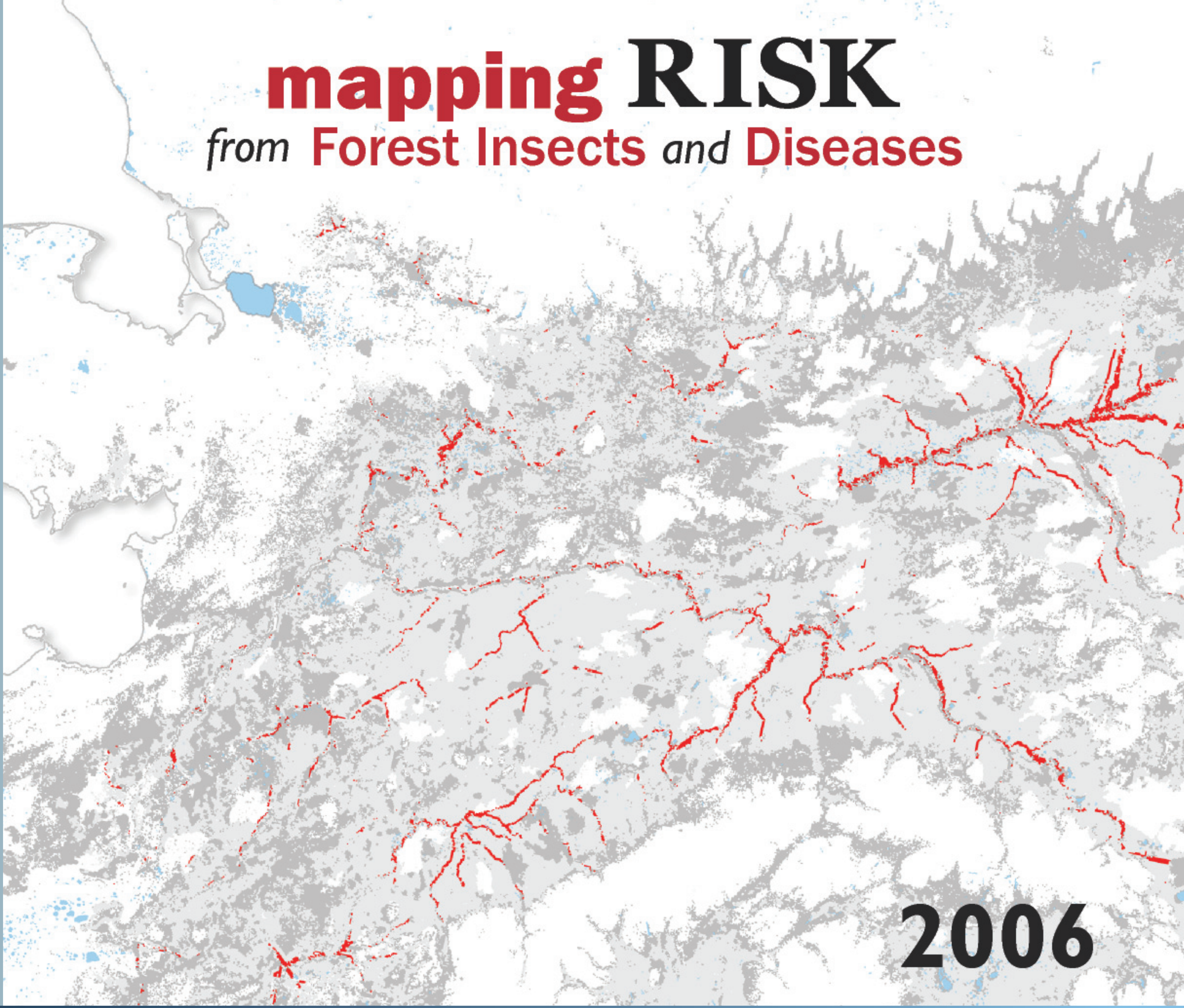
mapping RISK
from Forest Insects and Diseases



2006

Cover image shows expected insect and disease mortality in Central Alaska.

Photographs used in this publication can be accessed online through www.forestryimages.org.

Mapping Risk from Forest Insects and Diseases

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EXECUTIVE SUMMARY

The primary goal of the 2006 risk assessment is to provide a strategic assessment for risk of tree mortality due to major insects and diseases. For this report, the threshold for mapping risk is: the expectation that, without remediation, 25 percent or more of the standing live basal area[1] (BA) on trees greater than 1 inch in diameter will die over the next 15 years due to insects and diseases.

There are approximately 749 million acres of forested land[2] in the contiguous United States and Alaska (Smith and Darr 2005). The 2006 risk assessment estimates that 58 million acres of this total are at risk from insects and diseases. Most of this risk can be attributed to 42 risk agents, including 13 non-native (exotic) forest pest species already established in the contiguous U.S. and Alaska.

The 2006 National Insect and Disease Risk Map (NIDRM) displays the projected risk of mortality at a national scale. NIDRM is constructed at a 1-kilometer spatial resolution and may be updated as new data and/or models become available. This "live" or near-realtime approach will greatly facilitate the production of new risk maps, which are currently expected every five years.

But NIDRM is more than a map: it is an integration of 188 individual risk models constructed within a common framework that is adaptable to regional variations in current and future forest health. The 2006 risk assessement provides a consistent, repeatable, transparent process, through which interactive spatial and temporal risk assessments can be conducted at various scales to aid in the allocation of resources for forest health management. This modeling process is intended to enhance the utility of forest health risk maps and encourage future development of risk maps at resolutions finer than 1 kilometer.

The 2006 risk assessment has been a highly collaborative process coordinated by the Forest Health Monitoring Program (FHM) of the USDA Forest Service. Staff from FHM Regions, states, USDA Forest Service Forest Health Protection (FHP), USDA Forest Service Research and Development (R&D), and universities were invited to take part in the process of creating NIDRM. Forest Service R&D was instrumental in the development of the forest parameter (BA, diameter, age, etc.) data that drive individual models contributing to the NIDRM composite.

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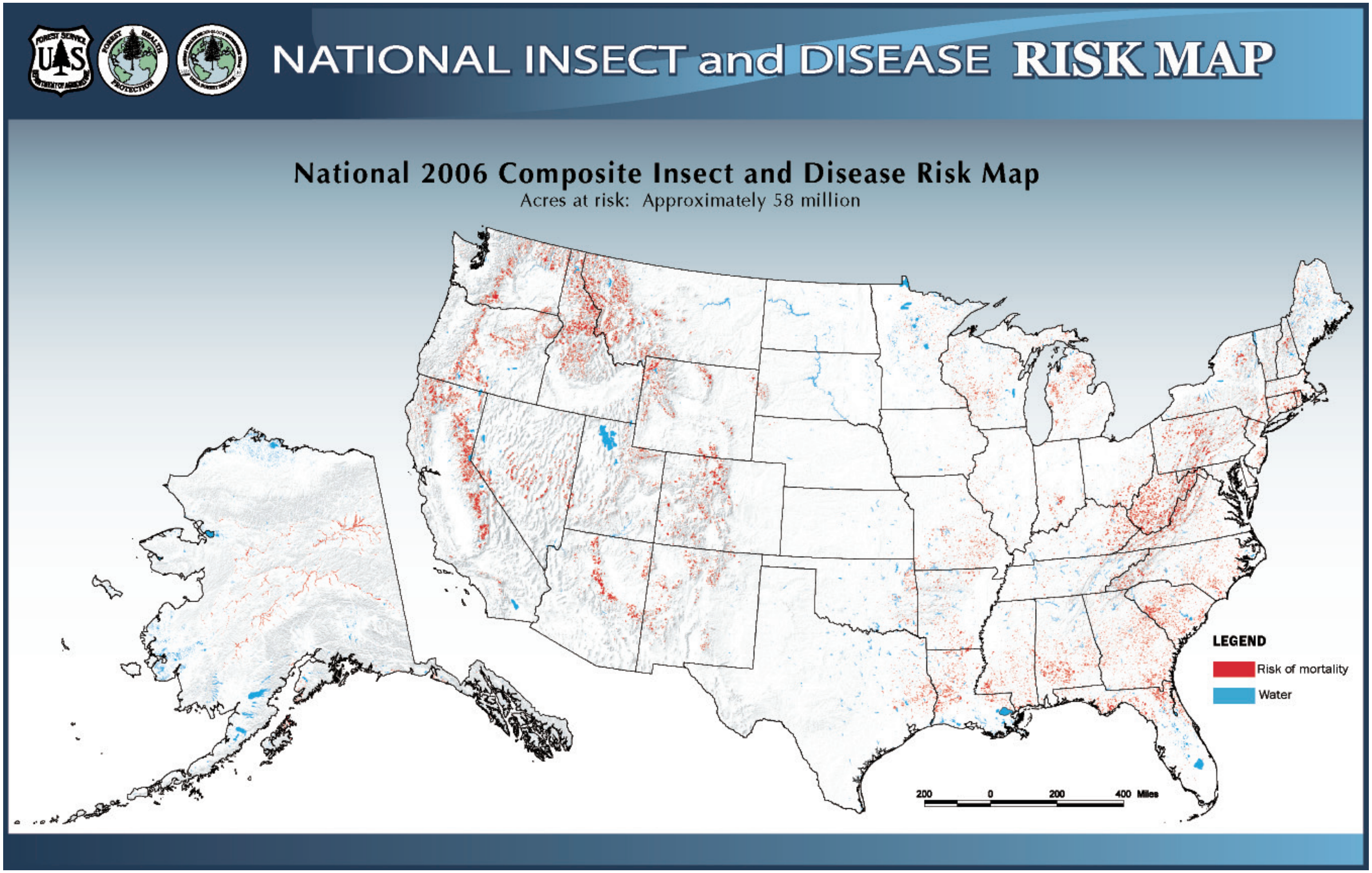
[1] Sum of cross-sectional areas of tree stems measured at 4.5 feet above ground, expressed per land unit area (square feet per acre for this project).

[2] Forest is defined as land that is at least 10 percent stocked by trees of any size.



NATIONAL INSECT and DISEASE RISK MAP

National 2006 Composite Insect and Disease Risk Map

Acres at risk: Approximately 58 million

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INTRODUCTION

Ensuring the health of America's forests requires the understanding and management of complex and interrelated natural resources. Increasing use of our nation's forests, continual threats from native and exotic insects and diseases (USDA 2005), and increasingly complex management policies make natural resource management very challenging.

To meet that challenge, resource managers and policy makers require information beyond tabular summaries to assess where and how forest resources are being impacted. This is creating an increasing need for spatially based decision-support systems that can quickly summarize a wide range of tabular and geographic information, providing resource managers with clear, informed choices and, thereby, the ability to allocate human and financial resources more efficiently.

Increasingly, integrated and comprehensive approaches that use technologies such as Geographic Information Systems (GIS), with their ability to concurrently analyze a large number of spatial variables, are being utilized for the modern-day protection and management of our nation's forest resources (Ciesla 2000).

TEAM APPROACH

The creation of the National Insect and Disease Risk Map (NIDRM) was a collaborative process coordinated by the Forest Health Monitoring (FHM) Program of the USDA Forest Service. Staff from FHM Regions, states, USDA Forest Service Forest Health Protection (FHP), USDA Forest Service Research and Development (R&D), and universities were invited to take part in the process of creating NIDRM.

A Risk Map Oversight Team (RMOT)[3] was formed to define products, provide general guidance, and schedule project development activities. A Regional Risk Mapping Team (RRMT)[4] was created with forest health and GIS participants from the Forest Service, state agencies, and academia to oversee and assist in multi-criteria[5] GIS model development and to revise draft products.

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[3] See Appendix A: Risk Map Oversight Team (RMOT)
[4] See Appendix A: Regional Risk Mapping Team (RRMT)
[5] See Glossary

Beginning in 2004, forest health experts met to develop descriptive models using group consensus and published information. In July 2004, the Risk Map Integration Team (RMIT)[6] was formed to coordinate development of a nationally consistent database for risk mapping.

In April 2005, forest health and GIS experts participated in regional workshops to run models, display results, and make adjustments. The process culminated with a collective review of results by RRMT members and FHM partners during the annual FHM Working Group meetings.

The National Forest Health Monitoring Research Team (USDA Forest Service Southern Research Station) was instrumental in the development of the forest parameter data that drive individual models in the NIDRM composite. Data surfaces were prepared by the USDA Forest Service Forest Health Technology Enterprise Team (FHTET) for access by Forest Service Regional and state cooperator staffs. Model deficiencies and applicability were discussed and plans were drawn up to develop models which would run within areas where optimal data are limited or no such published models existed.

MULTI-CRITERIA MODELING

With recent developments in the field of decision science, including its incorporation into GIS, and the introduction of the multi-criteria modeling environment (Eastman et al. 1995, Eastman 2001), GIS can now be used in a decision-support system. Using the multi-criteria tools available within GIS, the RMIT developed a framework in which periodic risk assessments of insect- and pathogen-caused tree mortality could be conducted and reviewed locally and nationally in an interactive way.

This report briefly describes the framework developed by the RMIT, how the process provides for continuous quality improvement, the results derived from the risk assessment that resulted in the 2006 National Insect and Disease Risk Map, and potential developments in future assessments.

This project is the second in a series that use GIS to identify the potential impact of both endemic and non-endemic forest pests in the contiguous United States and Alaska. While the earlier peer-reviewed effort, “Mapping Risk from Insect and Disease” (Lewis 2002), was truly a pioneering endeavor, the process described below bears little resemblance to its parent effort. Host distribution data and GIS methods, which include the introduction of an interactive multi-criteria risk assessment framework, are significantly different in this “next generation” product (Krist et al. 2007).

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[6] See Appendix A: Risk Map Integration Team (RMIT)

PRINCIPAL OBJECTIVES AND PROJECT REQUIREMENTS

The purpose of the 2006 risk assessment is to provide a five-year strategic appraisal of the risk of tree mortality due to major insects and diseases. The project also produced a framework to guide generation of national insect and disease risk maps that can be updated and compared across regions (Krist et al. 2007). In addition, the 2006 assessment functions as an interactive communication tool to provide for strategic planning at the national, ecoregional, and state levels by providing information on the following:

- Forest insects and diseases currently of major concern.
- Conditions under which forested areas are at risk from agents of concern.
- Conditions that contribute to multiple forest pest (risk agent) problems.
- Location of the conditions and risk agents of concern.

Using comments gathered during and just after the completion of the 2002 risk assessment (Lewis 2002), the RMOT identified the following requirements:

- Involve partners in the development of a nationally consistent risk modeling approach.
- Involve partners in the selection of the most important disturbance agents and the host species on which they act.
- Update forest attribute data, using spatially explicit data where feasible.
- Update specific forest pest models using best available information.
- Develop a modeling framework that can accommodate future enhancements in the spatial precision of NIDRM.
- Construct a risk modeling framework such that the resulting products may be easily linked with other risk mapping efforts (*e.g.*, threat of wildland fire).
- Where possible, maintain species-level information about disturbance agents and their hosts.

Prior to constructing a nationally consistent risk modeling framework, the RMIT identified five objectives that such a framework should address or accommodate:

1. *Integrative process.* NIDRM must be more than just a map; it should represent the collection and integration of multiple risk models developed through an iterative, hands-on process by local, state, and federal forest-health specialists.

2. *Transparency and repeatability.* The modeling framework must provide a consistent, repeatable, transparent process. Within this framework, forest-health specialists should be able to identify sources of data, examine how models for each region operate, and assess why an area is at risk, and so be able to provide feedback for models feeding NIDRM. This type of framework also can assist in identifying shortcomings in data and models, which in turn can be used to prioritize future research and data development.
3. *Interactivity and scalability.* The framework must be sufficiently interactive to support sensitivity analysis while allowing risk assessments to be conducted at various spatial and temporal scales to accommodate current and future work. Sensitivity analysis ensures that models can be adjusted according to local knowledge and/or as additional data and models become available. Scalability enables subject area experts to use a single framework to conduct both local and regional assessments, ensuring that national products are consistent with local knowledge. Although NIDRM was constructed using a national scale, the RMIT wanted to ensure that future products (possibly at a finer scale) could be developed within the same framework. This structure should incorporate the means for developing a set of strategic information usable at the national and state levels.
4. *Efficacy.* When developing a framework, the need for efficiency, precision, and utility must all be considered. A national risk map product, potentially with hundreds of models behind it, requires a highly efficient modeling process, but also must be able to capture the information and variation within each individual model. With a wide range of audiences, including both subject area experts and private citizens, the risk-map framework should produce easily interpreted results and detailed documentation.
5. *Comparability across geographic regions.* To ensure that regional comparisons can be made, the risk modeling framework must be constructed around a standard modeling process and data that provide a "level playing field" for every region being examined. Without standardization, NIDRM would be little more than a federation of maps with little or no consistency among them, making regional comparisons impossible.

It is within the context of these requirements that the RMIT began to examine the published literature for a holistic approach that could support a national risk assessment.

MORTALITY AND RISK

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

For the 2006 risk assessment and the construction of NIDRM, "normal" mortality was defined as "the average annual net volume of timber dying over a given time due to natural causes such as insects, disease, fire, and windthrow" (Smith et al. 2001:34). Since 1952, and measured in 10-15 year increments thereafter, normal tree mortality has hovered in the range of 0.56 - 0.76 percent of growing stock per year and is trending gradually upward. This is a nominal average, and local or regional mortality rates can deviate significantly from this level. Therefore, an early objective of the 2006 risk assessment was to identify areas at risk of realizing insect- and pathogen-caused tree mortality rates well above the normal average of about 0.75 percent annually over 15 years.

During the literature review, the RMIT 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, CENR 1999, EPA 1998). Rather than trying to reconcile the various definitions of risk and hazard, we use a *mortality-potential* construct.

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). Assigning the probability of insect and disease activity to specific locations requires data that is frequently lacking. Therefore, a probabilistic assessment was not undertaken for the 2006 risk mapping project, and we define *risk* as the *potential* for harm due to exposure from an agent(s) (For a full description of the process implemented, see the subsequent Methods section concerning the five-step process). We also accept Mott's (1963) distinction between susceptibility and vulnerability, but as *potentials* rather than *probabilities.*

Measured as stand basal area[7] (BA) (Avery and Burkhart 2002), our threshold value for mapping risk of mortality is defined as the expectation that, without remediation, 25 percent or more of standing live BA greater than 1 inch in diameter will die over the next 15 years (between years 2005 and 2020) due to insects and diseases. This

[7] See Glossary

threshold does not include mortality resulting from natural causes other than insects and diseases (*e.g.*, wildland fire), although they should be included in the future.

As in the 2002 risk assessment (Lewis 2002), a mortality level of 25 percent was deemed to represent "an uncommon, rather extraordinarily high amount of mortality." The 15-year period for risk assessment is consistent with the 2002 risk assessment 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).

Note: throughout this paper, *expected mortality* is reported in either of two units of measure:

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

The first measure allows us to compare and rank risk agents according to the BA loss for each, while the second allows us to aggregate the acres that meet the 25-percent-mortality threshold.

METHODS

Overview of a Standard GIS-Based Multi-Criteria Framework: A Five-Step Process

Utilizing the conceptual risk assessment process outlined in Figure 1 and discussed in detail by Krist et al. (2007), a five-step, GIS-based, multi-criteria process was designed that would produce a standard national depiction of risk at a 1-kilometer pixel or grid cell resolution.

Step 1. Identify a list of forest pests (risk agents) and their target host species.

This is conducted at the regional level with certain models constrained to select geographic areas. For this project, risk agents causing *significant* tree mortality, measurable at the regional level on an annual basis, are identified.

Although forest-health specialists focus on major pests, some of the selected agents do not result in mortality levels that exceed the 25-percent-mortality threshold set by the RMOT. In these instances, areas could still reach the 25-percent threshold if other agents were to be present in the same tree species and the additive BA loss exceeds 25 percent.

Forty-two risk agents[8] acting on 57 tree species and groups of species (such as white and red oaks) were selected for the 2006 national risk assessment.

Step 2. Identify, rank, and weight criteria (GIS layers acting as factors and constraints) that determine susceptibility and vulnerability to each risk agent.

In most cases, susceptibility to a risk agent approximates vulnerability, and only a single model is required in the risk assessment of that pest (Figure 1). This is true for pests such as white pine blister rust in the West, which will cause mortality regardless of tree vigor and thus requires only a susceptibility model. This is also true, and much more commonly so, for the endemic mountain pine beetle, for which tree mortality may vary depending on tree vigor and outbreak conditions, thus requiring only a vulnerability model. For other exotic agents, such as gypsy moth, both susceptibility and vulnerability models are required.

Procedures have been developed to aid in the collection, ranking, and weighting of these criteria; they are fully detailed in risk model worksheets[9].

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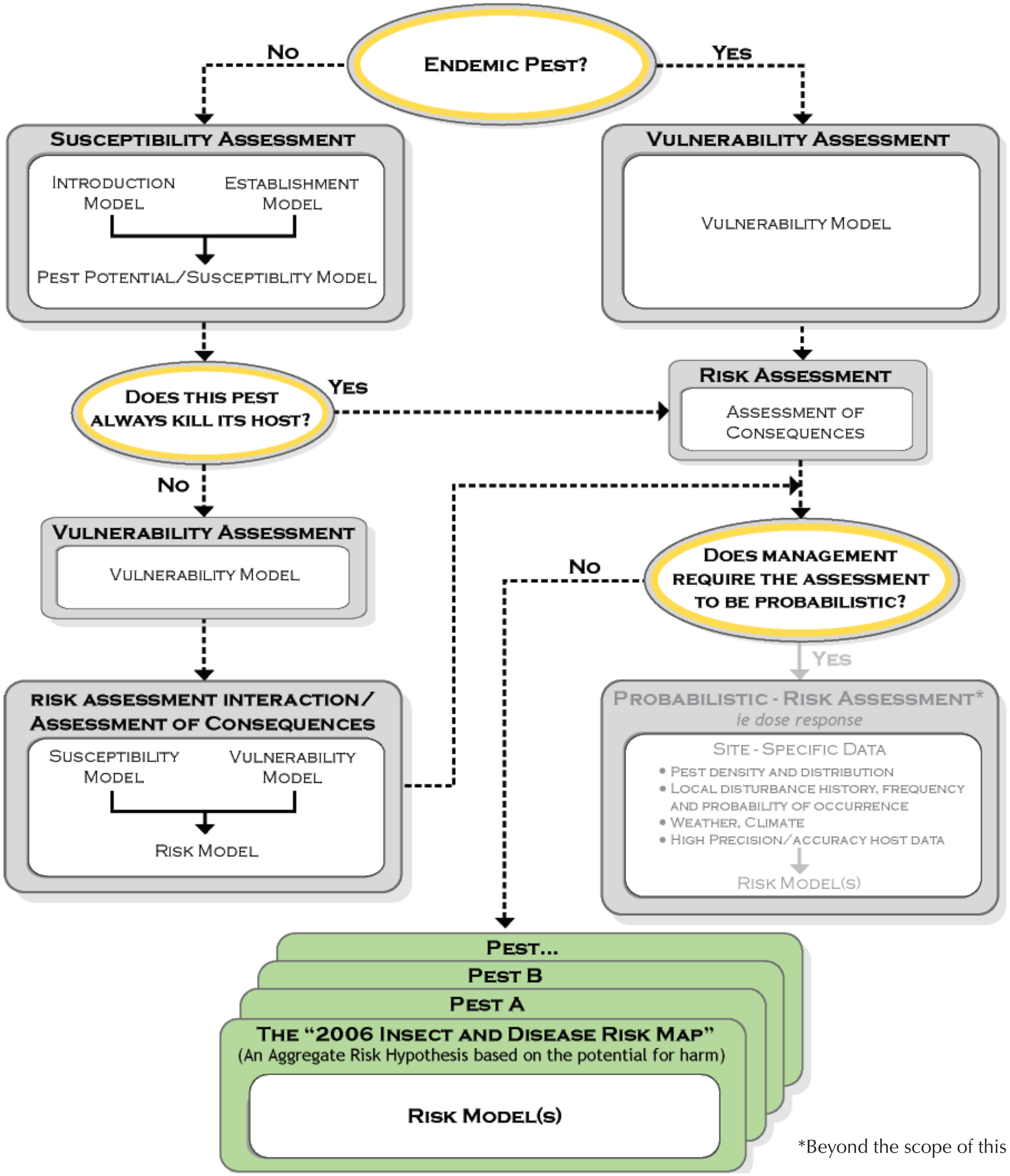
[8] See Appendix B: Risk Agent and Host Species List

[9] See Appendix C: Susceptibility and Vulnerability Contributions to Mortality Models

FIGURE 1

Conceptual Risk Assessment Process



*Beyond the scope of this analysis.

Step 3. Re-scale risk agent criteria values on each GIS layer from 0 to 10, and combine the resultant maps in a model of risk potential using a series of weighted overlays.

Standardization allows for the comparison of criteria with different scales, such as basal area (BA) (with units of square feet per acre) to temperature limitations (with ranges measured in degrees Fahrenheit). The RMIT chose a standard scale ranging from 0 to 10. Within this scale, a criterion value of 0 represents little or no potential for either susceptibility or vulnerability while a value of 10 exhibits the highest potential.

Using this scale (0 to 10), specialists assign a level of potential to values within GIS layers that represent criteria. Once the values on each GIS layer have been normalized, layers are combined by multiplying the factor weight by each criterion value followed by a summation of the adjusted layers (Saaty 1977).

Steps 2 and 3 often call for a highly iterative process involving interactions between GIS and forest-health specialists. Typically, relative weights are assigned and beginning and ending points for potential are determined after viewing intermediate map products for susceptibility and vulnerability. This is particularly true when little quantitative information exists about risk agent behavior, as is often the case.

Step 4. Convert modeled values representing potential risk of mortality for each agent to a predicted BA loss over a 15-year period.

This is accomplished for each risk agent/forest host species pair included in the national risk assessment. A *typical* maximum realizable mortality rate (mortality ceiling), assigned to each risk agent, is used to convert values of potential risk to BA loss.

The mortality ceiling is an estimation of mortality loss, expressed as a percent of host BA loss, for the next 15 years if all criteria are met in Step 2. The actual mortality ceiling varies depending upon the level of risk. For example, if the expected mortality rate is 100 percent of a tree species' basal area, then the highest-risk pixels would receive a mortality ceiling of 100 percent (standardized value of 10) while pixels with medium risk (standardized value of 5) would correspond to a mortality ceiling of 50 percent.

Predicted BA loss is calculated by multiplying the basal area of each individual host species by its corresponding mortality ceiling.

Step 5. Compile the resultant values from Step 4 and identify areas (1-kilometer pixels) on a national base map that are at risk of encountering a 25-percent or greater loss of total basal area in the next 15 years.

By accumulating BA losses for all host species (Step 4) and dividing by the total BA at each pixel, one may derive the percentage of BA loss.

Note: NIDRM maintains the entire range of predicted BA loss percentages—0 to 100 percent—so a mortality threshold other than 25 percent can be established by resource managers or policy makers (Dunn 2007).

Most of these five steps (described in greater detail in Krist et al. 2007) requires participation from both GIS and forest-health specialists. Step 1 requires the involvement of forest-health specialists, while Steps 2 and 3 involve coordination among both forest health and GIS specialists. Steps 4 and 5 primarily involve GIS specialists, with periodic feedback from forest-health specialists until the final models and maps are produced.

DATA DEVELOPMENT, DATASETS, AND DATA PROCESSING

Once risk agents, host species, and model criteria were identified, the RMIT was able to identify and prioritize GIS data needs. Fortunately, the data requirements are similar for many of the risk agent models, with forest parameters, soil wetness, and climate variables being the most commonly required data. This section discusses the importance of standardized datasets for a large national effort and describes most of the major data sets the RMIT assembled for the 2006 risk assessment.

In order to ensure consistency among all regions within NIDRM, the RMIT and RMOT selected a standard set of GIS data for the contiguous United States and Alaska. The use of standard input data minimizes mapping artifacts that may occur along administrative boundaries when using local and regional datasets and, more importantly, enables comparisons to be made across regions.

Model processing for the 2006 risk assessment was standardized. Models were individually constructed within Model Builder™ for ArcView® 3.x Spatial Analyst and run by regional GIS specialists on a central server located at the FHTET office in Fort Collins, Colorado. Each model draws upon standard data layers also located in the server environment, allowing models to be updated at any time by accessing Model Builder™.

The FHTET server provides a locally accessible interactive modeling environment that contains GIS data layers separate from the models. A server-based processing environment allows analysis and enhances understanding of risk models independent of their input GIS data layers. This also promotes continuous improvement of risk maps by allowing substitution of improved data surfaces as they become available and the update of individual models as they are improved at any time during the project.

Datasets: Forest Parameters

The identification of areas at risk to a particular risk agent first requires the acquisition of host species distributions. Forest-*type*[10] maps are readily available for the United States. However, despite recent advances in remote sensing, these maps do not contain information specific enough for insect and disease risk assessments. In particular, these data lack species locations and information about forest conditions, such as age and stocking—critical measures for conducting insect and disease risk assessments.

New processes now utilize both remote sensing and GIS analysis in conjunction with statistical modeling techniques such as generalized additive models and stochastic gradient boosting (Moisen and Frescino 2002, Moisen et al. 2006). These processes tease out forest attributes by identifying unique patterns in spectral signatures and in site parameters such as soil type, climate, and topography. For example, red and white pine may be difficult or impossible to distinguish by a spectral signature alone; however, when that signature is combined with a limiting factor, such as a known soil type, individual pine species can often be distinguished more precisely.

Although some of these models are yielding promising results, most are difficult to implement nationally because they require the compilation and normalization of large amounts of data. Numerous forest-type and range maps (Little 1971 and 1977) exist, but they do not contain information about species density or size. As a result, a set of nationwide forest attribute layers by individual tree species is lacking, a situation which prompted the RMIT to develop its own.

Due to the large number of tree species being examined and tight production deadlines, a highly automated process for generating forest attribute maps was required. Estimates for total and individual species' BA—along with quadratic mean diameter[11] (QMD) (Reineke 1933), stand density index[11] (SDI) (Reineke 1933), percent host composition, and predominant canopy position—were developed for all 57 tree species and/or species groups[12] examined in the 2006 risk assessment. Surfaces[11] were calculated for the contiguous United States and Alaska.

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[10] See Glossary

[11] See Glossary

[12] See Appendix B: Risk Agent and Host Species List

After extensively testing several interpolation methodologies (Krist 2005), the RMIT developed a simple interpolation/modeling approach. The technique utilizes a national array of perturbed and swapped[13] (McRoberts et al. 2005) Forest Inventory and Analysis (FIA) data. These plot data are laid out in an array across the United States, with each plot representing roughly 6,000 acres.

National datasets were assembled and used to produce estimates of various forest parameters. Figure 2 depicts the distribution of FIA plot data throughout the contiguous United States and Alaska selected for use in the project by the RMIT. The plot intensity and the date that field data were collected on the plots vary depending on the state (Table 1) or FIA Region, with darker green shades representing higher densities of plots. When selecting plot data, the RMIT attempted to obtain the greatest available plot coverage by balancing plot density against the time frame within which plot data was collected.

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. Despite these efforts, several data gaps remained within national parks, some wilderness areas, urban areas, and in sparsely tree-covered regions. In other areas, such as the Pacific Northwest Region, supplemental plots were available to provide additional coverage.

Table 1

FIA PLOT DATA MEASUREMENT YEARS BY STATE

2000s	
Alaska	2005
Louisiana	2000-2004
Michigan	2000-2003
Nebraska	2001-2004
Pennsylvania	2000-2003
Texas	2001-2003
1990s	
Alabama	1999-2003
Arkansas	1999-2004
Connecticut	1997-1998
Delaware	1999-1999
Florida	1995-1995
Georgia	1997-1997
Indiana	1998-2003
Iowa	1999-2003
Kansas	1992-1994
Kentucky	1999-2003
Maine	1999-2003
Maryland	1999-2000
Massachusetts	1997-1998
Minnesota	1998-2003
Mississippi	1992-1994
Missouri	1998-2003
New Hampshire	1996-1997
New Jersey	1998-1999
New York	1991-1994
North Carolina	1998-2002
North Dakota	1992-1994
Ohio	1990-1992
Oregon	1993-1999
Rhode Island	1998-1998
South Carolina	1998-2002
South Dakota	1994-1999
Tennessee	1997-2004
Vermont	1996-1998
Virginia	1997-2002
West Virginia	1999-2002
Wisconsin	1999-2003
Wyoming	1998-2004
1980s	
Arizona	1984-2001
California	1980-2000
Illinois	1987-1998
Idaho	1981-2004
Montana	1988-2001
New Mexico	1986-2001
Oklahoma	1988-1992
Utah	1988-1996
Washington	1988-1998
1970s	
Colorado	1979-2003
Nevada	1978-1997

FIA plots provide an excellent data source for monitoring tree species that are relatively common, but may not capture the variations of rare species within larger populations. Therefore, tree species such as limber pine, which often constitutes less than 1-2 percent of the land base, is much harder to model. In addition, FIA plots are laid out in an array across the landscape, making some forest patterns more difficult to

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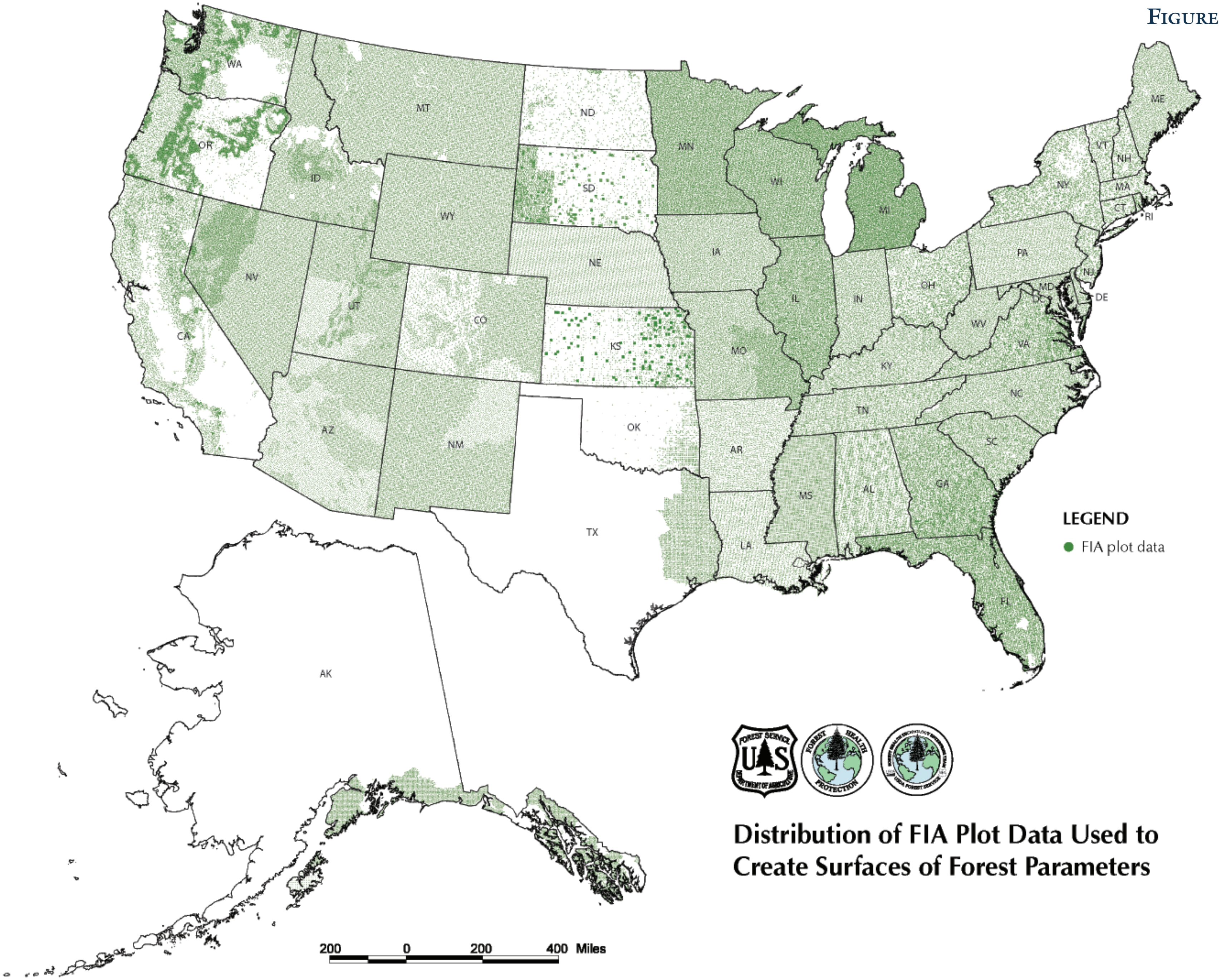
[13] See Glossary

Figure 2



Distribution of FIA Plot Data Used to Create Surfaces of Forest Parameters discern. For example, whitebark pine, which often occupies ridge lines, is difficult to model because its distribution is not well captured by the FIA plot system.

Where FIA plot data were available, surfaces of BA/SDI, QMD, canopy position, percent composition and a forest/non-forest mask were generated using the following steps:

BA/SDI

1. Interpolated individual tree species BA or SDI values from FIA plots at a 1-kilometer resolution using Inverse Distance Weighting (IDW) (Isaaks and Srivastava 1989).

   Total BA was generated from estimates calculated at the FIA plot level and included all tree species, whether they were included in the 2006 risk assessment or not. In order to ensure that values on the total BA surface were not lower than the sum of the individual tree species, the two layers were compared (overlaid), and the larger value selected for total BA.

2. Multiplied the resultant surfaces by a percent evergreen and/or deciduous layer derived from resampled 1992 National Land Cover Data (NLCD) (Vogelmann et al. 2001). Used this higher-resolution (30-meter pixel) dataset to limit the spatial distribution of interpolated results and reduce the values where coniferous or deciduous trees were not as prevalent.

   For example, a pixel interpolated with 50 square feet BA of limber pine that had a 50-percent evergreen cover would be reduced to 25 square feet BA. If the same pixel had zero percent evergreen coverage associated with it, the BA would be set to zero for limber pine.

3. Offset the negative bias (under-representation of high BA values) in the adjusted BA values by multiplying the resultant surfaces by a constant of 1.645.

   This constant was derived after comparing resultant BA surfaces with precise plot locations taken from the Bartlett Experimental Forest in Bartlett, New Hampshire (Krist 2005).

During the production of NIDRM, the RMIT did not have access to exact FIA plot locations and thus was unable to develop a regional constant for reporting areas throughout the United States to better represent regional ecological variation. In the example presented in Step 2, 25 square feet of limber pine BA would be raised to 41 square feet using a constant of 1.645.

QMD

1. Interpolated QMD values by species from FIA plot values using IDW.

   The total QMD or QMD for all species was also interpolated. Surfaced QMD values were not adjusted.

2. Masked the by-species QMD surface according to the distribution of a tree species using the previously derived BA surface (from Step 1) to define that geographic distribution.

Canopy Position

Simulated the predominant canopy position of a tree species associated with each 1-kilometer pixel by dividing the QMD surface for each tree species by the QMD surface representing all tree species assigned to each pixel:

$$\text{canopy position} = \frac{\text{QMD individual species}}{\text{QMD all tree species}}$$

Pixels with values greater than 1 were defined as dominant or overstory; pixel values near 1 were defined as co-dominant; and pixel values less than 1 were defined as understory. This approach assumes that larger-diameter trees tend to be taller, which may not always be the case, particularly in areas with mixed forest types.

Percent Composition

Lastly, calculated percent composition by dividing individual species BA values by the total BA.

All surfaces were automatically calculated using ArcInfo® 9.x Arc Macro Language® (AML). Despite the simplicity of the approach used to generate forest parameter surfaces and the speed at which they can be generated, the results are surprisingly accurate when formally tested (Krist 2005) against the Bartlett Experimental Forest plot data. Although formal accuracy assessments were not conducted throughout the United States, all surfaces were reviewed by local subject area experts to ensure that the layers capture observed regional variations and patterns in BA/SDI, QMD, canopy position, and percent composition.

The results were positive, but the reader must remember that the surfaces of forest attributes are models themselves, and the accuracy (or uncertainty) of these results has not been quantified. Also, it is important to recognize that, with an interactive risk assessment framework, the RMIT will be able to replace current layers depicting forest attributes with better, more complete data layers, such as imputed tree lists with known error bounds, as they become available.

In Alaska, recent FIA plot data are available only in the extreme southern and eastern part of the state. In central, western, and northern Alaska, a 1-kilometer resolution 1991 Advanced Very High Resolution Radiometer (AVHRR) (Zhu and Evans 1994) forest-type map was used to estimate BA. Local experts were asked to assign the maximum stocking values (BA) likely to occur throughout each of the AVHRR forest types containing white spruce and paper birch, the only species simulated in central and northern Alaska. To reduce assigned BA values where stocking levels are likely to be lower, these estimates were assigned to the AVHRR cover type map and were adjusted by multiplying the resultant cover type map by a percent canopy cover layer.

The percent canopy cover layer for Alaska was derived from annual MODIS data from the TERRA Vegetation Continuous Fields (VCF) L3 global 500-meter-resolution Integrated Sinusoidal (ISIN)-projected data (Hansen et al. 2003). This layer incorporates activities, such as fires and bark beetle outbreaks that have occurred in the last five years but are not accounted for in the AVHRR data.

The Forest/non-Forest Mask

With forest parameter layers calculated for Alaska and the contiguous United States, the extent of these layers was restricted to a current forest/non-forest mask. This mask was built from a modified national forest-type geospatial database developed by the FIA Remote Sensing Band (RSB) and the Forest Service Remote Sensing Applications Center (RSAC) in Salt Lake City, Utah (Ruefenacht et al. 2007). The forest-type map was modified to include recent mortality derived from multi-temporal Terra MODIS surface reflectance composites acquired in July 2000 and July 2005 using Tasseled Cap transformation (Crist and Cicone 1984) components compiled for each date.

A change-detection procedure, based on thresholding a difference image of Tasseled Cap wetness between the two dates, was used to derive a mortality dataset. Thresholds established for the change-detection procedure were guided by evaluation of change-detection image statistics, visual review of wetness band indices, and available ancillary data, such as fire perimeters and mortality surveys. These data were filtered and resampled to a spatial resolution of 1-kilometer using an area-weighted criterion and then draped onto the forest-type layer, preventing areas with recent catastrophic mortality from being included in NIDRM (see **Figure 3**).

Again, it is important to note that the forest/non-forest mask, the Tasseled Cap change product, and all other forest parameter data layers are models themselves. These are intermediate products and, as such, have not undergone the peer review process and are of unknown precision and accuracy[14].

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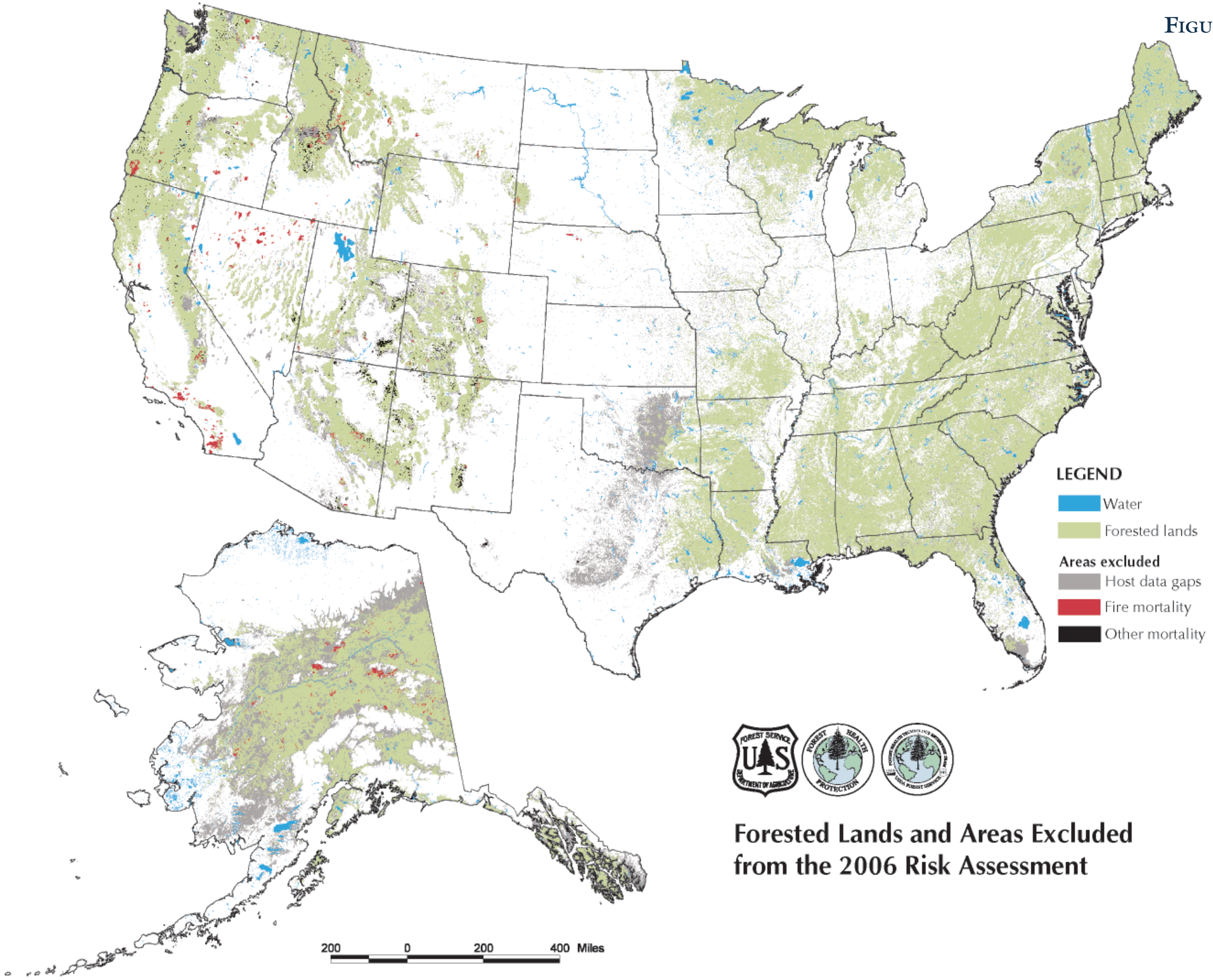
[14] See Glossary

FIGURE 3



Forested Lands and Areas Excluded from the 2006 Risk Assessment

Datasets: Site Parameters

Several other layers, including measures of climate, topography, and soil moisture content, were utilized during the 2006 risk assessment. This section describes some of the more important layers selected by the RMIT.

Climate. The RMIT purchased 35 proprietary GIS layers at a 2-kilometer resolution depicting monthly and annual averages of climate variables, such as temperature, precipitation, and relative humidity. These data were produced as 30-year averages by the Spatial Climate Analysis Service at Oregon State University (SCAS/OSU) and are distributed by ClimateSource® (Daly et al. 2001). The climate data used for the 2006 assessment are based on measurements recorded from either 1961 to 1990 or from 1971 to 2000.

In order to generate interpolated surfaces of climate variables, the SCAS/OSU used a Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM uses input from weather stations, topographic information, and other datasets to create estimates of climatic elements (Daly et al. 2001).

Climate layers produced using PRISM were selected by the RMIT because of their physically realistic detail and ability to capture topographic effects, rain shadows, and lake effects. The climate data produced by the SCAS/OSU is national in extent and has been peer-reviewed (Daly et al. 2001).

Topography. Slope, aspect, and elevation data were derived from the Global 30 Arc-Second Elevation (GTOPO30) data (USGS 2001). GTOPO30 is a global 1-kilometer-resolution digital elevation model (DEM) gridded from contours on the 1:1,000-000-scale Digital Chart of the World (DCW). The data are gridded using the ANUDEM program developed by the Australian National University (Hutchinson 1989). ANUDEM produces a hydrologically correct DEM that more accurately captures the shape of most landscapes by incorporating lakes and streams into the gridding process.

The RMIT selected GTOPO30 because of its native, 1-kilometer resolution and its ability to reasonably capture the shape of various types of terrain at a coarse scale. Slope and aspect were calculated from GTOPO30 in ArcInfo® GRID using the SLOPE and ASPECT functions.

Soil Drainage Index (DI). Patterns related to soil moisture content, including both excess and scarcity, are often a primary factor related to tree stress and the subsequent effects of insects and diseases (Elliot and Swank 1994, He and Richard 2000). Current measures available from the Natural Resources Conservation Service (NRCS) soils data, such as available water holding capacity (AWC), do not adequately describe natural soil wetness. This is because measures such as AWC reflect only the ability of a soil series to retain and release water to plants, not the long-term mean amount of water that is in the soil. In order to address this data gap, a soil drainage index (DI) layer was developed for use in the 2006 risk assessment.

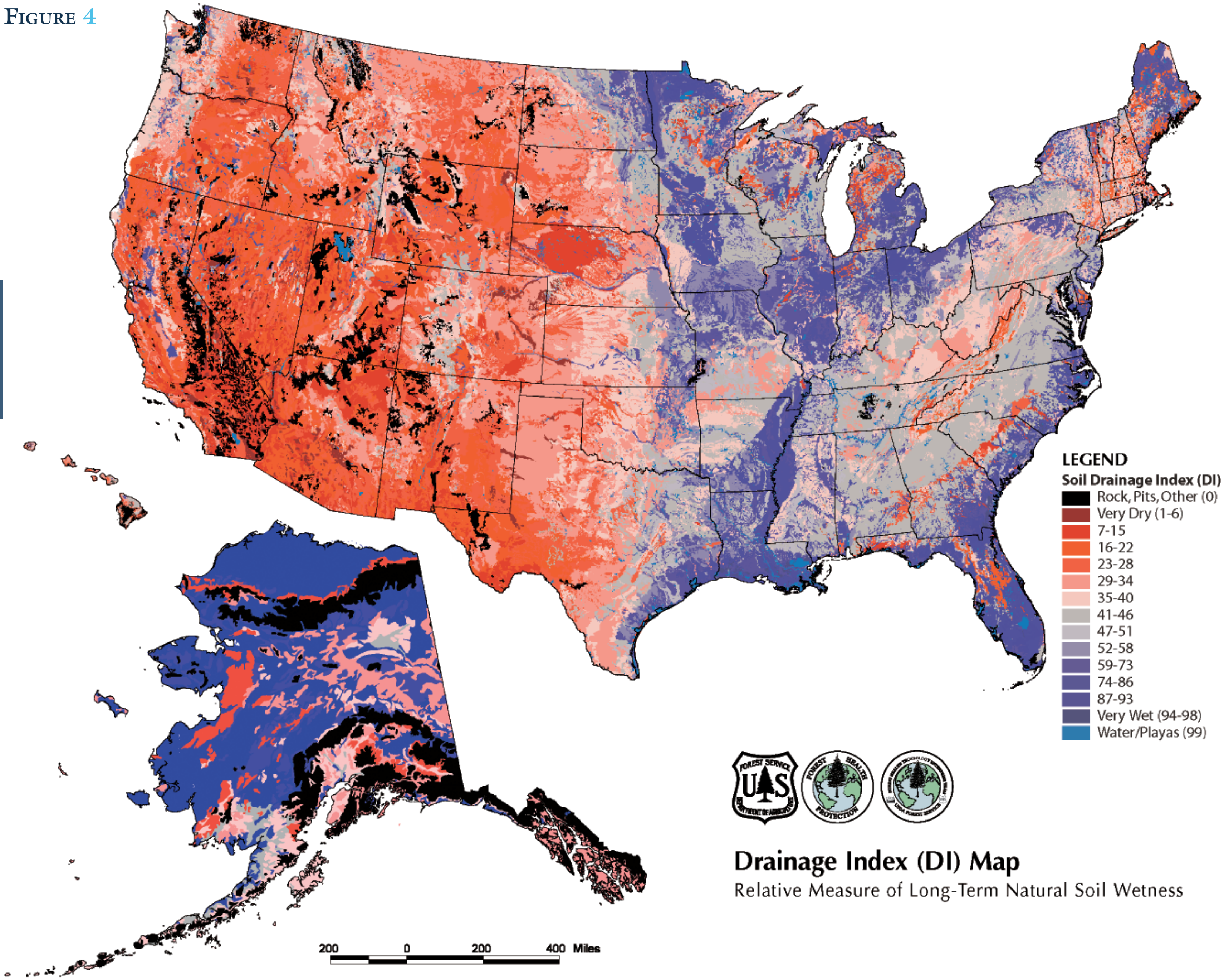
The DI concept was first initiated by Hole (1978) and Hole and Campbell (1985), expanded upon by Schaetzl (1986), and more recently refined by Schaetzl et al. (2007). Originally named the "natural soil wetness index" (Schaetzl 1986), DI indicates the relative amount of water (wetness) that a soil contains, long-term, and makes available to plants under normal climatic conditions. It is not meant to mimic the concept of "plant available water," which is largely dependent on soil texture. The DI only secondarily takes soil texture into consideration.

The main factors affecting DI are the depth to the water table, soil moisture regime, volume available for rooting, and texture. Therefore, the DI is calculated primarily from the soil's taxonomic subgroup classification in the U.S. system of soil taxonomy.

Drainage index values range from 0 to 99. The higher the DI, the more water a soil can supply to plants. Sites with a DI of 99 are almost constantly waterlogged, while a soil with a DI value of zero is thin and dry enough to almost be bare rock or raw sand. Because a soil's taxonomic classification is not (initially) affected by such factors as irrigation or artificial drainage, the DI does not change as soils become irrigated or drained unless the long-term effects of this involve a change in the soil's taxonomic classification. Instead, the DI reflects the soil's "natural" wetness condition. In theory, each soil series has its own unique DI.

Some soil series span two or more drainage classes and thus may have more than one DI. A national map (Figure 4) was generated by assigning a DI value to the dominant soil component for each of the polygons in the State Soil Geographic Database (STATSGO) (USDA 1994). The RMIT utilized the DI layer in the construction of several risk agent models comprising the NIDRM composite.

Figure 4


LEGEND
Soil Drainage Index (DI)
Rock, Pits, Other (0)
Very Dry (1-6)
7-15
16-22
23-28
29-34
35-40
41-46
47-51
52-58
59-73
74-86
87-93
Very Wet (94-98)
Water/Playas (99)
Drainage Index (DI) Map
Relative Measure of Long-Term Natural Soil Wetness
200
0
200
400 Miles

RESULTS/DISCUSSION

Recommended Guidelines for Appropriate Uses of the Data

In order to promote the appropriate use of information derived from the 2006 risk assessment and NIDRM in particular, the RMIT formulated two basic guidelines based on visual inspection of the data and past experience (Lewis 2002):

- Maximum Display Scale. Most of the base data layers used in NIDRM were imported directly, or built in part, from USGS 1:2,000,000-scale Digital Line Graph (DLG) layers (U.S. Geological Survey 1990b). The DLG layers include state and county boundaries, Forest Service boundaries, congressional districts, and federal land ownership. The 1:2,000,000-scale layers work well (i.e., are not too detailed for use) with model outputs at a 1-kilometer resolution.

  To highlight broad areas at risk and avoid maps that appear pixilated, the RMIT recommends that NIDRM and any of its derivative products be displayed at a maximum scale ranging from 1:2,000,000 to 1:4,000,000.

  Note: From a practical perspective, 1:4,000,000 is the largest scale at which either Forest Service Region 6—Oregon and Washington—or the New England states can be plotted on individual 8.5 x 11 sheets.

- Minimum Analysis Unit. Having a 1-kilometer resolution, NIDRM is primarily a national planning tool designed to describe broad regional and national trends. Inquiries regarding units smaller than multi-state regions should be posed to regional experts who may have conducted finer-resolution risk assessments and are familiar with local variation.

Acres at Risk on the 2006 National Insect and Disease Risk Map

The 2006 national risk assessment employed 188 risk-agent models representing 42 agents acting on 57 tree species or species groups[15]. It is common for multiple pests to act on any given location (**Figure 5**). Results from all models were assembled into a national composite map (NIDRM) depicting about 58 million acres at risk (**Figure 6**). Several risk agents were represented

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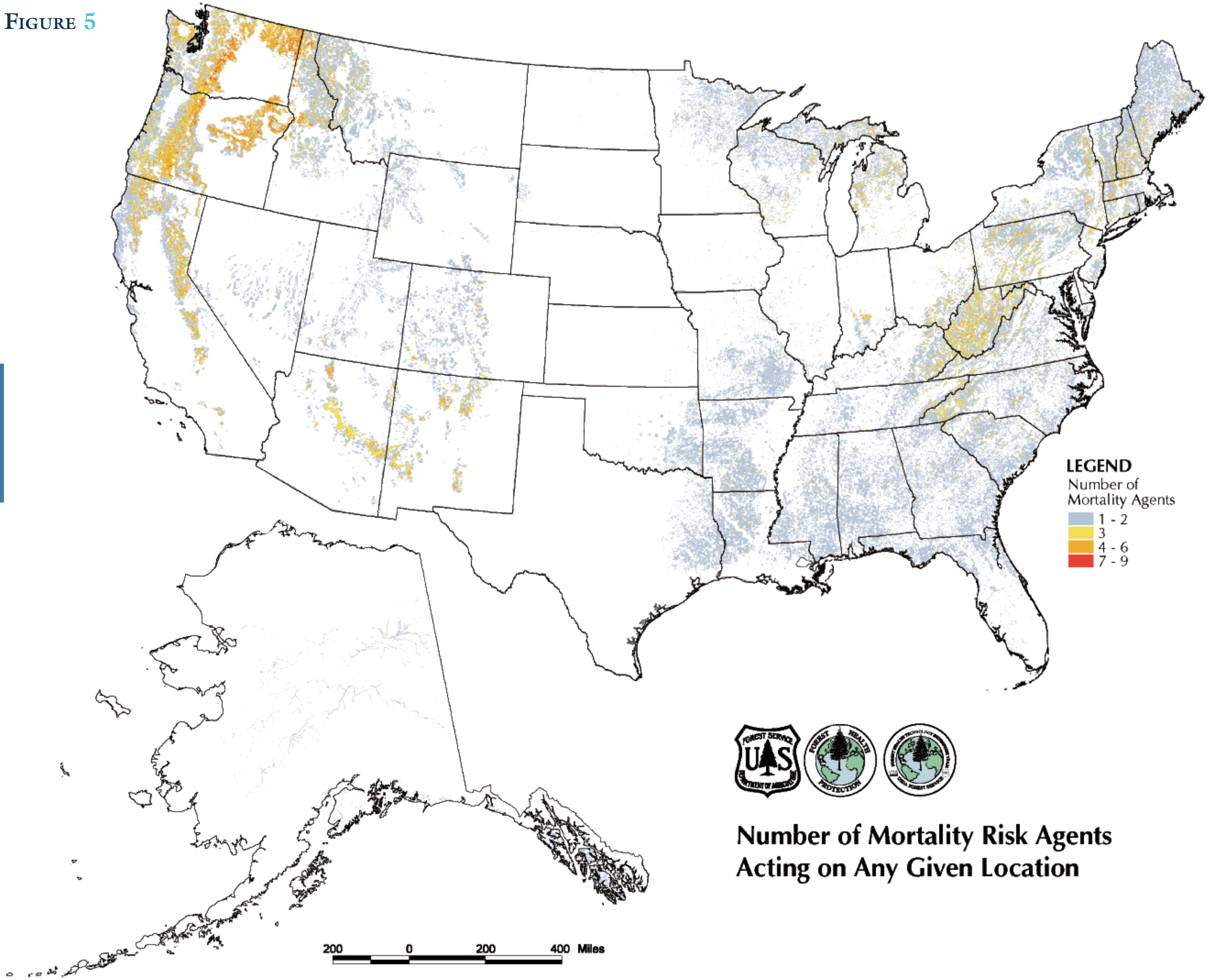
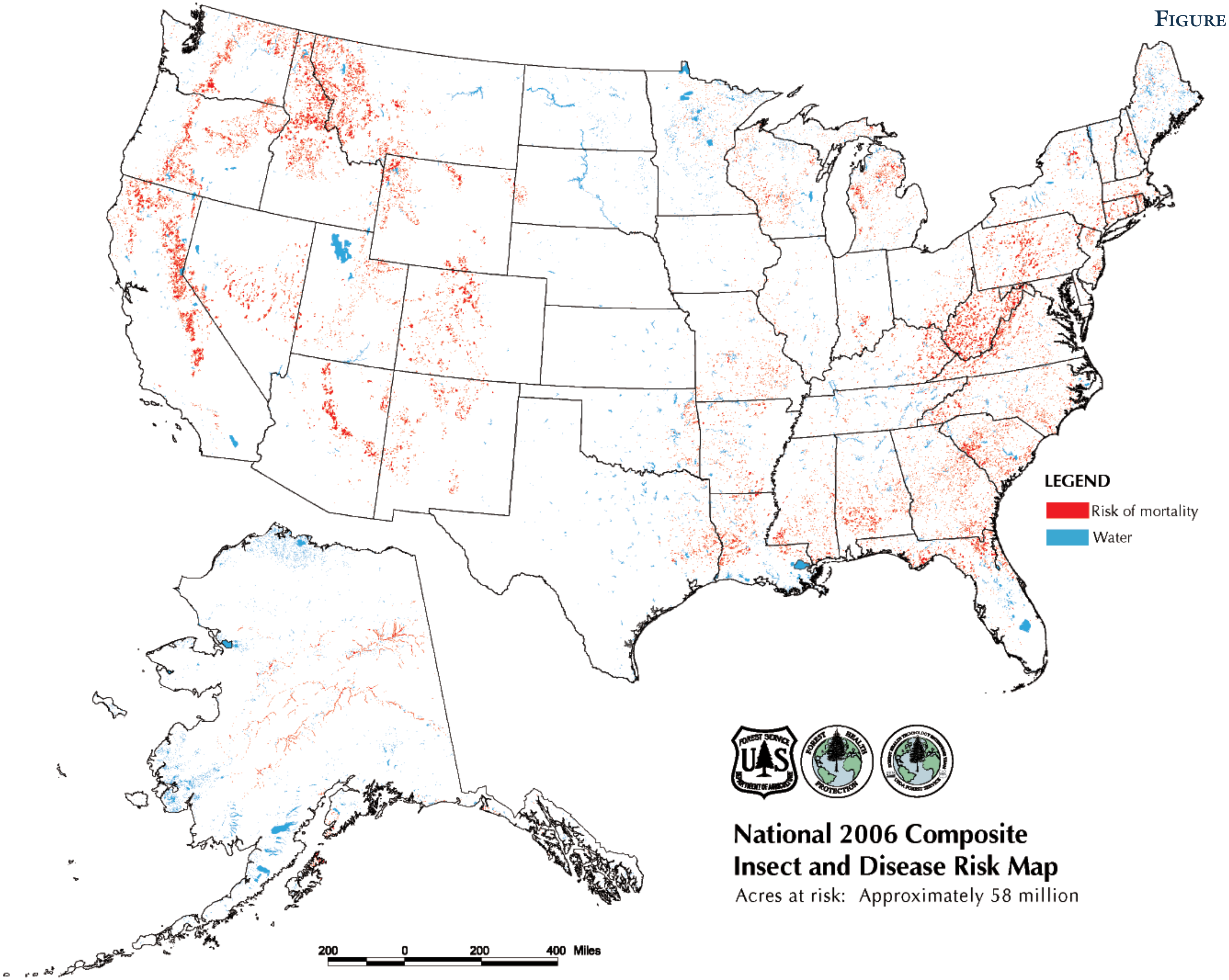
[15] See Appendix B: Risk Agent and Host Species List

Figure 5



Number of Mortality Risk Agents Acting on Any Given Location

FIGURE 6


LEGEND
🟥 Risk of mortality
🟦 Water
National 2006 Composite
Insect and Disease Risk Map
Acres at risk: Approximately 58 million
200
0
200
400 Miles

by more than one model within the NIDRM composite because the mortality ceiling and/or the model for a particular risk agent varied depending on the ecoregion(s) for which the model was constructed. **Figure 7** shows the variety of ponderosa pine models built for the Interior West Region (Ryerson 2006).

Areas depicted as "host data gaps" (**Figure 3**) on the national composite map represent areas where forest attributes could not be mapped due to a lack of FIA plot data. We will fill these data gaps as additional FIA plot data are collected and/or host attributes are mapped using statistical modeling techniques.

One of the major advantages of the framework used during the 2006 risk assessment is that it allows the production of maps with continuous values rather than simply discrete categories of risk (at or above 25 percent) and no risk (below 25 percent). **Figure 8** depicts percent of potential BA loss broken into three classes. With values that range from 0 to 100 percent potential mortality, categories can be broken out in different ways depending on goals. For example, areas with the highest potential for risk may not be treatable, while areas at or near 25 percent may be the best candidates for management.

Note: there are several regions, including the Pacific Northwest, West Virginia, parts of Louisiana and Arkansas, and Kodiak Island, Alaska, that contain significant areas just below the 25-percent threshold. These areas are similar enough to those at or above the 25-percent threshold that they may also be of interest.

In Alaska, NIDRM depicts approximately 2.8 million acres at or above the 25-percent-mortality threshold, while approximately 55.2 million acres are at or above 25 percent in the contiguous United States.

The combined total of approximately 58 million acres represents about 7.7 percent of the 748.7 million acres of forested lands within the contiguous United States and Alaska. Forty-seven percent of the combined risk is distributed across state, private, and other ownerships (**Figure 9**), while 53 percent is located on National Forest System, tribal, and other federal lands.

When summarizing risk by Forest Service Region, excluding Alaska, the eastern (Regions 8 and 9) and western (Regions 1 - 6) regions have less than a one million-acre difference in total areas at risk of mortality (**Figure 10**). However, all six western regions have a higher percentage of forested lands at risk than either of the two eastern regions. **Table 2** lists, by Forest Service Region, which risk agents may result in mortality over the next 15 years.

From a different perspective on risk aggregation, **Figure 11** shows U.S. watersheds with percentages of forested land at risk.

Figure 7

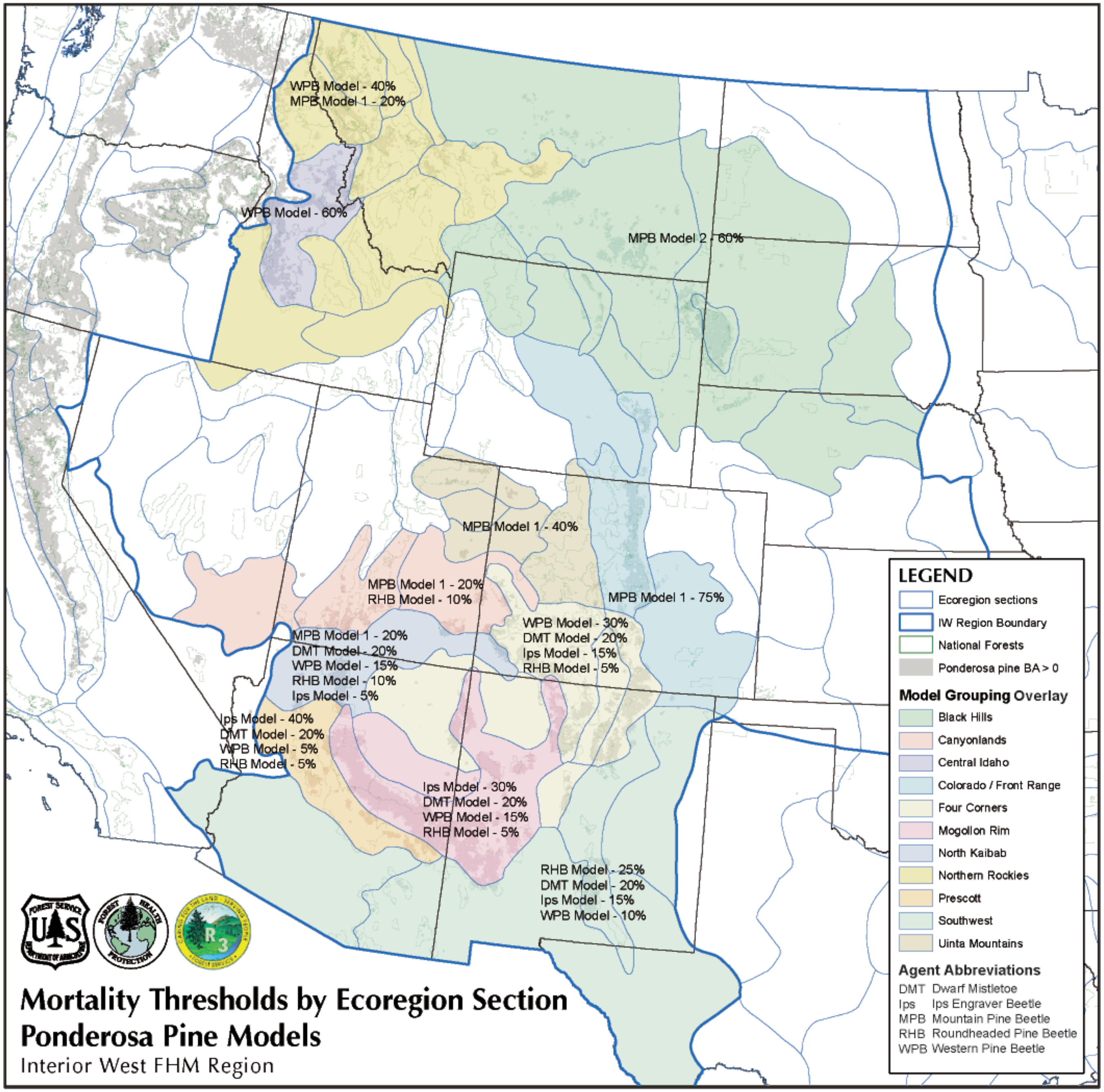
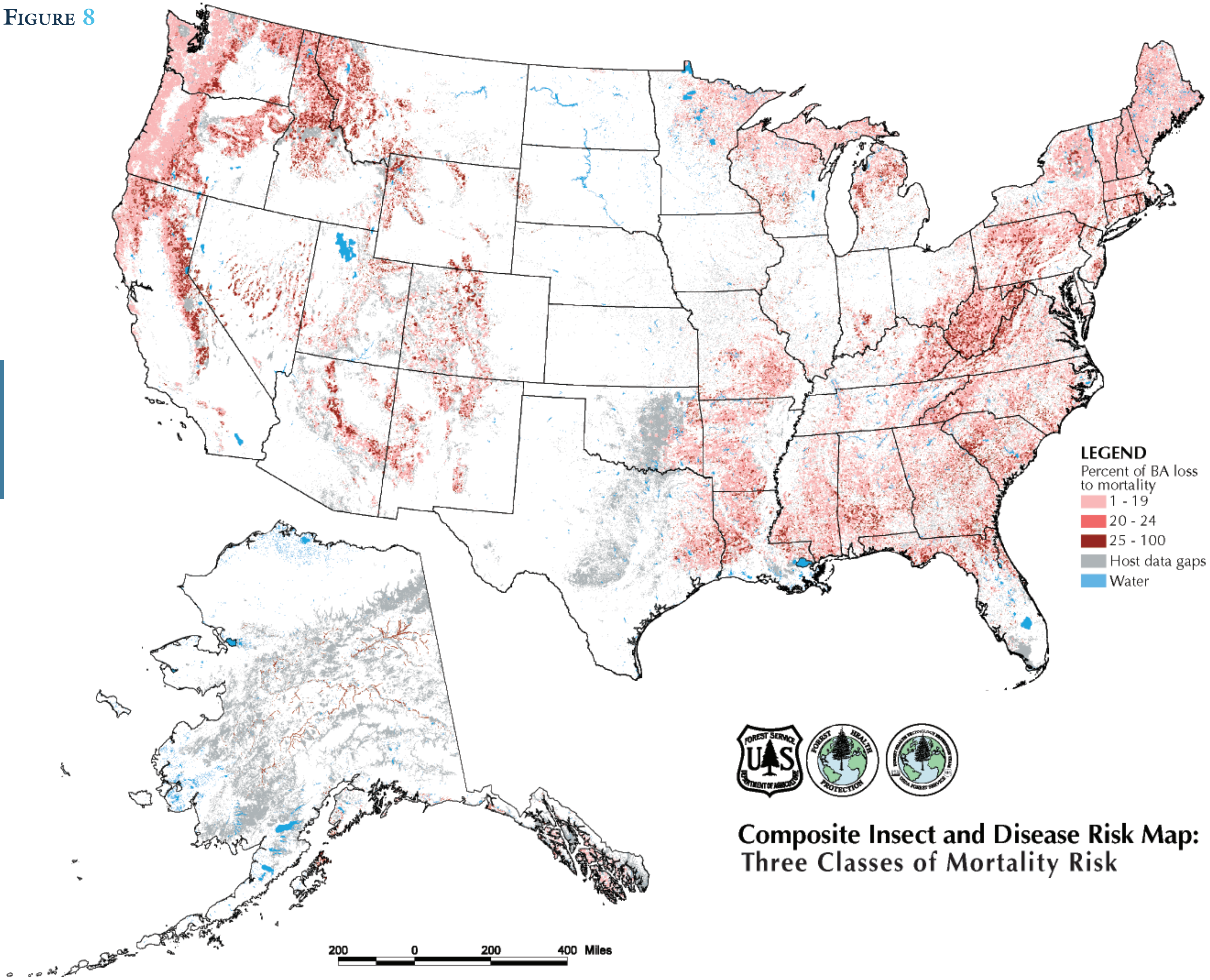
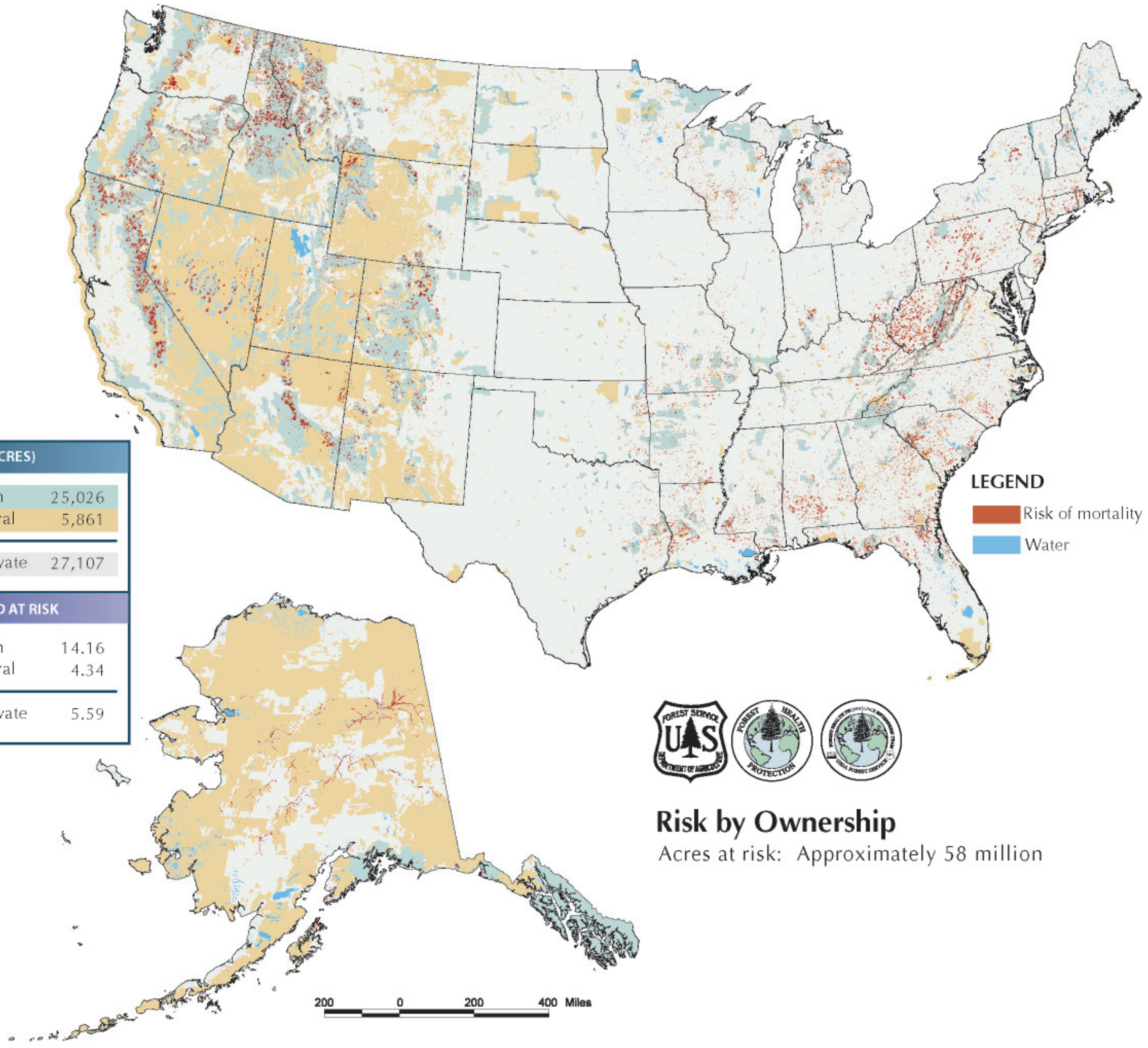

WPB Model - 40%
MPB Model 1 - 20%
WPB Model - 60%
MPB Model 2 - 60%
MPB Model 1 - 40%
MPB Model 1 - 20%
RHB Model - 10%
MPB Model 1 - 75%
WPB Model - 30%
DMT Model - 20%
Ips Model - 15%
RHB Model - 5%
MPB Model 1 - 20%
DMT Model - 20%
WPB Model - 15%
RHB Model - 10%
Ips Model - 5%
Ips Model - 40%
DMT Model - 20%
WPB Model - 5%
RHB Model - 5%
Ips Model - 30%
DMT Model - 20%
WPB Model - 15%
RHB Model - 5%
RHB Model - 25%
DMT Model - 20%
Ips Model - 15%
WPB Model - 10%
LEGEND
Ecoregion sections
IW Region Boundary
National Forests
Ponderosa pine BA > 0
Model Grouping Overlay
Black Hills
Canyonlands
Central Idaho
Colorado / Front Range
Four Corners
Mogollon Rim
North Kaibab
Northern Rockies
Prescott
Southwest
Uinta Mountains
Agent Abbreviations
DMT Dwarf Mistletoe
Ips Ips Engraver Beetle
MPB Mountain Pine Beetle
RHB Roundheaded Pine Beetle
WPB Western Pine Beetle
Mortality Thresholds by Ecoregion Section
Ponderosa Pine Models
Interior West FHM Region

FIGURE 8



Composite Insect and Disease Risk Map:
Three Classes of Mortality Risk

FIGURE 9

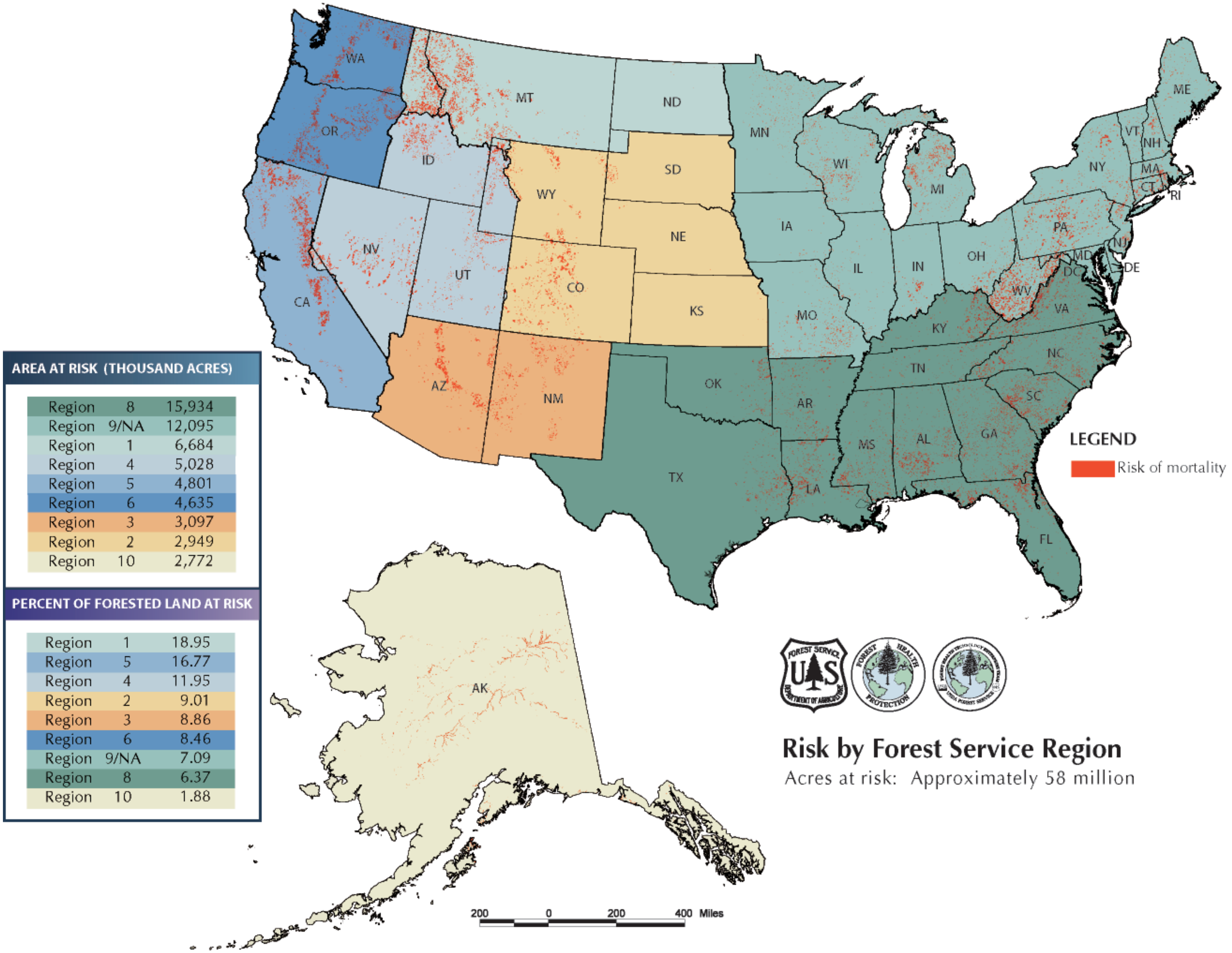


AREA AT RISK (THOUSAND ACRES)	
National Forest System	25,026
Tribal and Other Federal	5,861
State , County and Private	27,107
PERCENT OF FORESTED LAND AT RISK	
National Forest System	14.16
Tribal and Other Federal	4.34
State , County and Private	5.59

Risk by Ownership

Acres at risk: Approximately 58 million

Figure 10



AREA AT RISK (THOUSAND ACRES)

Region	8	15,934
Region	9/NA	12,095
Region	1	6,684
Region	4	5,028
Region	5	4,801
Region	6	4,635
Region	3	3,097
Region	2	2,949
Region	10	2,772

PERCENT OF FORESTED LAND AT RISK

Region	1	18.95
Region	5	16.77
Region	4	11.95
Region	2	9.01
Region	3	8.86
Region	6	8.46
Region	9/NA	7.09
Region	8	6.37
Region	10	1.88

LEGEND

🟥 Risk of mortality

Risk by Forest Service Region

Acres at risk: Approximately 58 million

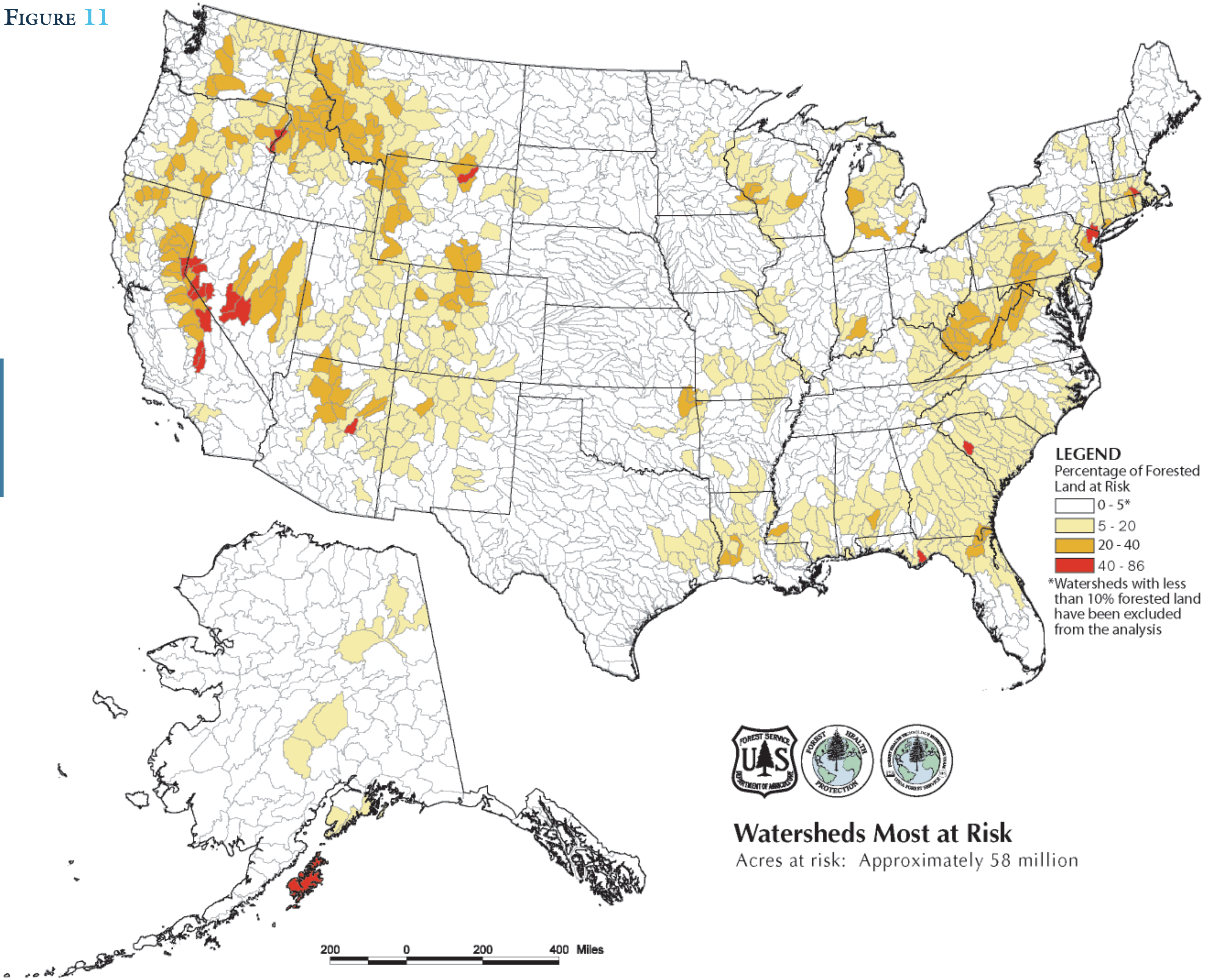
TABLE 2

PRESENCE OF MORTALITY AGENTS BY FOREST SERVICE REGION

Agent Name	R 1	R2	R3	R4	R5	R6	R8	R9/NA	R10
Alaska Yellow-Cedar Decline									X
Asian Longhorn Beetle								X	
Aspen Decline	X	X	X	X	X				
Aspen Forest Tent Caterpillar	X							X	
Balsam Woolly Adelgid	X			X		X	X	X	
Beech Bark Disease							X	X	
Bronze Birch Borer	X	X				X		X	
Butternut Canker							X	X	
Douglas-Fir Beetle	X	X	X	X	X	X			
Douglas-Fir Tussock Moth				X	X	X			
Douglas-Fir, White and Grand Fir Defoliators*	X			X		X			
Dutch Elm Disease	X	X					X	X	
Dwarf Mistletoes	X	X	X	X	X	X			
Eastern Larch Beetle								X	
Emerald Ash Borer								X	
Fir Engraver Beetle	X	X	X	X	X	X			
Fusiform Rust							X		
Gypsy Moth							X	X	
Hardwood Decline	X	X					X	X	
Hemlock Looper	X					X			
Hemlock Woolly Adelgid							X	X	
Jack Pine Budworm								X	
Jeffrey Pine Beetle				X	X	X			
Mountain Pine Beetle	X	X	X	X	X	X			
Northern Spruce Engraver Beetle									X
Oak Decline on Red Oaks		X	X		X	X	X	X	
Oak Wilt		X					X	X	
Pacific Madrone Decline						X			
Pacific Silver Fir Beetle						X			
Pine Engraver Beetle (Ips)	X	X	X	X	X	X		X	
Root Diseases - All	X			X	X	X	X		X
Round Headed Pine Beetle		X	X	X					
Southern Pine Beetle							X	X	
Spruce Aphid									X
Spruce Beetle	X	X	X	X	X	X			X
Spruce Budworm								X	
Sudden Oak Death					X	X			
Western Balsam Bark Beetle	X	X	X	X					
Western Pine Beetle	X	X	X	X	X	X			
Western Redcedar Mortality	X					X			
Western Spruce Budworm	X	X	X	X					
White Pine Blister Rust	X	X	X	X		X	X	X	

*Douglas-Fir Tussock Moth and Western Spruce Budworm were included with other defoliators in only the West Coast-Northwest Region.

Figure 11



Watersheds Most at Risk

Acres at risk: Approximately 58 million

Primary Contributors to the Risk of Mortality

Table 3 lists the 42 risk agents included in the study and highlights the 11 agents contributing the most to the total predicted basal area loss on NIDRM. The 11 risk agents were selected from a class break at 100 million square feet of BA loss. The total losses include all areas with potential for activity above and below the 25-percent-mortality threshold.

For risk agents with multiple models representing varying ecoregions and hosts (see Figure 7 and **Appendix B**), such as mountain pine beetle, results in predicted square - footage loss were summed by risk agent, reducing model outputs from 188 to 42. Figures 12 to 22 depict the spatial distribution of the predicted BA loss from the top 11 agents contributing to NIDRM. Individual models and map outputs for all risk agents can be viewed at the FHTET website.

The BA losses for these 11 agents were broken into three classes in each map's legend in accordance with Jenks' Natural Breaks algorithm (Jenks 1977).

Table 3

TOP MORTALITY AGENTS BY RANK

Agent Name	BA Losses (millions of sq. feet)
Mountain Pine Beetle	750.5
Oak Decline on Red Oaks	657.9
Southern Pine Beetle	589.2
Root Diseases - All	518.5
Gypsy Moth	448.0
Pine Engraver Beetle (Ips)	345.4
Fir Engraver Beetle	270.2
Douglas-Fir Beetle	242.8
Spruce Beetle	195.2
Hardwood Decline	181.2
Western Pine Beetle	136.0
Spruce Budworm	84.0
Beech Bark Disease	78.9
Douglas-Fir, White and Grand Fir Defoliators*	78.2
Jeffrey Pine Beetle	70.2
Dwarf Mistletoes	66.1
Aspen Decline	65.5
Western Balsam Bark Beetle	57.0
Sudden Oak Death	53.3
Hemlock Looper	53.1
Western Redcedar Mortality	39.8
Balsam Woolly Adelgid	39.5
Hemlock Woolly Adelgid	21.1
White Pine Blister Rust	18.3
Round Headed Pine Beetle	15.0
Fusiform Rust	14.3
Oak Wilt	14.0
Aspen Forest Tent Caterpillar	13.3
Dutch Elm Disease	12.3
Northern Spruce Engraver Beetle	12.1
Jack Pine Budworm	8.6
Douglas-Fir Tussock Moth	8.6
Bronze Birch Borer	6.3
Alaska Yellow-Cedar Decline	5.3
Western Spruce Budworm	4.9
Emerald Ash Borer	4.7
Butternut Canker	2.7
Eastern Larch Beetle	1.9
Asian Longhorn Beetle	1.4
Pacific Silver Fir Beetle	1.2
Spruce Aphid	0.5
Pacific Madrone Decline	0.2

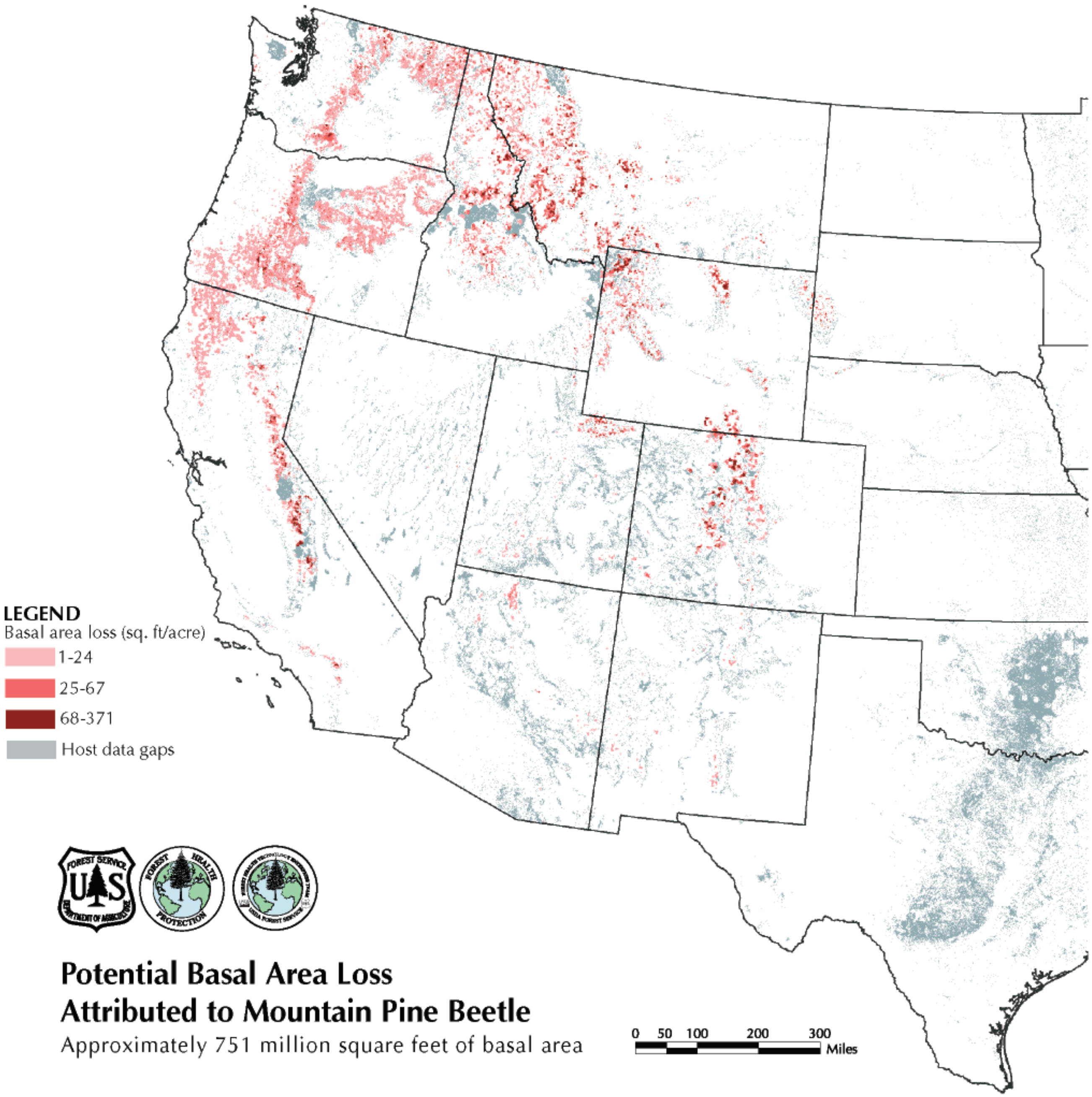
*Douglas-Fir Tussock Moth and Western Spruce Budworm were included with other defoliators in only the West Coast-Northwest Region.

Mountain Pine Beetle (*Dendroctonus ponderosae*)

Mountain pine beetle outbreaks have been on the rise since the late 1990s, with outbreaks recently reaching epidemic levels in many areas of the interior West (USDA 2005). Mountain pine beetle is the largest contributor to NIDRM, with a projected loss of 750.5 million square feet in the next 15 years. A wide range of pine species, including lodgepole, ponderosa, sugar, and western white pines, are preferred mountain pine beetle hosts (Amman et al. 1990).

Like other bark beetles, mountain pine beetles spend most of their lifecycle as larvae under the bark feeding on the phloem or inner bark. During outbreaks, mountain pine beetles can rapidly kill millions of trees, significantly altering ecosystems in the western United States. Crown discoloration, pitch tubes (yellowish-white masses of resin), and boring dust around the trunks of attacked trees are evidence of infestation.

FIGURE 12

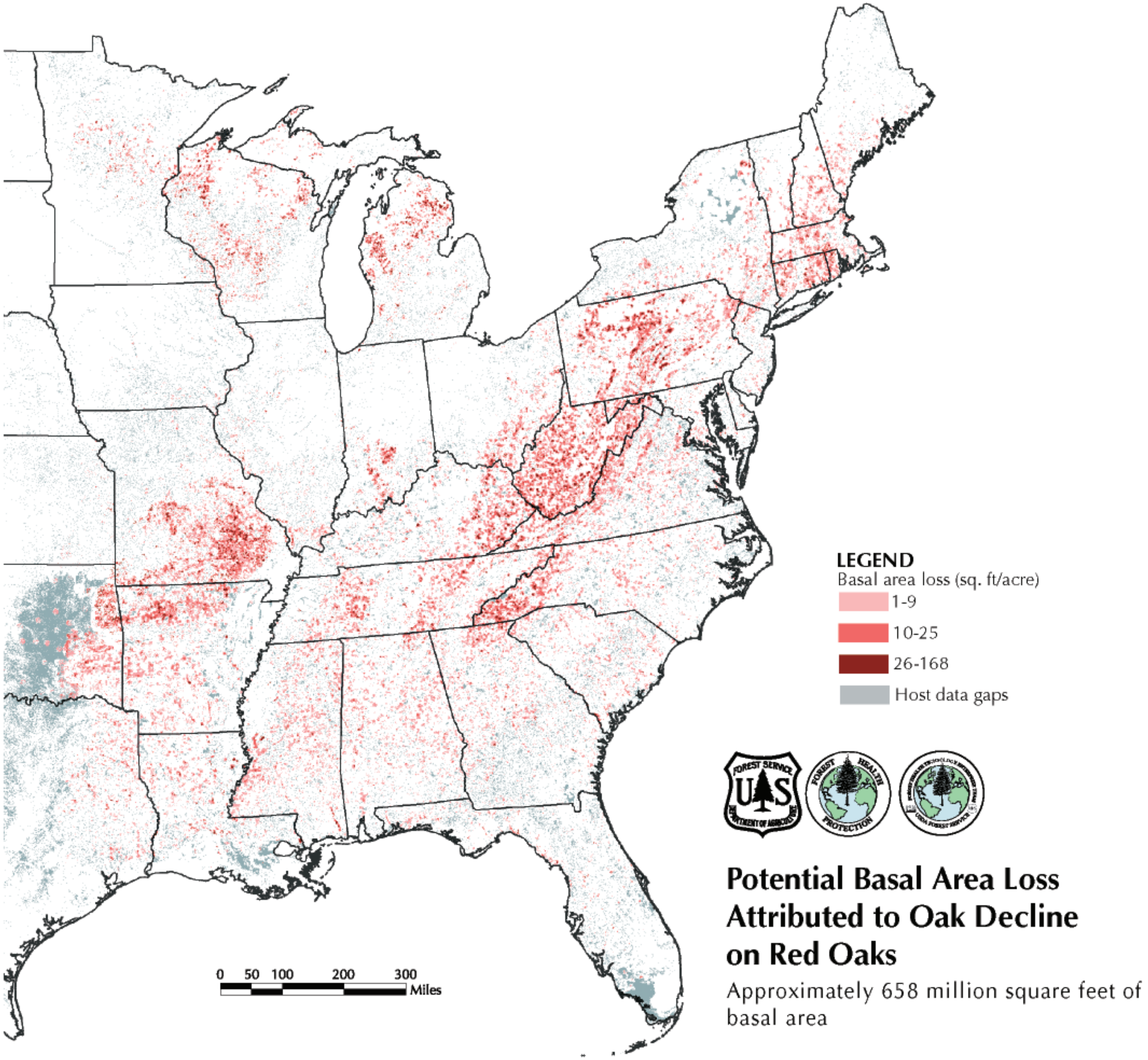

LEGEND
Basal area loss (sq. ft/acre)
🟥 1-24
🟥 25-67
🟥 68-371
▨ Host data gaps
Potential Basal Area Loss
Attributed to Mountain Pine Beetle
Approximately 751 million square feet of basal area
0
50
100
200
300
Miles

Oak Decline on Red Oaks

Not surprisingly, oak decline for the red oak species group was the second-highest contributor to NIDRM, with nearly 658 million square feet of BA loss projected for the next 15 years. Oak decline is found throughout the red oak range, which encompasses a large portion of the central and eastern United States (Wargo et al. 1983) and small areas in the West. Caused by the interaction of many factors, including age, site conditions, and insect and pathogen activity, oak decline can result in significant mortality. Decline in oak species has been reported in the United States for over 130 years and is characterized by gradual but significant crown dieback. Oak plays an important role in a wide range of wildlife habitats, and its continued decline will likely have a significant impact on many ecosystems. Oak decline was not modeled for the white oak species group.

Red oak decline is also projected to occur in the West Coast Region. Due to its modest contribution to the total and its marginal visibility at the scale used, it was not included in the map.

Figure 13



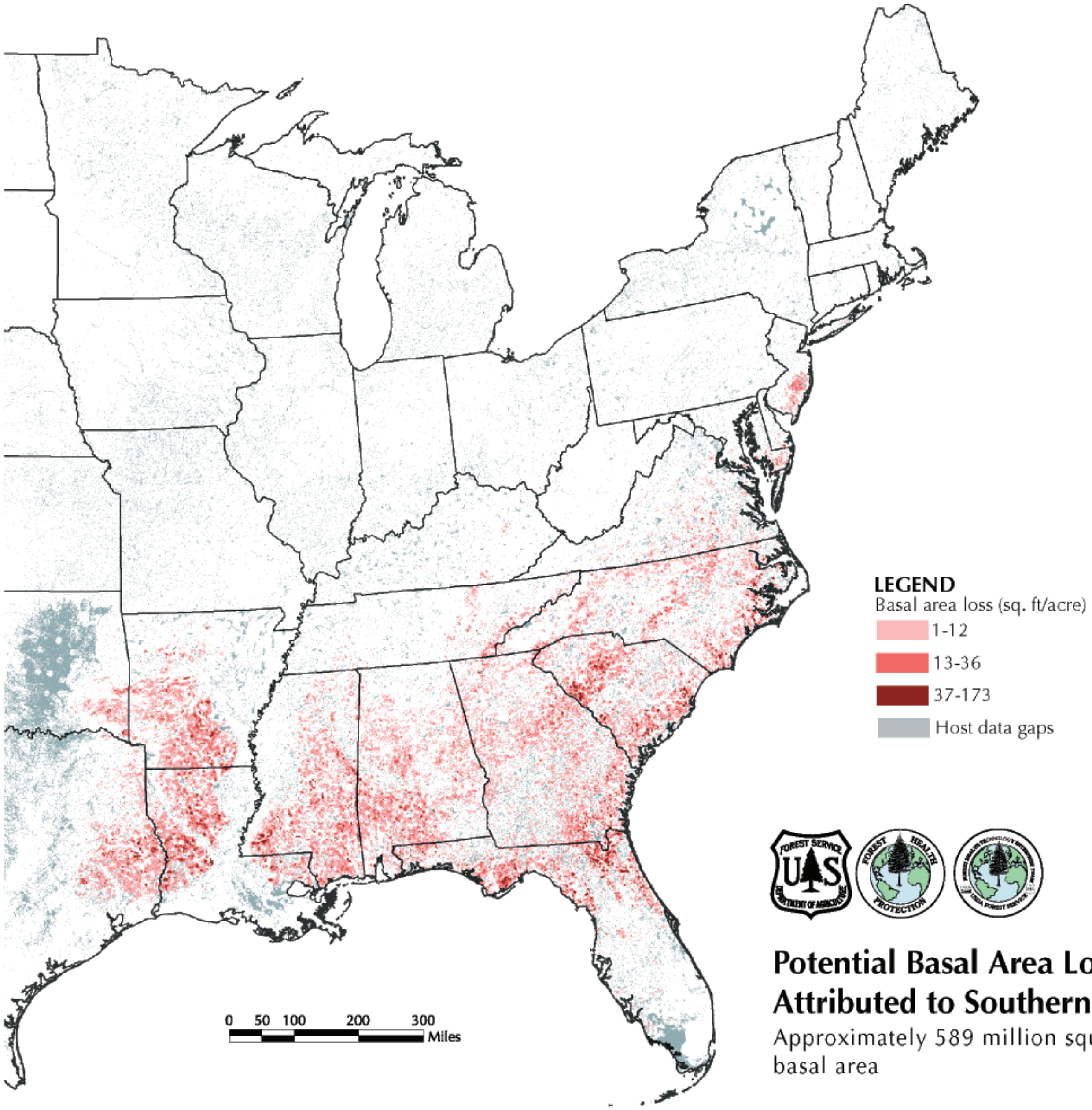
Potential Basal Area Loss Attributed to Oak Decline on Red Oaks

Approximately 658 million square feet of basal area

Southern Pine Beetle (*Dendroctonus frontalis*)

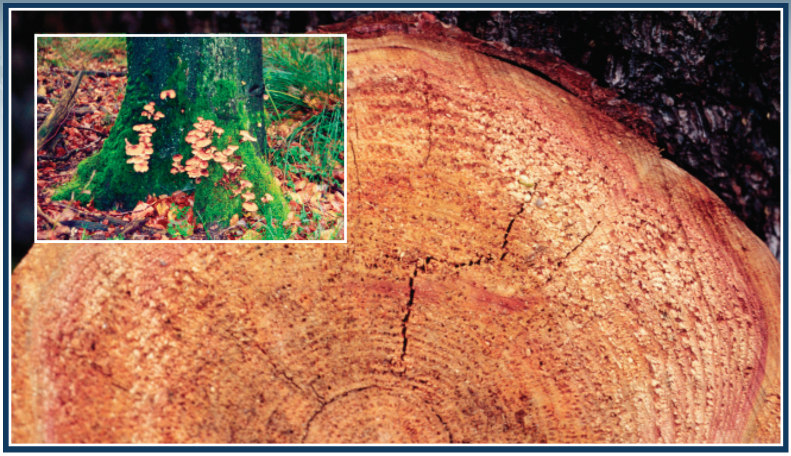
The southern pine beetle is one of the most destructive insects in the southern United States (Thatcher and Barry 1982). Although southern pine beetle outbreaks declined in 2003 and 2004, significant outbreaks are expected in the next few years as drought and other environmental stresses continue to weaken host species across the South. Preferred hosts are shortleaf, loblolly, Virginia, and pitch pines. Crown discoloration and pitch tubes are the first indications of infestation. Southern pine beetle contributed 589 million square feet to the national risk map.

Figure 14



Potential Basal Area Loss Attributed to Southern Pine Beetle

Approximately 589 million square feet of basal area

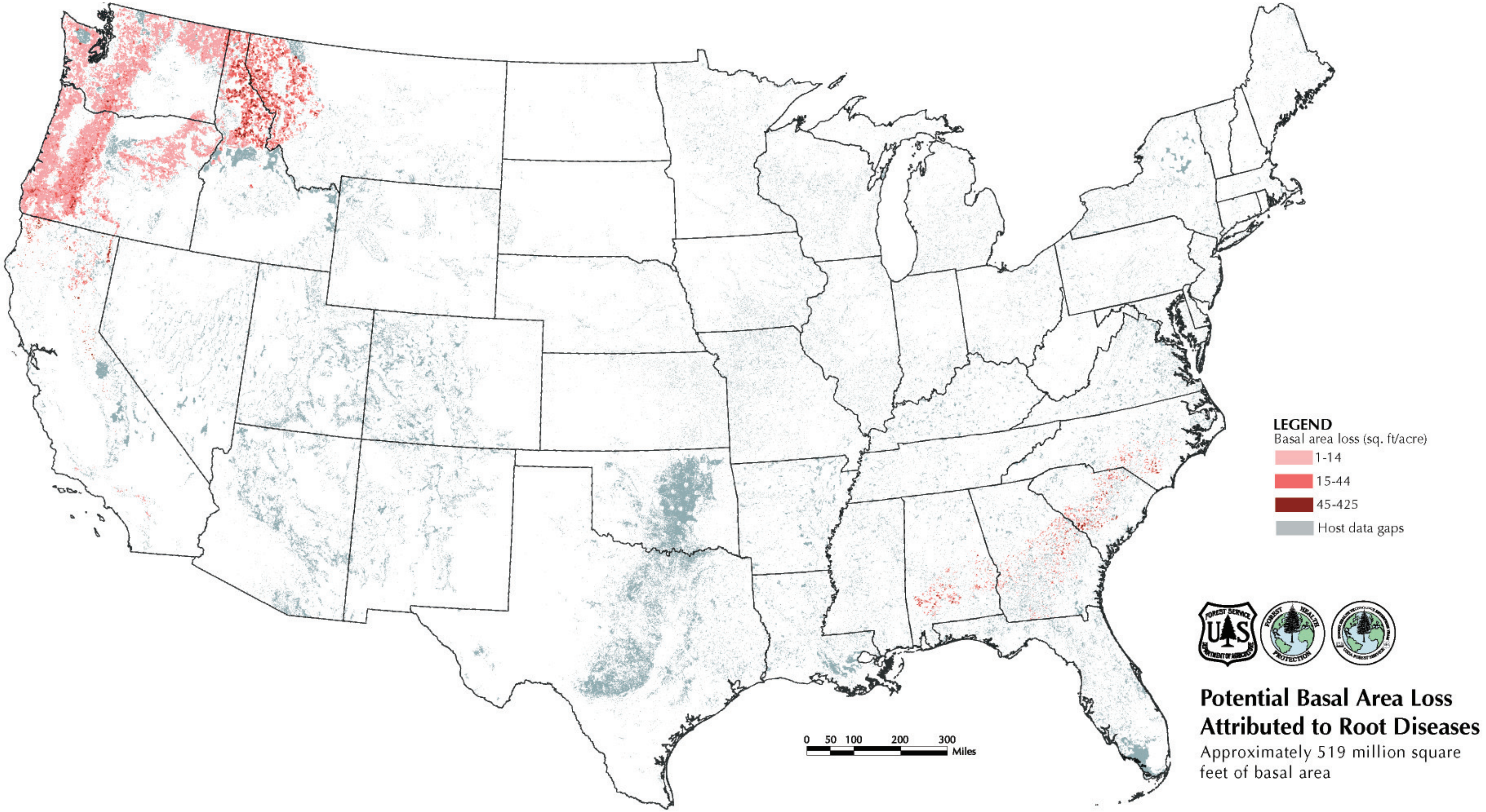


Root Diseases

Relatively little is known about the behavior of many root diseases, which are often difficult to identify in the field. As a result, several of the root disease models were based on surfaces of known root disease distributions and intensities. Root diseases and their causal agents making up this group include: annosus root and butt rot (caused by *Heterobasidion annosum*), armillaria root disease (caused by *Armillaria* spp.), black stain root disease (caused by *Leptographium wageneri*), laminated root rot (caused by *Phellinus weirii*), Port-Orford-cedar root disease (caused by *Phytophthora lateralis*), and tomentosus root disease (caused by *Inonotus tomentosus*).

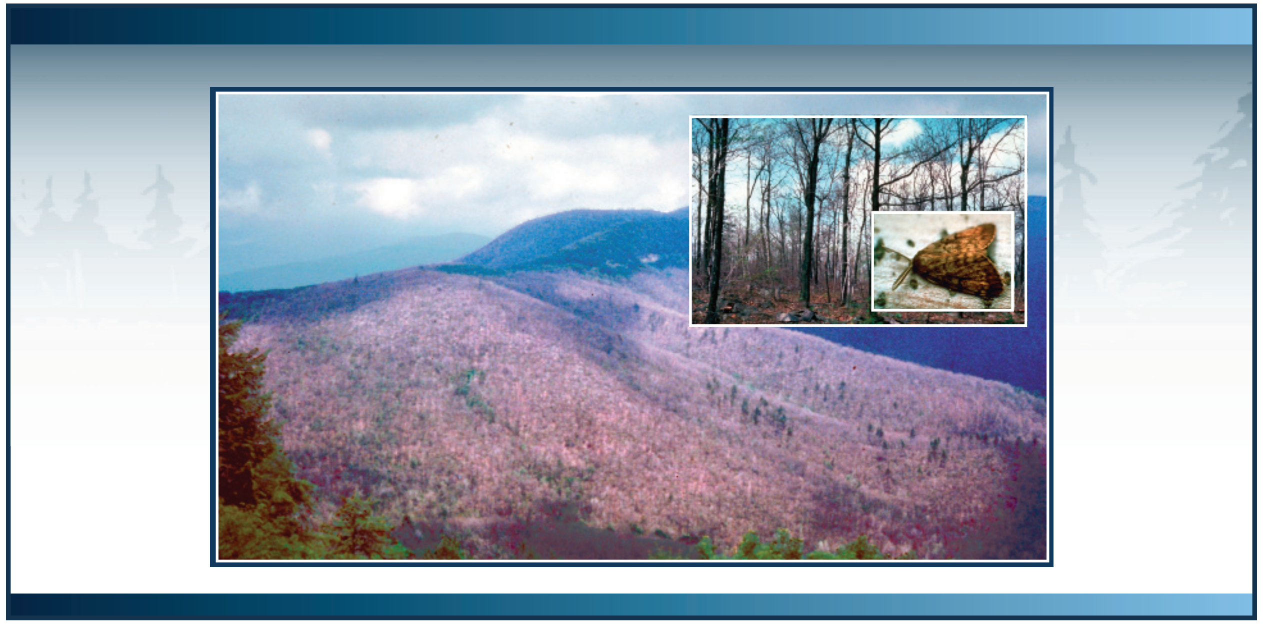
Root diseases are generally caused by fungi found naturally in forests, infecting roots and stems of both hardwood and coniferous trees. Most of these fungi can live on both living and dead tissue, acting as parasites, pathogens, or saprophytes, respectively. Root disease can attack and kill trees weakened by environmental stress or infect healthy trees, predisposing them to attacks by other risk agents or root diseases. *Phytophthora lateralis* is the only exotic pathogen causing root disease examined in this project. It is an oomycete belonging to the family Pythiaceae; oomycetes are no longer considered true fungi, but belong to a separate kingdom from fungi. Armillaria root rot is the most common root disease and has been reported in nearly every state in the contiguous United States (Williams et al. 1986). Root diseases contributed an estimated 518.5 million square feet to NIDRM.

FIGURE 15



Potential Basal Area Loss Attributed to Root Diseases

Approximately 519 million square feet of basal area



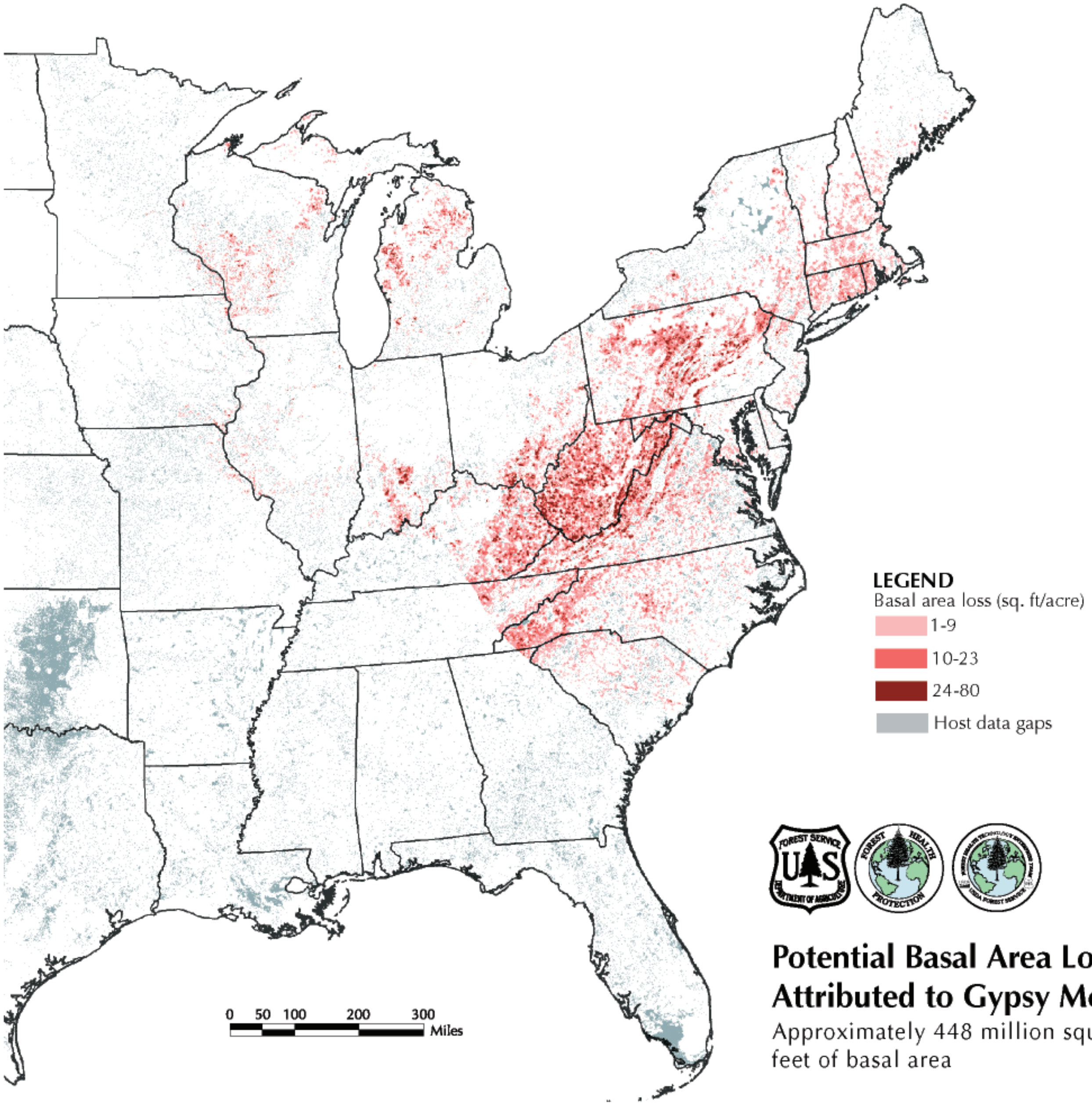
Gypsy Moth (*Lymantria dispar*)

Since 1980, when moth populations began to increase significantly, gypsy moth has defoliated about one million acres each year in the eastern United States (McManus et al. 1989, USDA 2005). The extent of defoliated trees and the presence of millions of larvae on roads, trees, signs, and even in homes each year have made the gypsy moth one of the most notorious pests in the East.

Although red and white oaks are preferred hosts, gypsy moth feeds on the leaves of several hundred different deciduous species, frequently weakening its host but not necessarily killing it (McManus et al. 1989). However, gypsy moth is so widespread that it has the potential to produce about 448 million square feet of BA loss in the next 15 years.

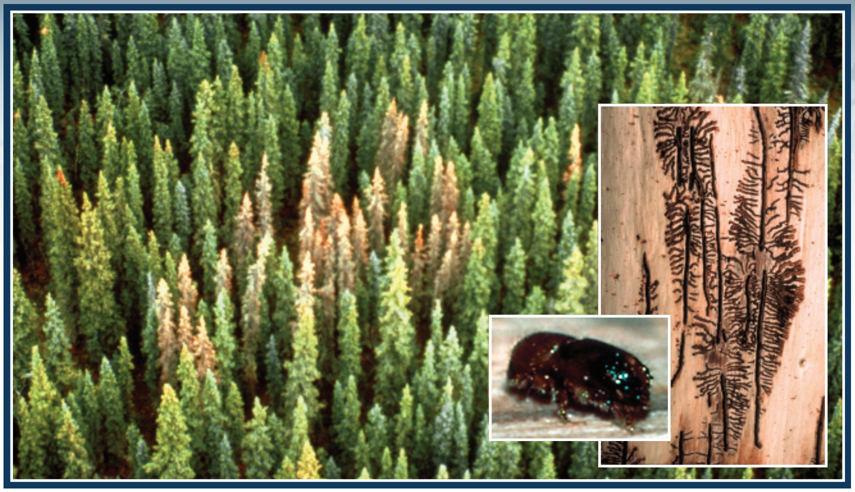
Note: gypsy moth is commonly detected in the western United States, but is aggressively eradicated. If this practice continues, gypsy moth is not expected to cause detectable mortality in the West.

Figure 16



Potential Basal Area Loss Attributed to Gypsy Moth

Approximately 448 million square feet of basal area

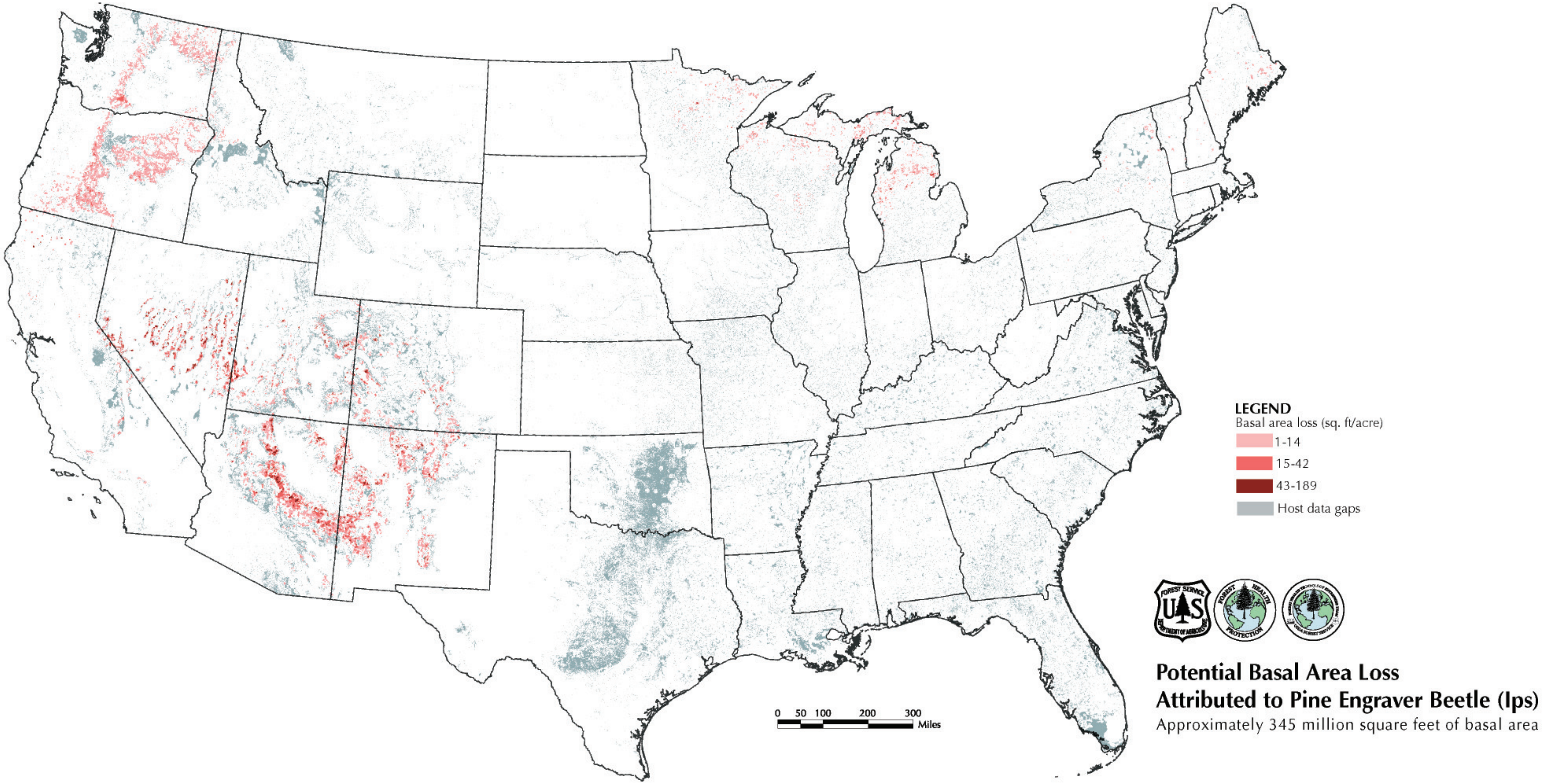


Pine Engraver Beetle (*Ips* spp.)

Pine engraver beetles affect pine species in both the eastern and western United States, including lodgepole, pinyon, ponderosa, knobcone, and red pines (Kegley et al. 1997). The appearance of reddish-orange boring dust on trees in the spring is the first indicator of attack. As larvae, pine engraver beetles feed on the phloem just under the bark, much like mountain pine beetles and southern pine beetles. Feeding larvae disrupt the flow of water and nutrients throughout the tree by girdling branches and the trunk. By late summer or early fall, tree foliage begins to fade.

Generally, pine engraver beetles are not aggressive tree killers; however, attacks on severely stressed trees can result in mortality. For example, after several years of drought in the western United States, pine engraver beetles reached unprecedented levels in 2003, with over 3.7 million acres showing some level of mortality (USDA 2004). Continued drought in some regions suggests future outbreaks. At a projected mortality of 345 million square feet, pine engraver beetles as a group are the sixth-highest contributor to NIDRM.

FIGURE 17



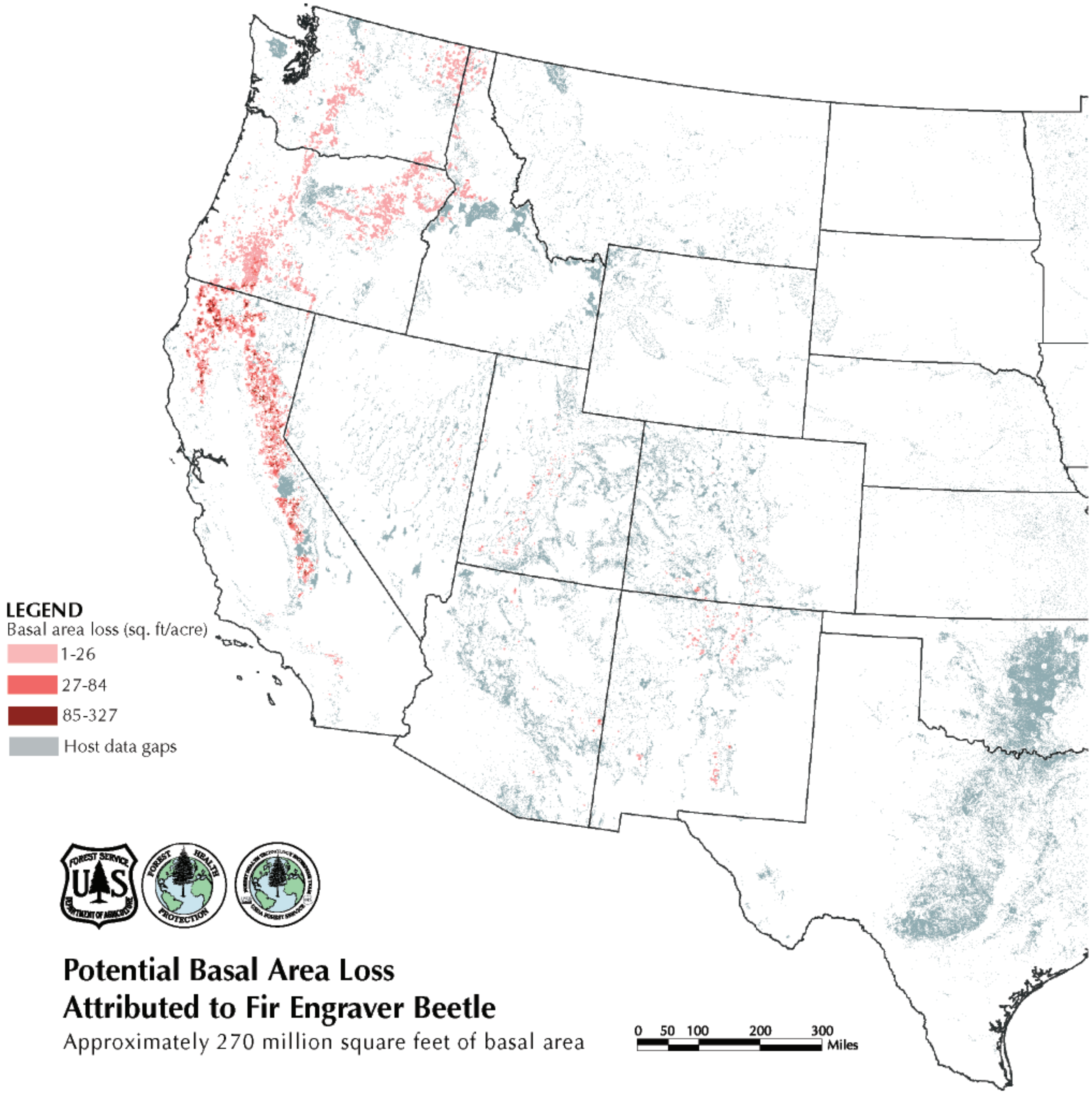
Potential Basal Area Loss Attributed to Pine Engraver Beetle (Ips)

Approximately 345 million square feet of basal area

Fir Engraver Beetle (*Scolytus ventralis*)

In the next 15 years, potential loss to fir engraver beetle may reach 270 million square feet. Mortality from fir engraver beetle has been on the increase in the western United States, primarily due to continued drought conditions (USDA 2004 and 2005). Most western fir species are attacked by fir engraver, with white, grand, and red fir being preferred hosts (Ferrell 1986). Behavior and evidence of attack is similar to pine engraver beetles.

Figure 18



Potential Basal Area Loss Attributed to Fir Engraver Beetle

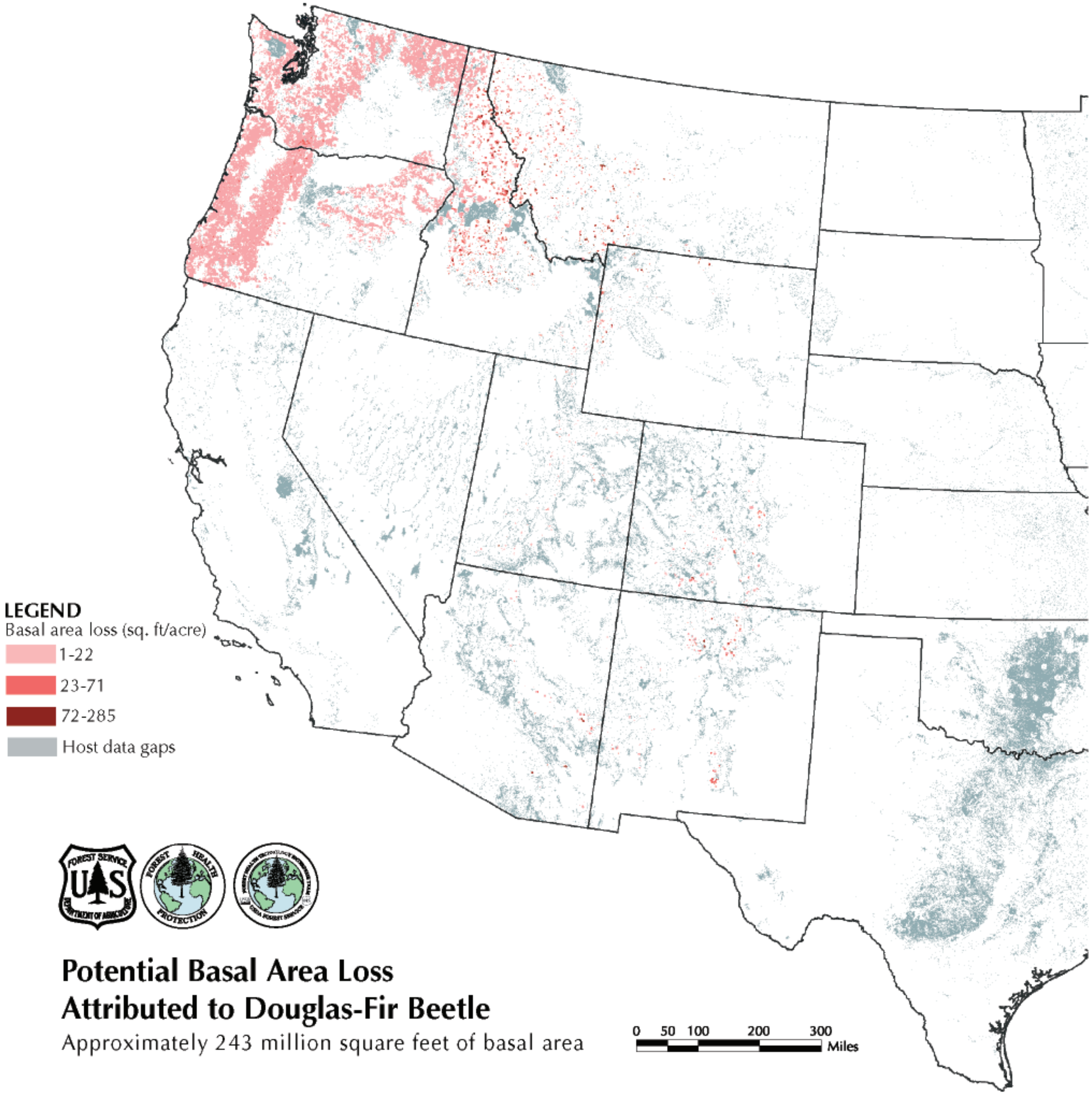
Approximately 270 million square feet of basal area

Douglas-Fir Beetle (*Dendroctonus pseudotsugae*)

Throughout the western United States, Douglas-fir beetle attacks primarily Douglas-fir and occasionally is found in western larch (Schmitz and Gibson 1996). Although significant periodic Douglas-fir beetle outbreaks do occur, this bark beetle typically kills small groups of trees scattered across the landscape. Usually, damaged and weakened trees are the most susceptible to Douglas-fir beetle attack, while healthy trees are often able to "pitch out" beetles with resin flows.

As beetle populations increase, mortality is greatest in dense, mature stands. The presence of reddish-orange boring dust is the first sign of infestation, with foliage subsequently becoming discolored several months later. If uncontrolled, nearly 243 million square feet of BA loss may occur in the next 15 years.

Figure 19



Potential Basal Area Loss Attributed to Douglas-Fir Beetle

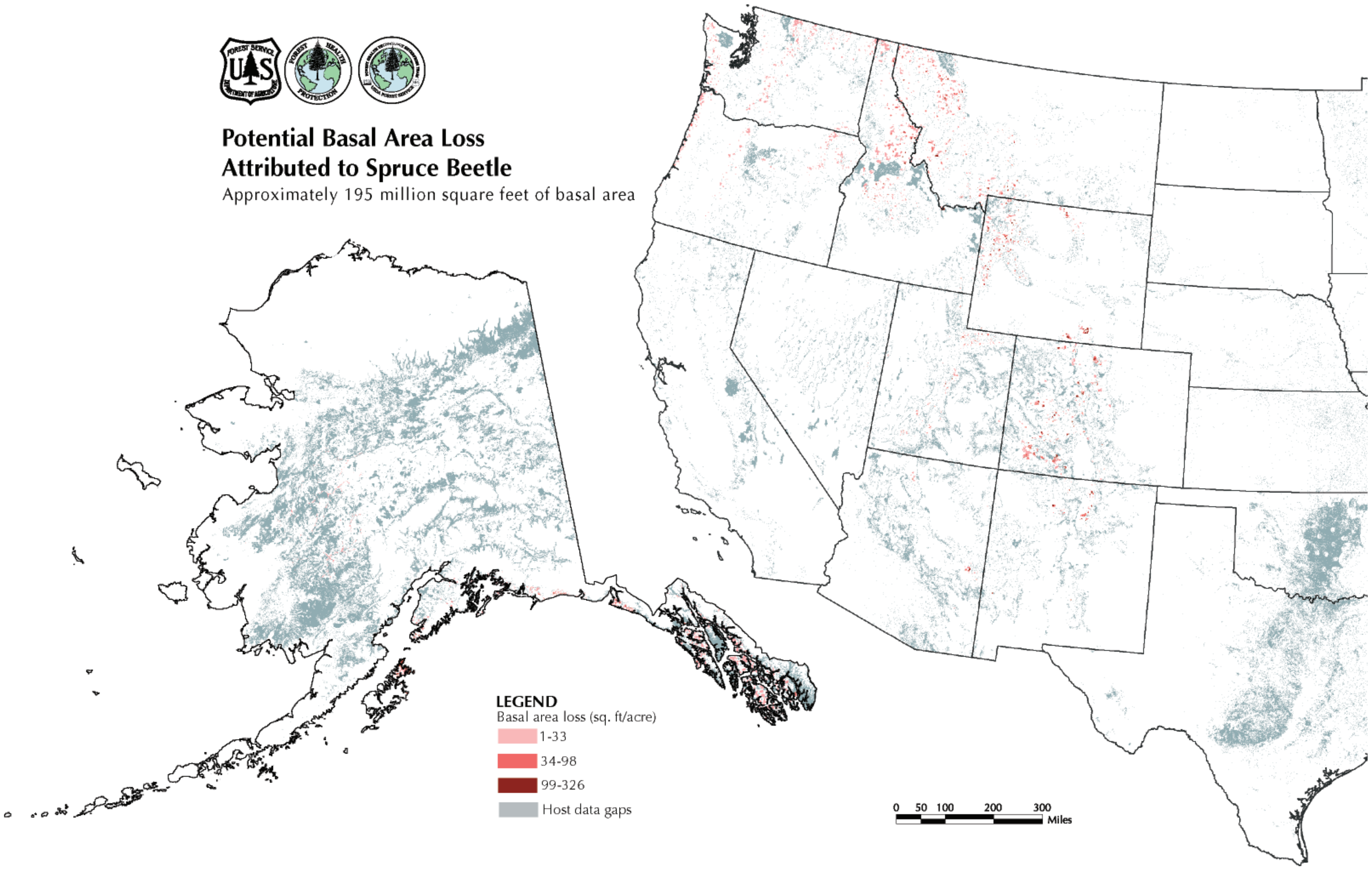
Approximately 243 million square feet of basal area

Spruce Beetle (*Dendroctonus rufipennis*)

Spruce beetle is the primary natural mortality agent of mature spruce in the western United States and Alaska (Holsten et al. 1999). Outbreaks generally result in significant mortality, greatly altering stand conditions. During the 1990s, spruce beetle reached epidemic levels in Alaska, resulting in mortality exceeding 90 percent in some areas (USDA 2005).

Although numbers began to decrease in the late 1990s, mild winters and warm, dry summers are resulting in increased activity. Evidence of attack from spruce beetle is the presence of reddish-brown boring dust, entrance holes, and the subsequent discoloration of tree crowns. Spruce beetle contributed over 195 million square feet of BA loss to NIDRM.

Figure 20



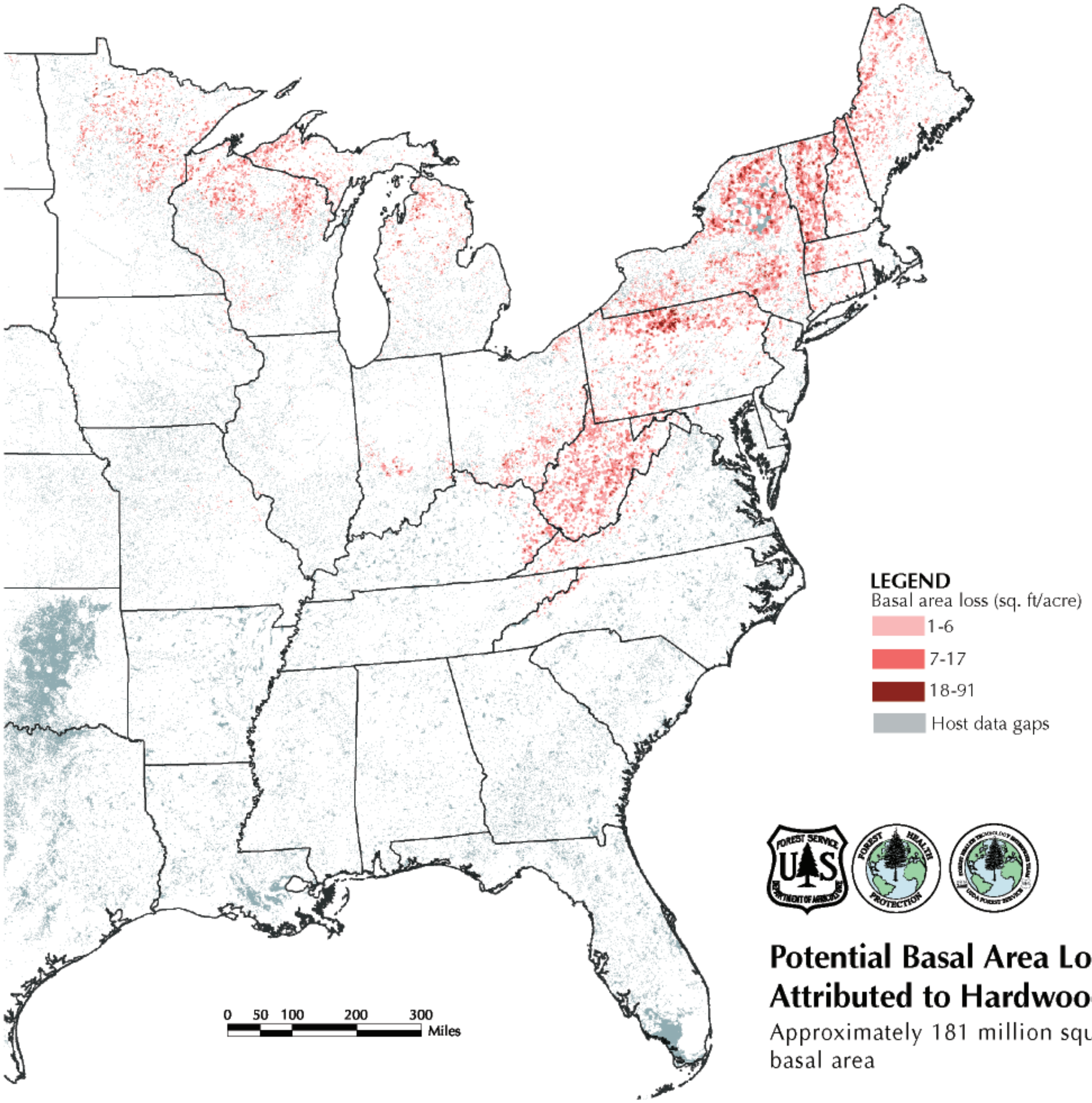
Potential Basal Area Loss Attributed to Spruce Beetle

Approximately 195 million square feet of basal area

Hardwood Decline

Although not as extensive as oak decline, declines in hardwoods such as ash, basswood, and sugar maple are significant contributors to NIDRM, with over 181 million square feet of BA loss expected. Like oak decline, hardwood decline is caused by the interaction of several factors, including site conditions (e.g., poor soils and drought), stand conditions, and insect and pathogen activity (Wargo et al. 1983). Many of these interactions occur over relatively long periods of time; thererfore, they are more visible when considered over the 15-year period that NIDRM spans. Also, hardwood decline may enable exotic species, such as emerald ash borer, to become established more rapidly than otherwise possible.

FIGURE 21



Potential Basal Area Loss Attributed to Hardwood Decline

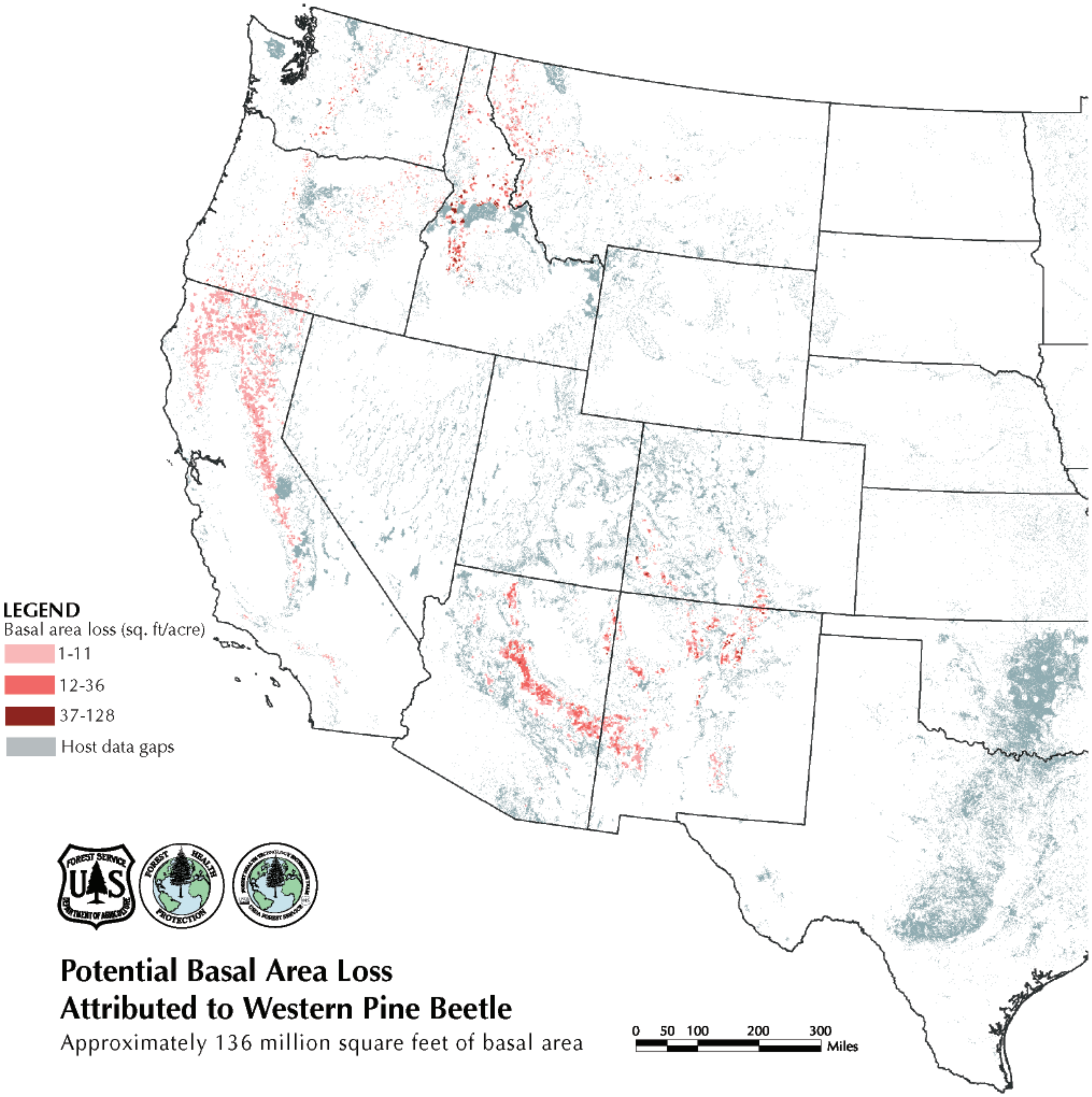
Approximately 181 million square feet of basal area

Western Pine Beetle (*Dendroctonus brevicomis*)

Western pine beetles preferentially attack ponderosa and Coulter pines, frequently resulting in significant timber losses (DeMars and Roettgering 1997). Generally, western pine beetles breed in over-mature and weakened trees; however, mortality is often the greatest in areas where stands are pure and overstocked.

As with other bark beetles, crown discoloration, pitch tubes, and boring dust are evidence of infestation. As adult western pine beetles move through the bark, they deposit spores of a blue-staining fungus (*Ceratocystis minor*), which invades and blocks the conductive vessels of the inner bark, thus killing the tree. Western pine beetle contributes 136 million square feet of BA loss to NIDRM.

FIGURE 22



**Potential Basal Area Loss
Attributed to Western Pine Beetle**

Approximately 136 million square feet of basal area

Bark Beetles

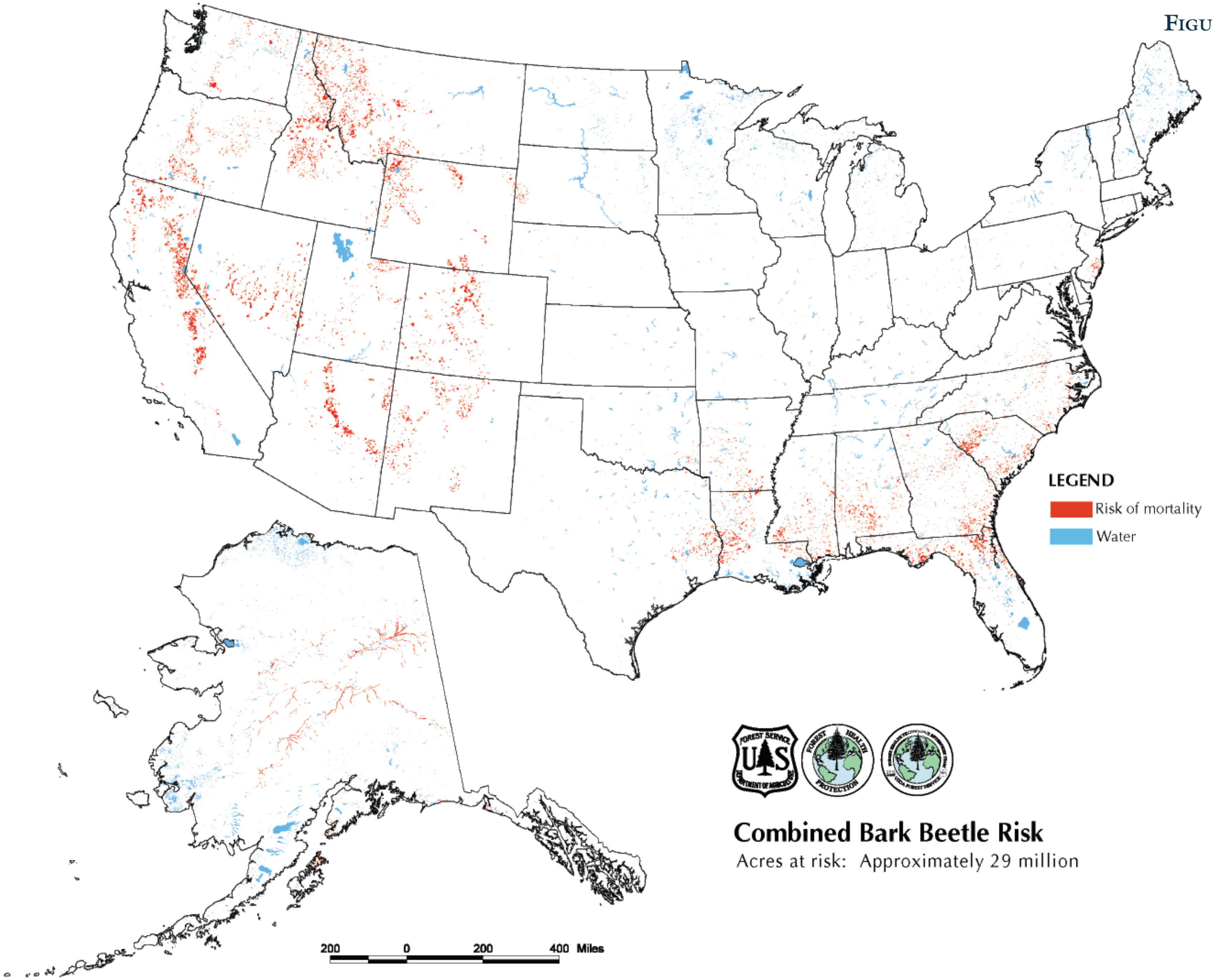
Much of the risk in the western and southern United States can be attributed to bark beetles, with about 29 million acres reaching the 25-percent-mortality threshold due to bark beetles alone (see **Table 4 and Figure 23**).

Table 4

AREA AT RISK (THOUSAND ACRES) TO BARK BEETLES					
California	3,571	North Carolina	608	Kentucky	<1
Montana	3,026	Washington	553	Connecticut	0
Alaska	2,730	Texas	536	D.C.	0
Idaho	2,341	Arkansas	376	Illinois	0
Nevada	1,725	New Jersey	114	Indiana	0
Arizona	1,692	South Dakota	111	Iowa	0
Wyoming	1,647	Virginia	83	Kansas	0
Colorado	1,628	Oklahoma	83	Massachusetts	0
Florida	1,544	Michigan	48	Missouri	0
New Mexico	1,301	Tennessee	43	New Hampshire	0
South Carolina	1,146	Minnesota	31	North Dakota	0
Louisiana	1,145	Wisconsin	19	Ohio	0
Oregon	1,123	Maryland	11	Pennsylvania	0
Georgia	1,029	Nebraska	8	Rhode Island	0
Alabama	977	Delaware	2	Vermont	0
Mississippi	859	Maine	1	West Virginia	0
Utah	735	New York	1		

BARK BEETLES
Douglas-Fir Beetle
Fir Engraver Beetle
Jeffrey Pine Beetle
Mountain Pine Beetle
Northern Spruce Engraver Beetle
Pacific Silver Fir Beetle
Pine Engraver Beetle
Roundheaded Pine Beetle
Southern Pine Beetle
Spruce Beetle
Western Balsam Bark Beetle
Western Pine Beetle

Figure 23



Combined Bark Beetle Risk

Acres at risk: Approximately 29 million

EXOTIC FOREST PESTS

Although only one exotic forest pest, gypsy moth, was in the list of top 11 risk agents (**TABLE 2**), nearly 695 million square feet of BA may be lost to all exotics within the next 15 years. About 2.4 million acres reach the 25-percent-mortality threshold due to exotics alone (see **TABLE 5 and FIGURE 24**). Most basal area loss to exotic pests occurs in the eastern United States and California. Gypsy moth is the primary contributor to mortality in the East, sudden oak death is the largest contributor to basal area loss in California, and white pine blister rust is the greatest exotic mortality agent in the interior West.

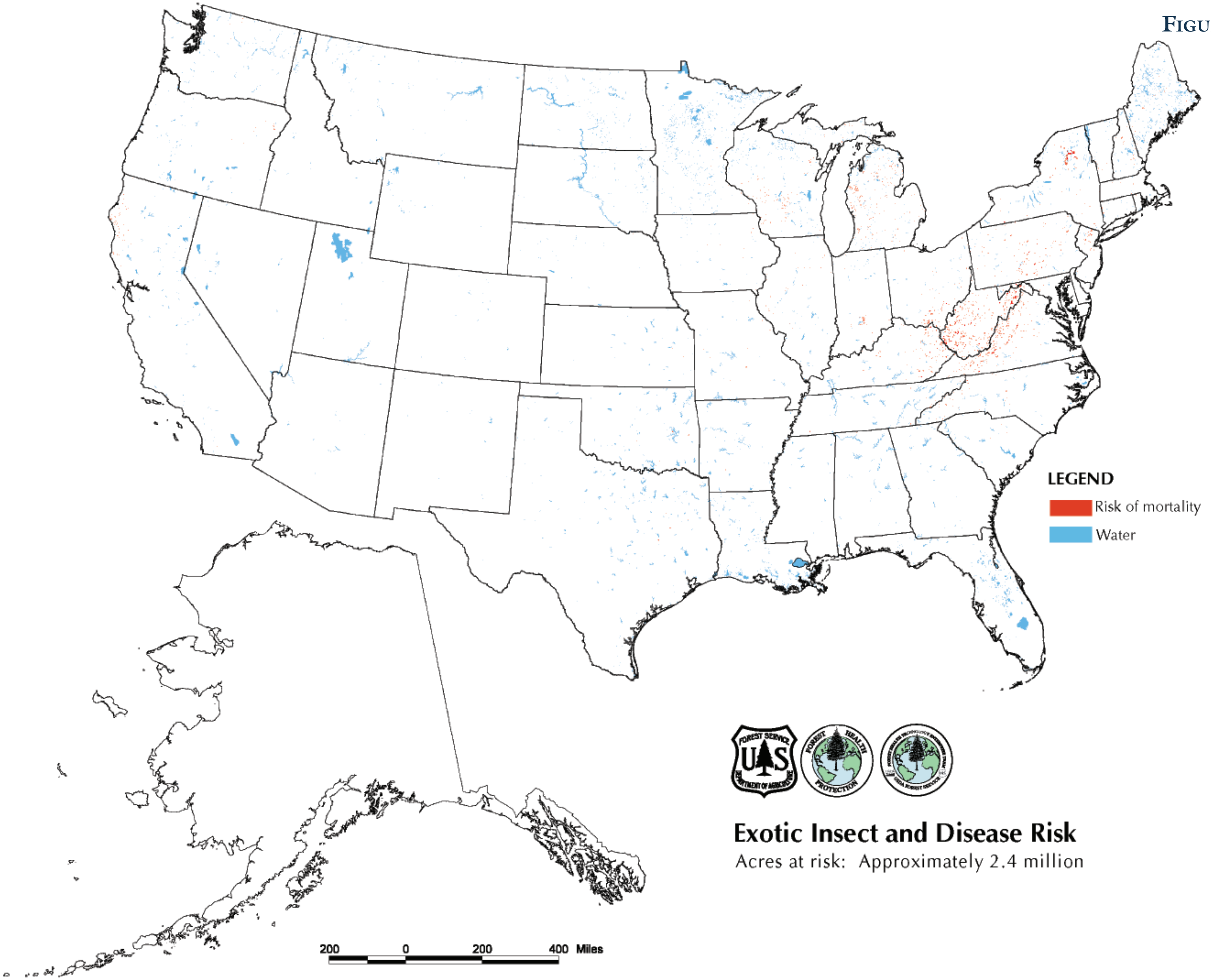
Several exotic forest pests have been introduced into Alaska. Fortunately, some species, such as western tent caterpillar and gypsy moth, have been eradicated or have not become established (Wittwer 2004 and 2005). Spruce aphid is the only exotic pest included in the 2006 risk assessment for Alaska.

In some regions of southeastern Alaska, spruce aphid has caused significant amounts of needle drop in Sitka spruce. Spruce aphid generally does not result in high mortality rates, and thus contributes little to the NIDRM composite's areas at or above the 25-percent threshold. Although spruce aphid occurs in the contiguous United States, it was modeled only in Alaska. For the contiguous United States, spruce aphid was included as a species of special concern (see page 75).

TABLE 5

AREA AT RISK (THOUSAND ACRES) TO EXOTIC INSECTS AND DISEASES						EXOTIC INSECTS AND DISEASES
West Virginia	651	Oregon	16	Georgia	<1	Asian Longhorned Beetle
Virginia	389	Minnesota	15	Mississippi	<1	Balsam Woolly Adelgid
Michigan	208	Missouri	14	Alaska	0	Beech Bark Disease
New York	192	Texas	12	Arizona	0	Butternut Canker
Pennsylvania	171	Iowa	12	Colorado	0	Dutch Elm Disease
Kentucky	166	Oklahoma	10	D.C.	0	Emerald Ash Borer
Ohio	109	Massachusetts	9	Delaware	0	Gypsy Moth
Wisconsin	103	Vermont	9	Florida	0	Hemlock Woolly Adelgid
California	64	Connecticut	8	Louisiana	0	Oak Wilt
North Carolina	58	Washington	5	Montana	0	Port-Orford-Cedar Root Disease
New Jersey	44	Rhode Island	3	Nevada	0	Spruce Aphid
Indiana	42	Kansas	3	New Mexico	0	Sudden Oak Death
Maine	35	South Carolina	2	North Dakota	0	White Pine Blister Rust
Tennessee	26	Arkansas	2	South Dakota	0	
Illinois	22	Alabama	1	Utah	0	
New Hampshire	19	Idaho	1	Wyoming	0	
Maryland	16	Nebraska	1			

Figure 24



Exotic Insect and Disease Risk

Acres at risk: Approximately 2.4 million

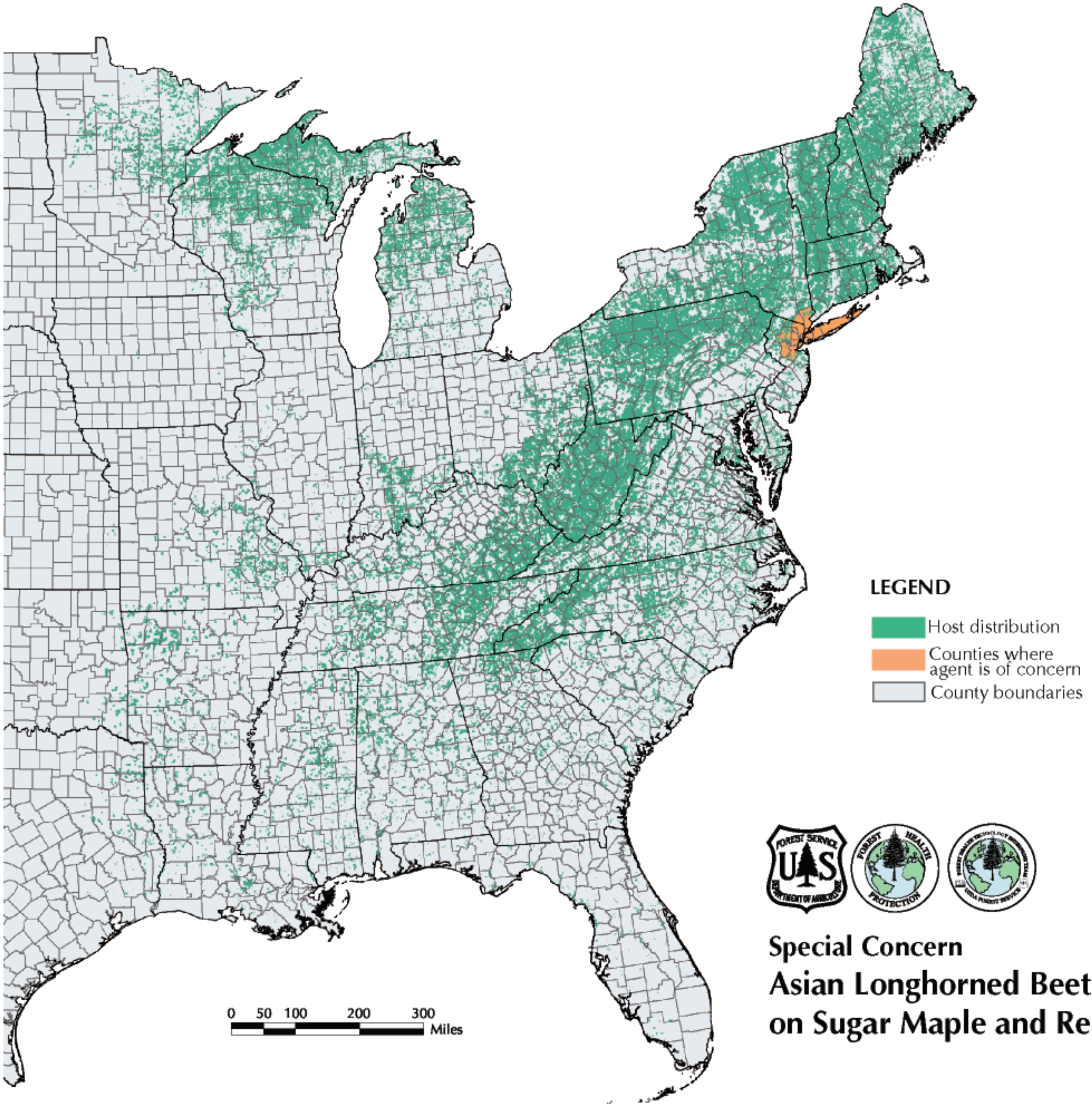
Forest Pests of Special Concern

Nineteen agents were identified as being of special concern during the 2006 risk assessment (Figures 25-43), and slightly over half (10 of the 19) are also exotic forest pests. In general, these agents were classified as special concerns for one of the following reasons:

1. These agents were identified by specialists as being of high ecological, social, or economic concern, but the agents were not considered during the risk assessment due to insufficient model or spatial information. An example of this type of agent is pinewood nematode (*Bursaphelenchus xylophilus*).
2. These agents affect tree species that do not constitute a large portion of the forest or are limited in their distribution for some other reason. The agents were modeled, but are not well-represented on NIDRM. An example of this type of agent is butternut canker (caused by the *Sirococcus clavigignenti-juglandacearum* fungus): this agent was included in the risk assessment, but butternut is a minor component of the total forest composition, and therefore, maps of the modeled effects of butternut canker appear minor relative to agents affecting more dominant tree species. Because butternut is a highly valued tree species and is in jeopardy throughout its range, butternut canker was identified as a species of special concern in order to highlight its considerable ecological and economic impacts.

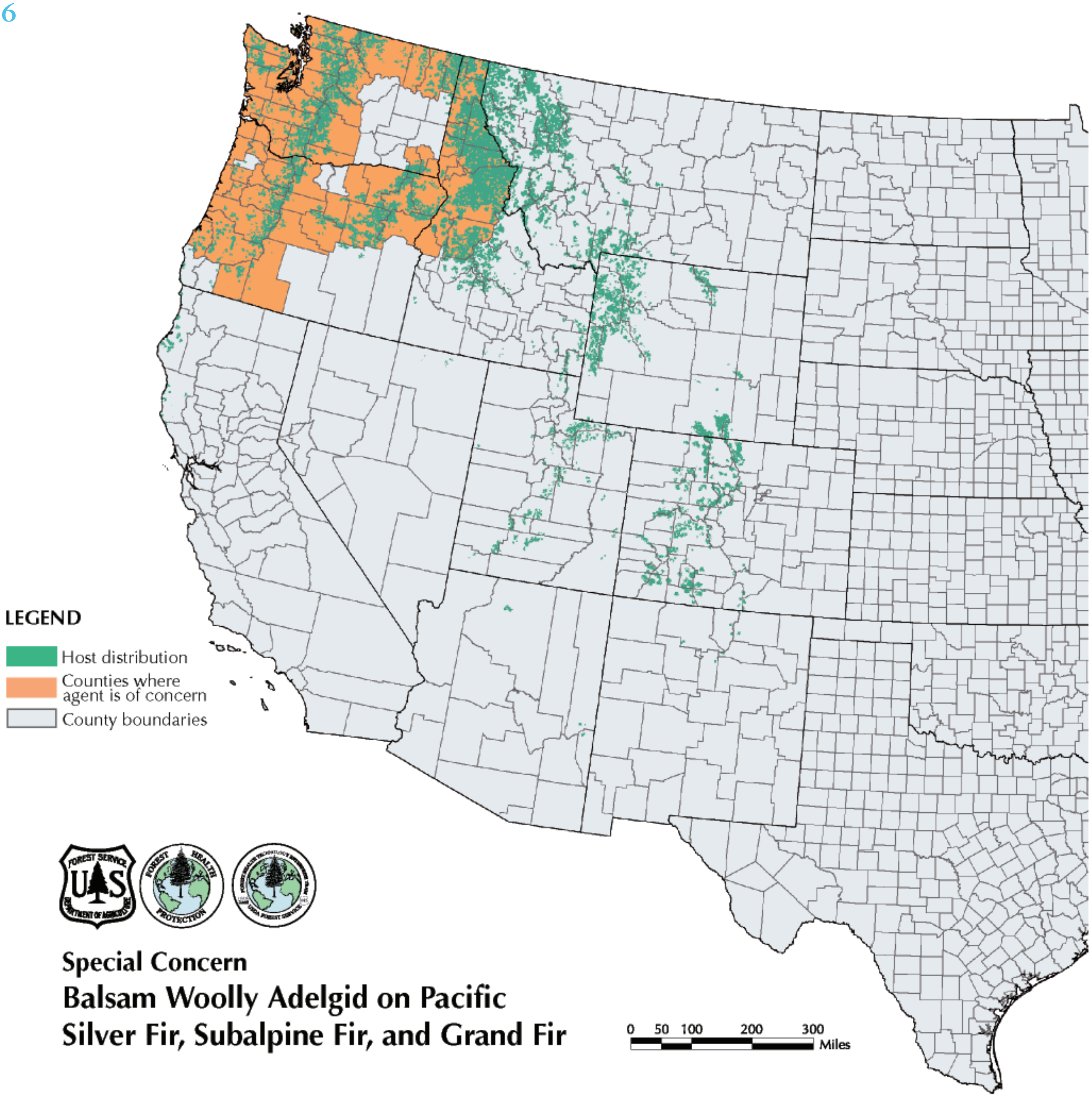
Many of the agents that fall into these two categories attack hosts that are relatively minor components of the landscape and, as such, are difficult to model or map. As a result, the RMIT identified counties where agents are of concern rather than points of occurrence (see the following maps). A highlighted county does not indicate that a forest pest occupies an entire county, but indicates that the pest is active or being quarantined somewhere in the county.

FIGURE 25



Special Concern
Asian Longhorned Beetle
on Sugar Maple and Red Maple

Figure 26



Special Concern
Balsam Woolly Adelgid on Pacific Silver Fir, Subalpine Fir, and Grand Fir

FIGURE 27

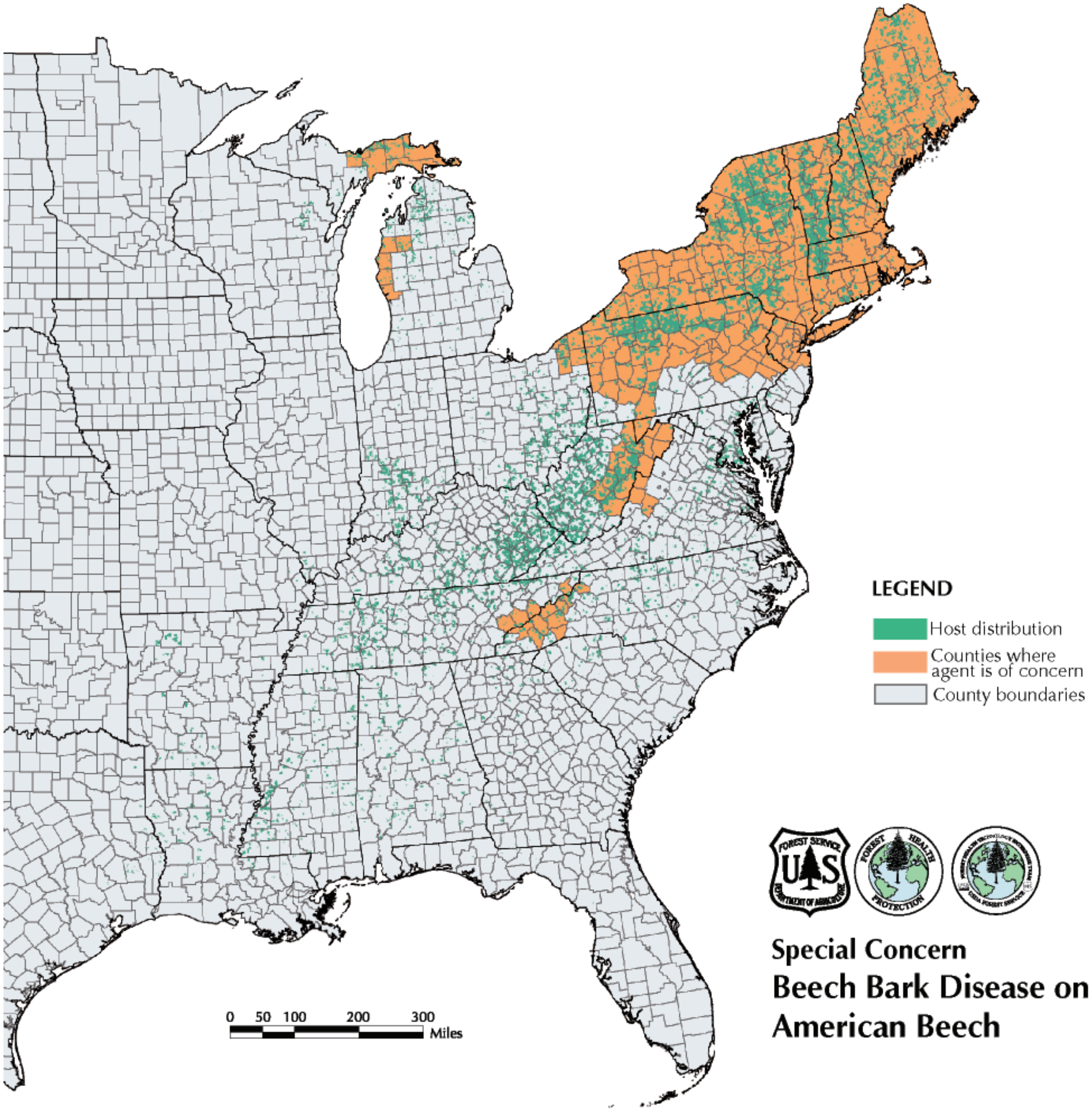

LEGEND
Host distribution
Counties where agent is of concern
County boundaries
0 50 100 200 300
Miles
Special Concern
Beech Bark Disease on
American Beech

FIGURE 28

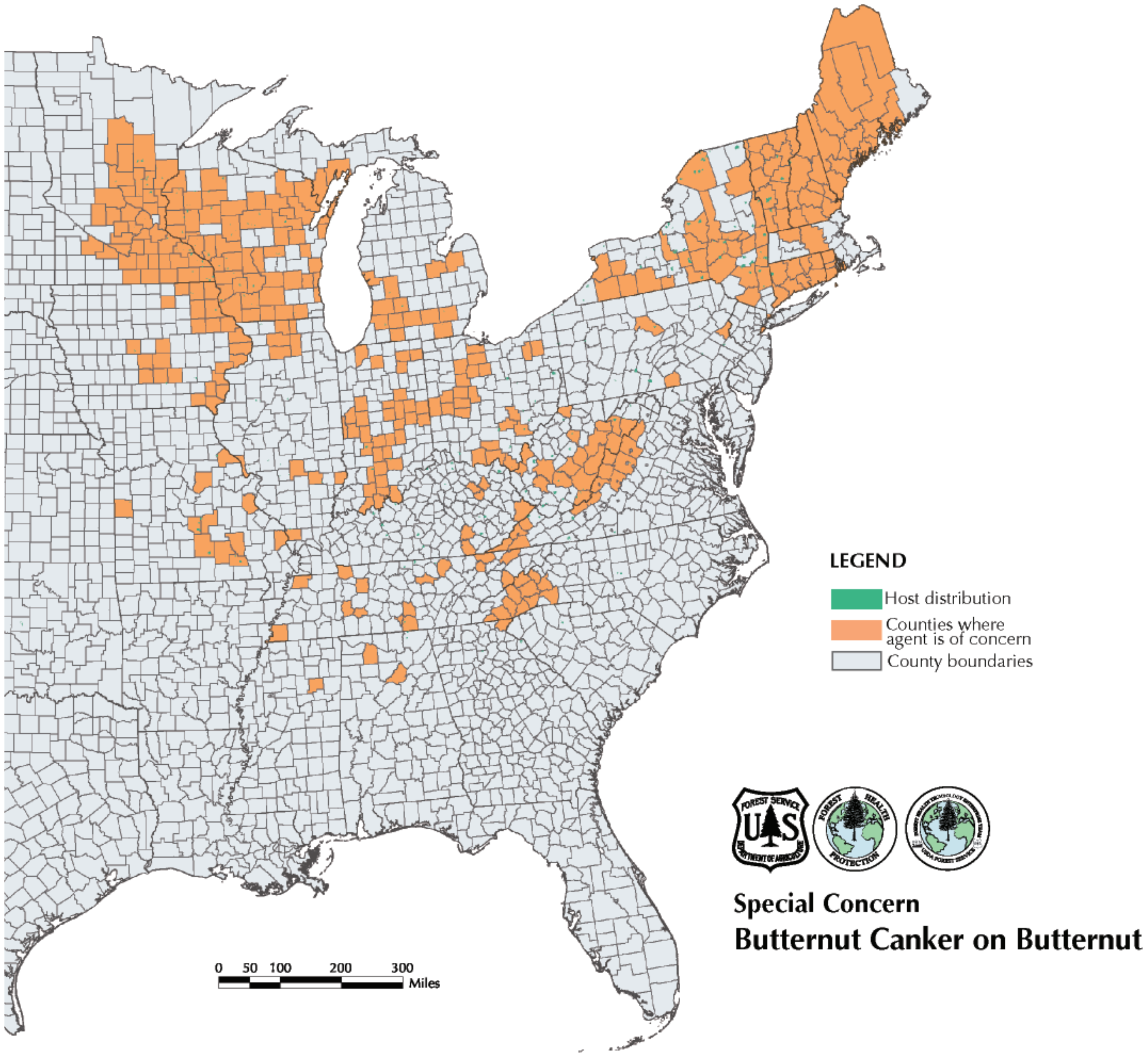
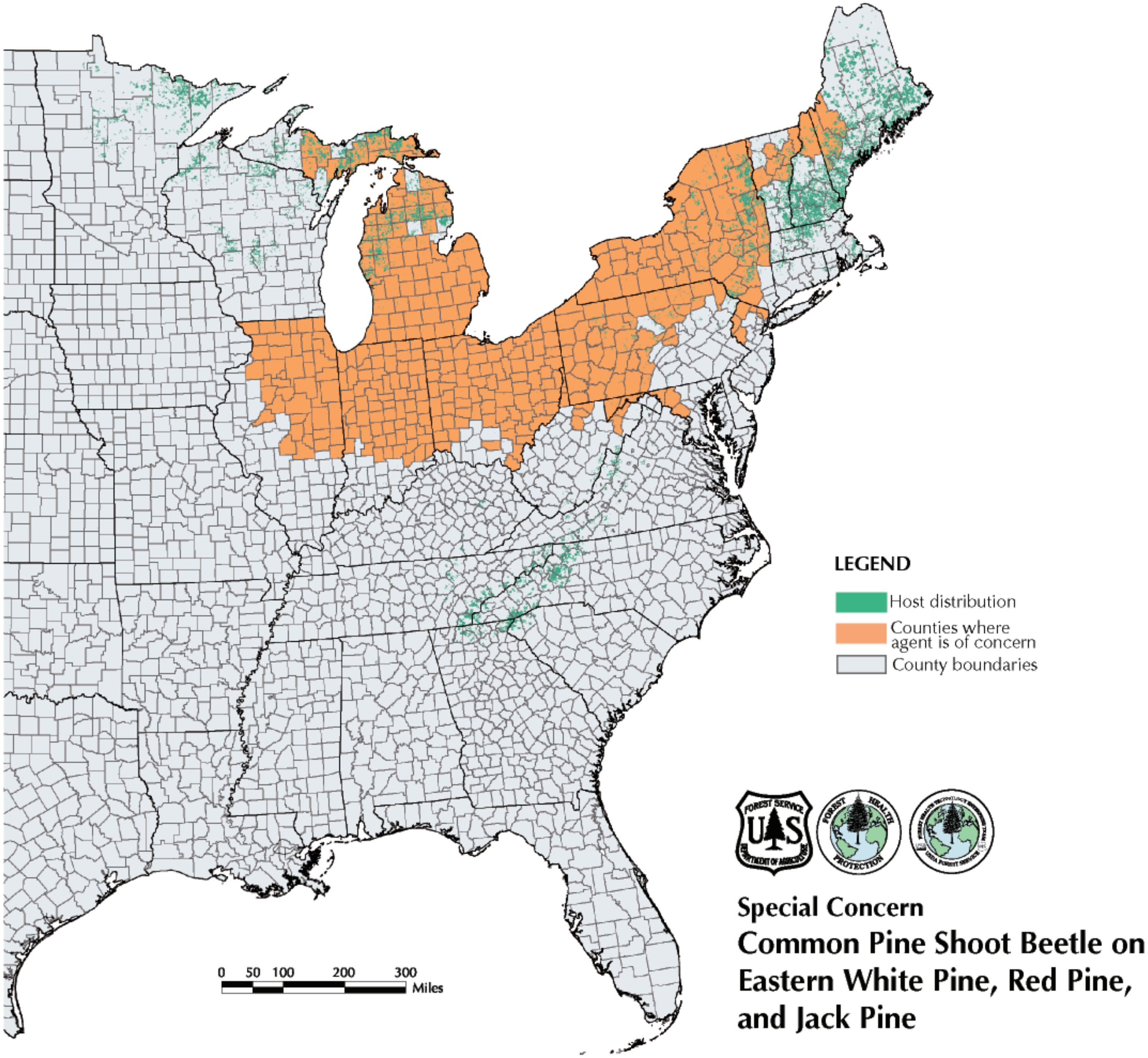

LEGEND
🟩 Host distribution
🟧 Counties where agent is of concern
☐ County boundaries
Special Concern
Butternut Canker on Butternut
0 50 100 200 300
Miles

Figure 29



Special Concern
Common Pine Shoot Beetle on Eastern White Pine, Red Pine, and Jack Pine

Figure 30

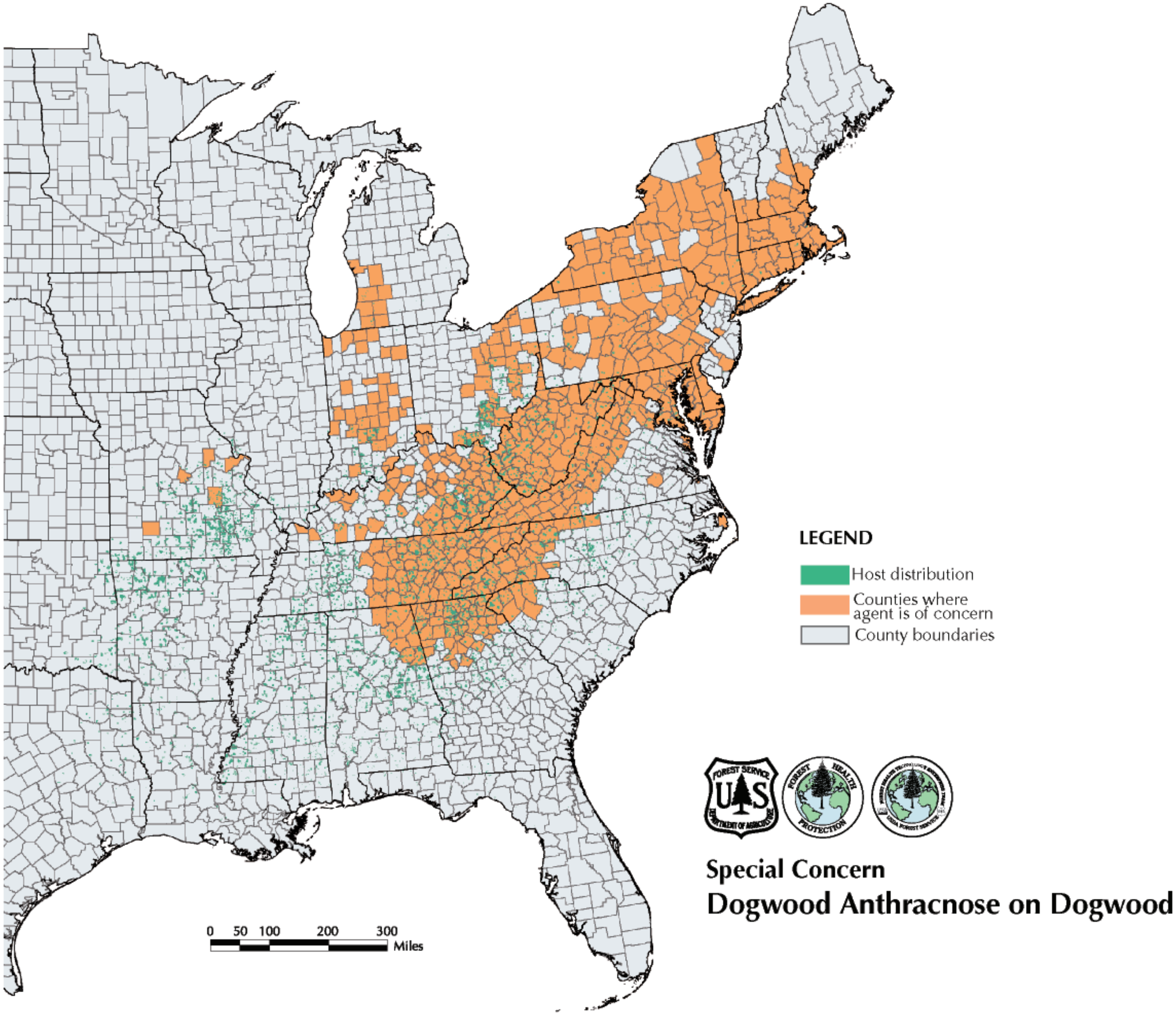
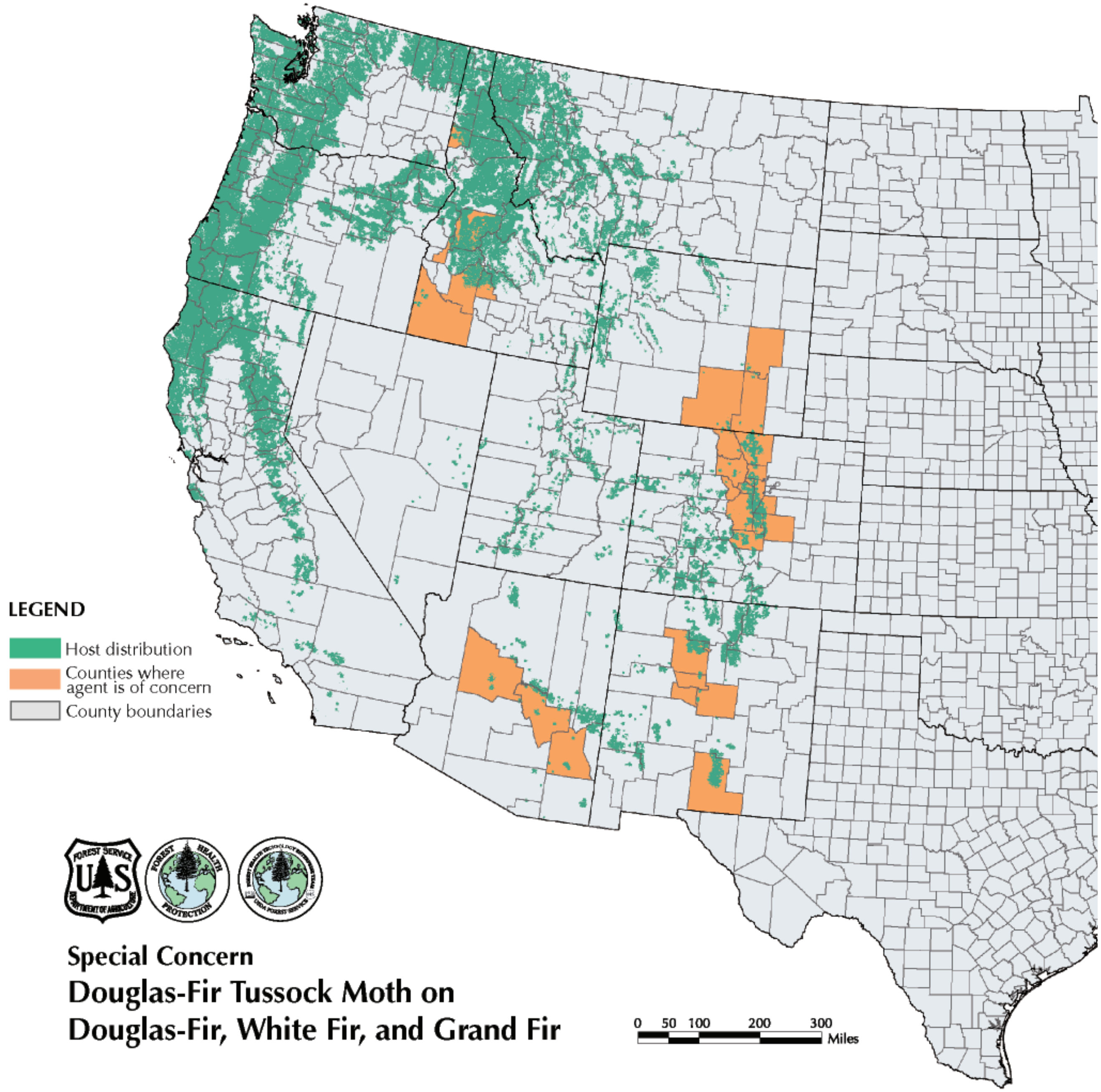

LEGEND
🟩 Host distribution
🟧 Counties where agent is of concern
▭ County boundaries
0 50 100 200 300 Miles
Special Concern
Dogwood Anthracnose on Dogwood

Figure 31



Special Concern

Douglas-Fir Tussock Moth on Douglas-Fir, White Fir, and Grand Fir

Figure 32

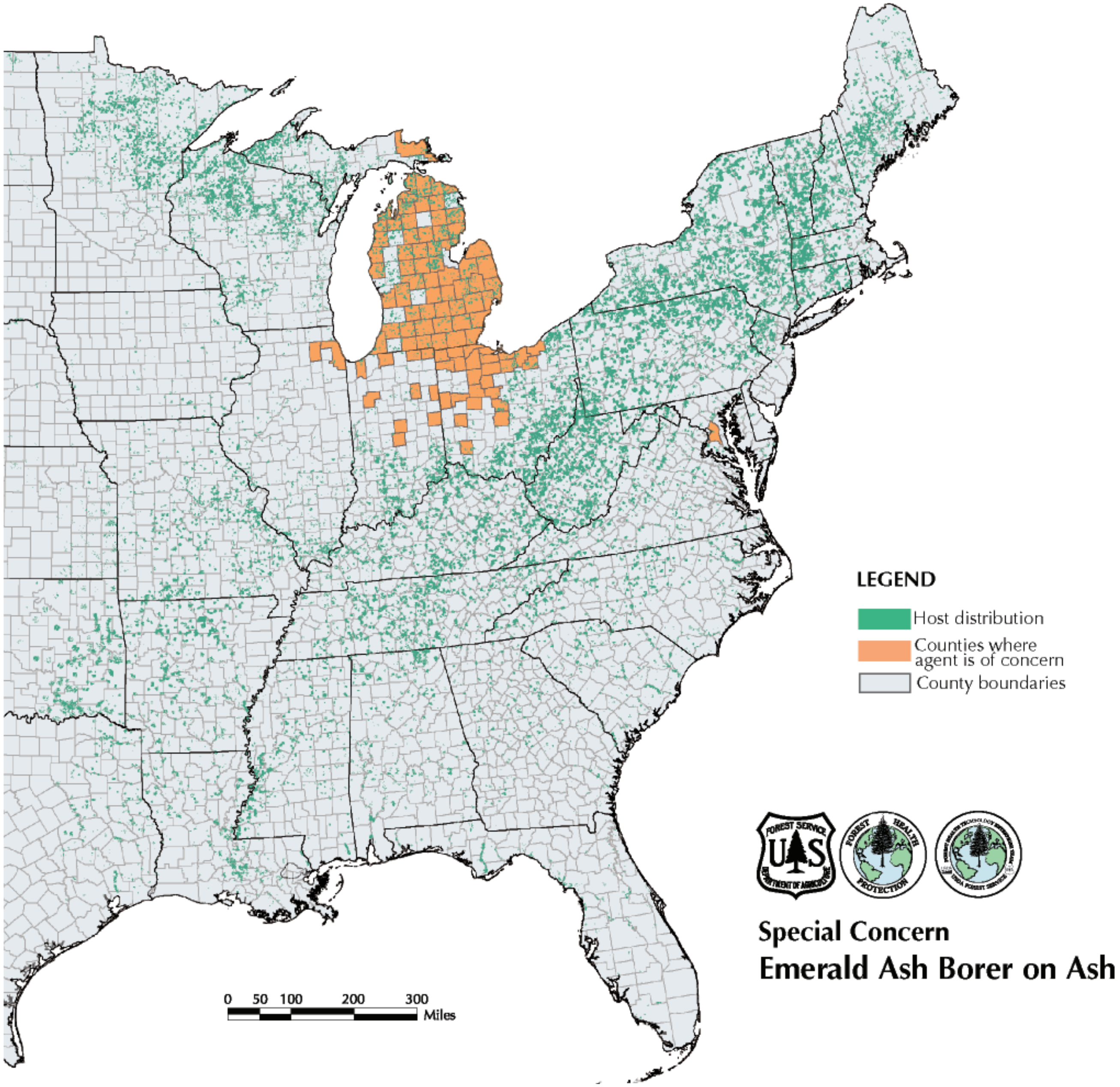

LEGEND
Host distribution
Counties where agent is of concern
County boundaries
Special Concern
Emerald Ash Borer on Ash
0 50 100 200 300
Miles

FIGURE 33

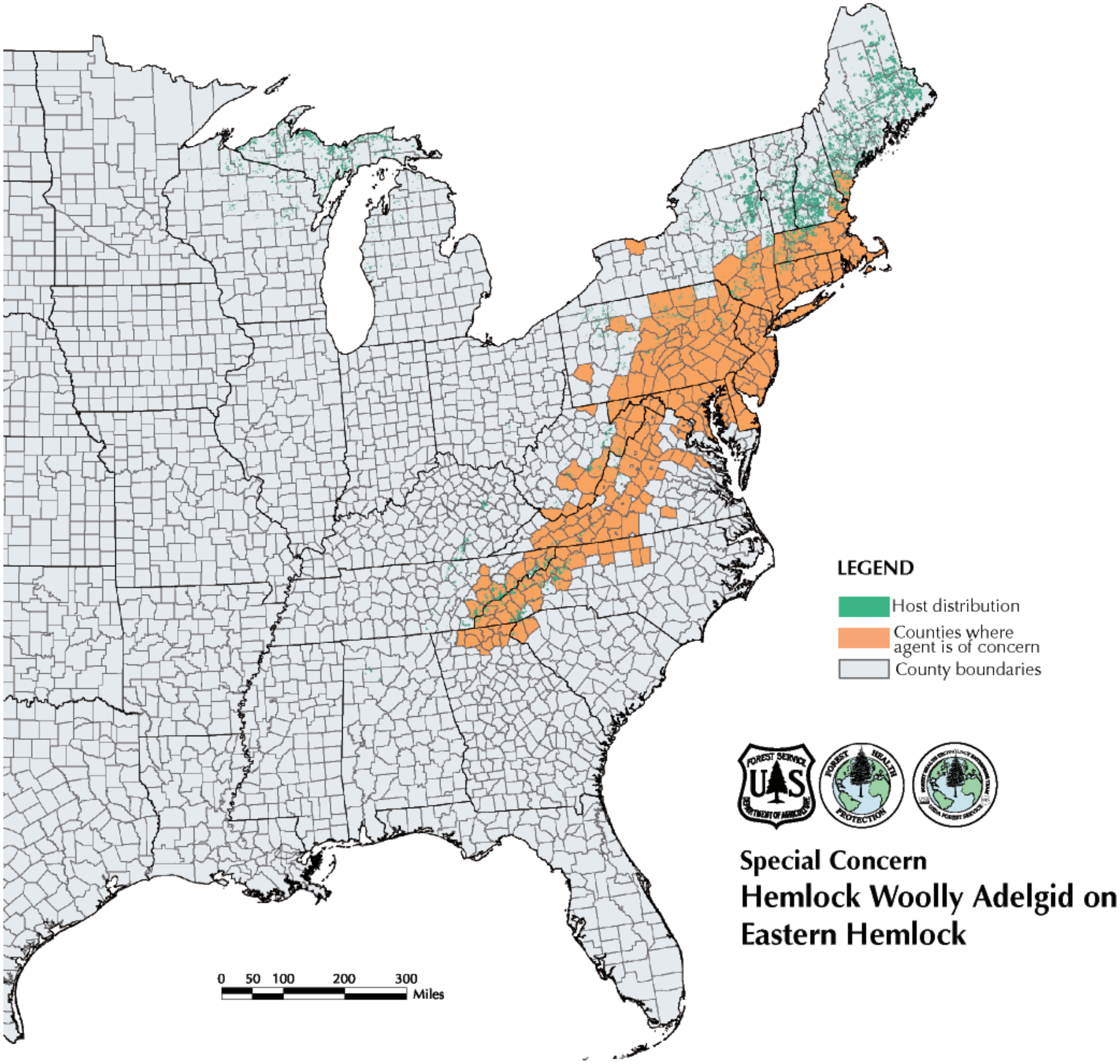

LEGEND
🟩 Host distribution
🟧 Counties where agent is of concern
▭ County boundaries
Special Concern
Hemlock Woolly Adelgid on Eastern Hemlock
0 50 100 200 300
Miles

FIGURE 34

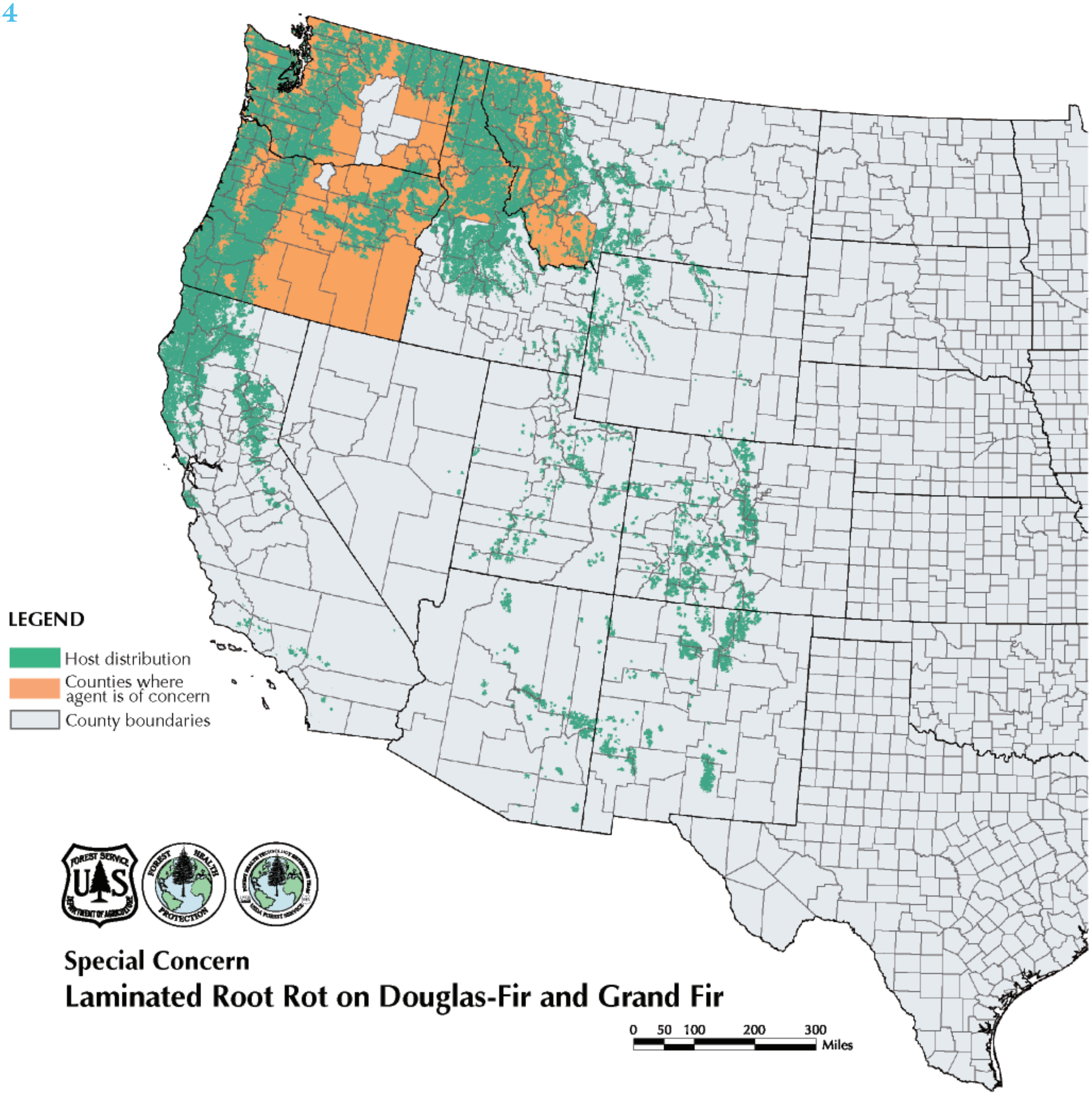

LEGEND
🟩 Host distribution
🟧 Counties where agent is of concern
⬜ County boundaries
Special Concern
Laminated Root Rot on Douglas-Fir and Grand Fir
0 50 100 200 300
Miles

Figure 35

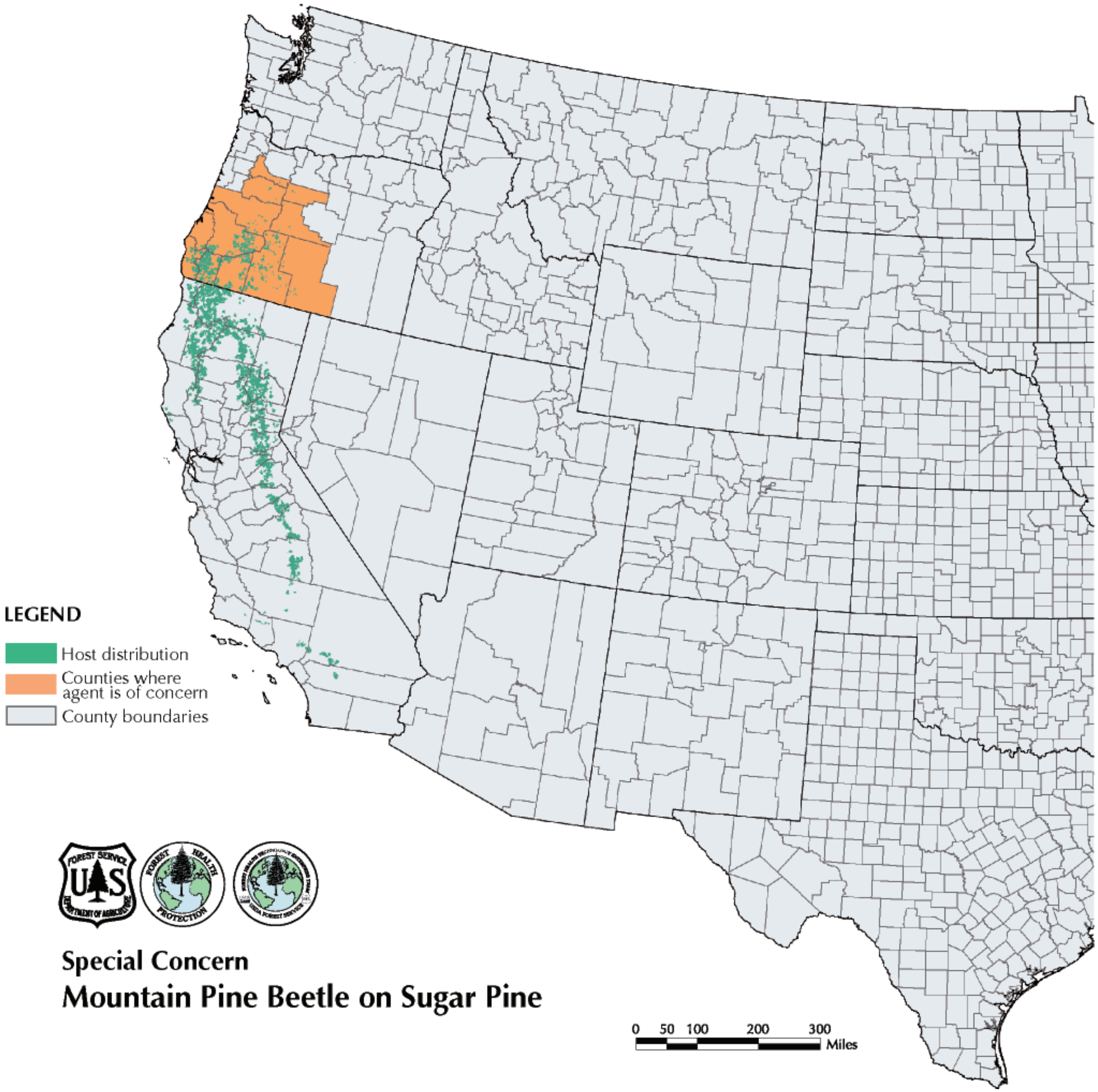

LEGEND
Host distribution
Counties where agent is of concern
County boundaries
Special Concern
Mountain Pine Beetle on Sugar Pine
0 50 100 200 300
Miles

Figure 36

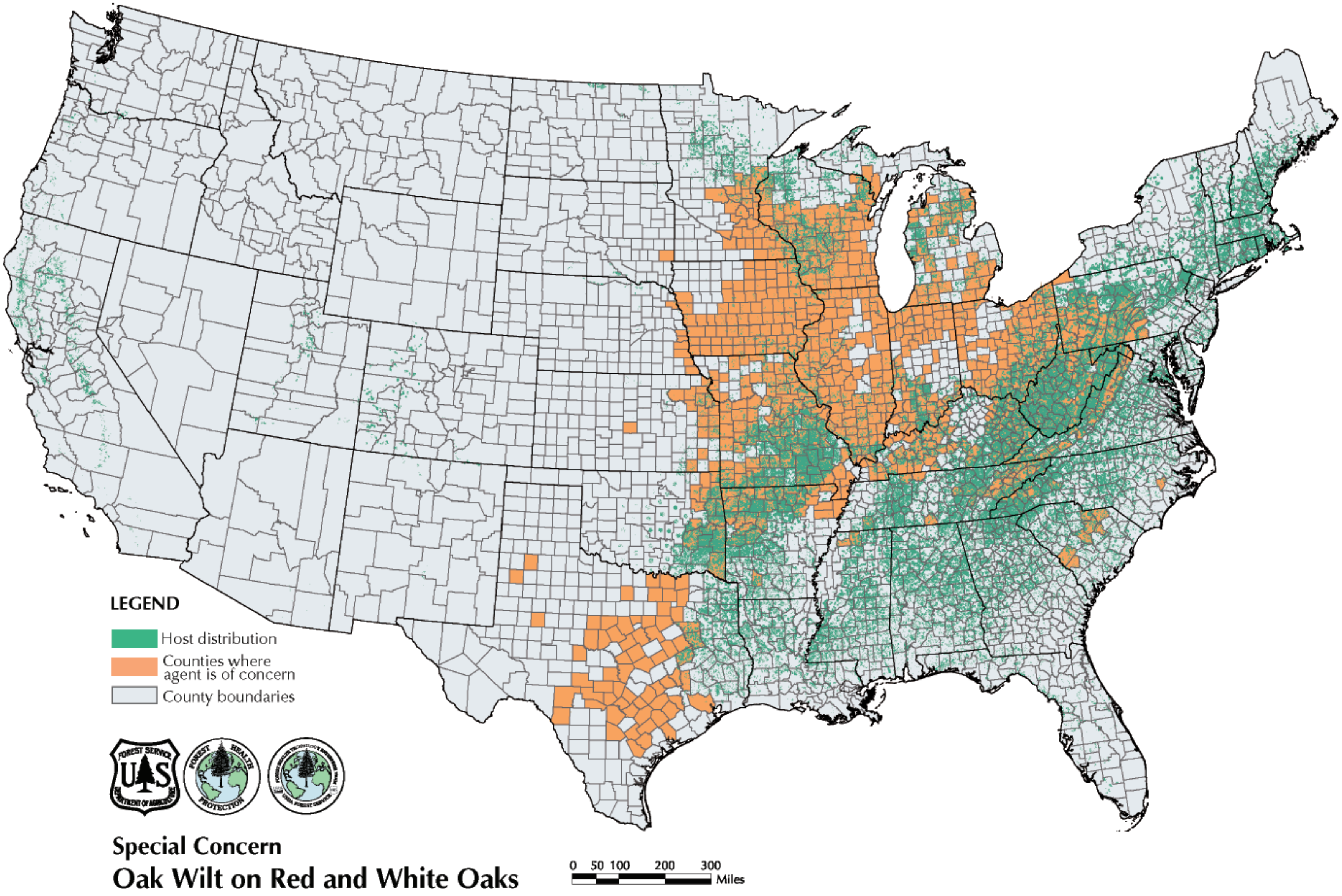
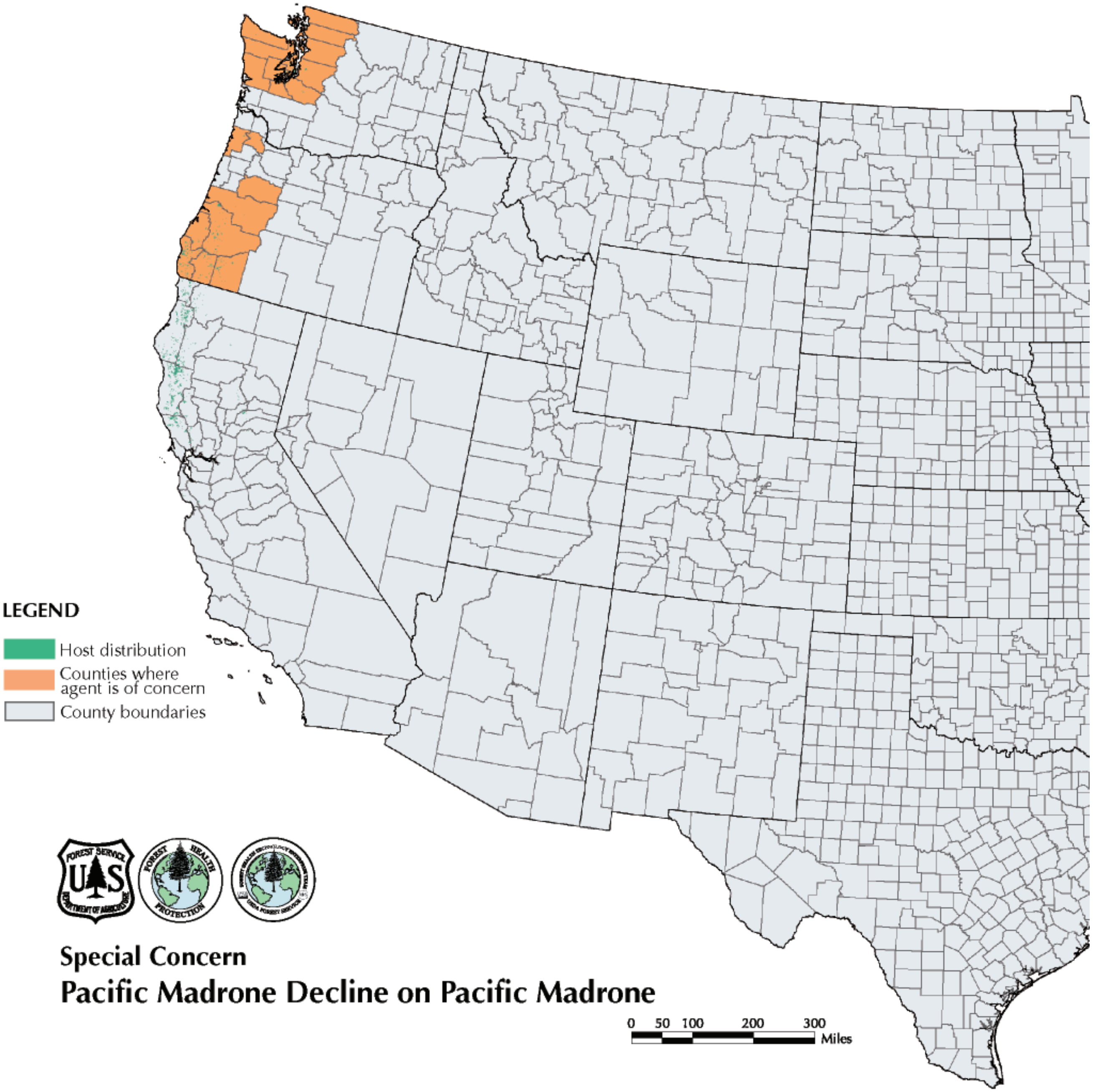

LEGEND
🟩 Host distribution
🟧 Counties where agent is of concern
☐ County boundaries
Special Concern
Oak Wilt on Red and White Oaks
0 50 100 200 300
Miles

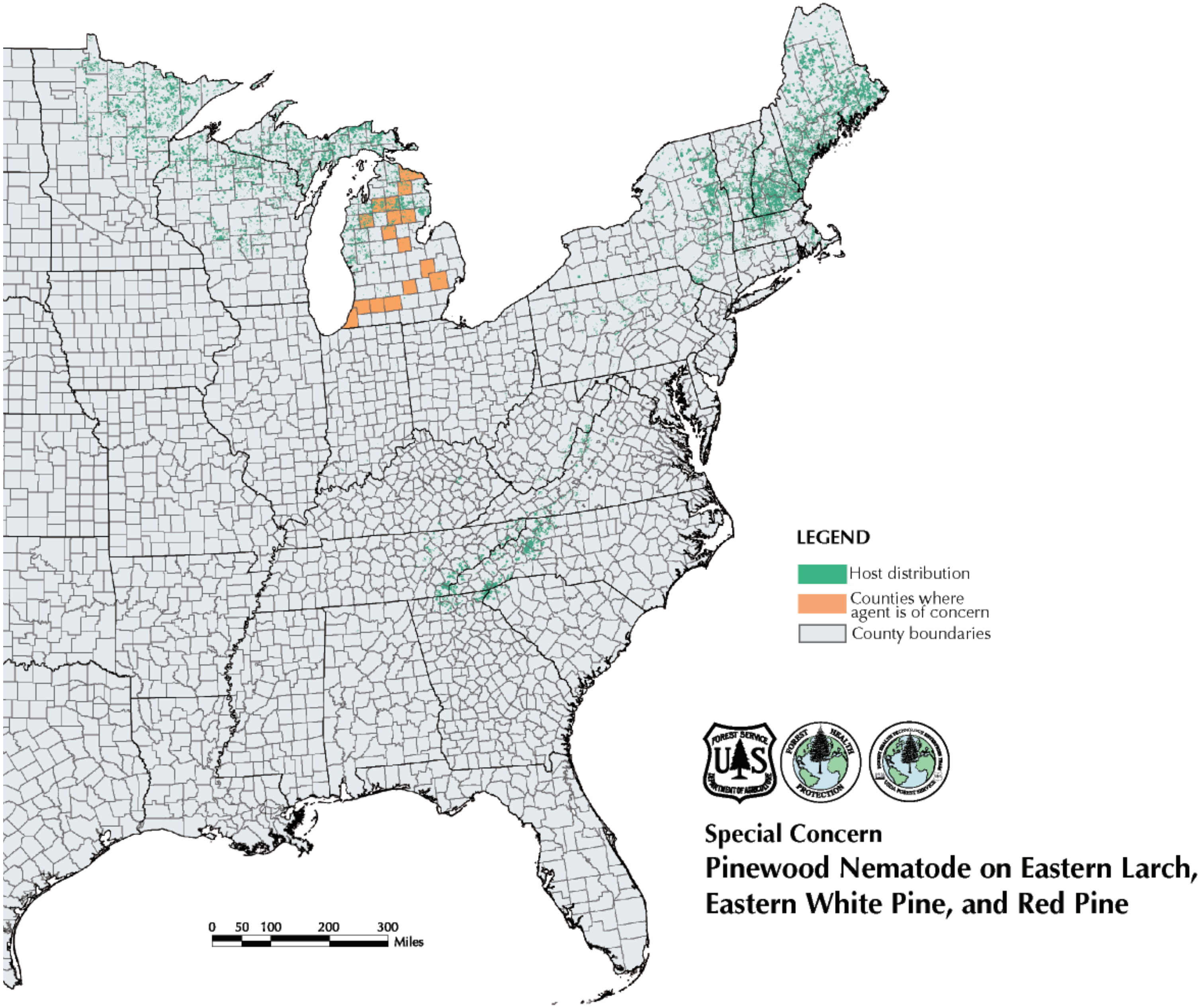
FIGURE 37



Special Concern

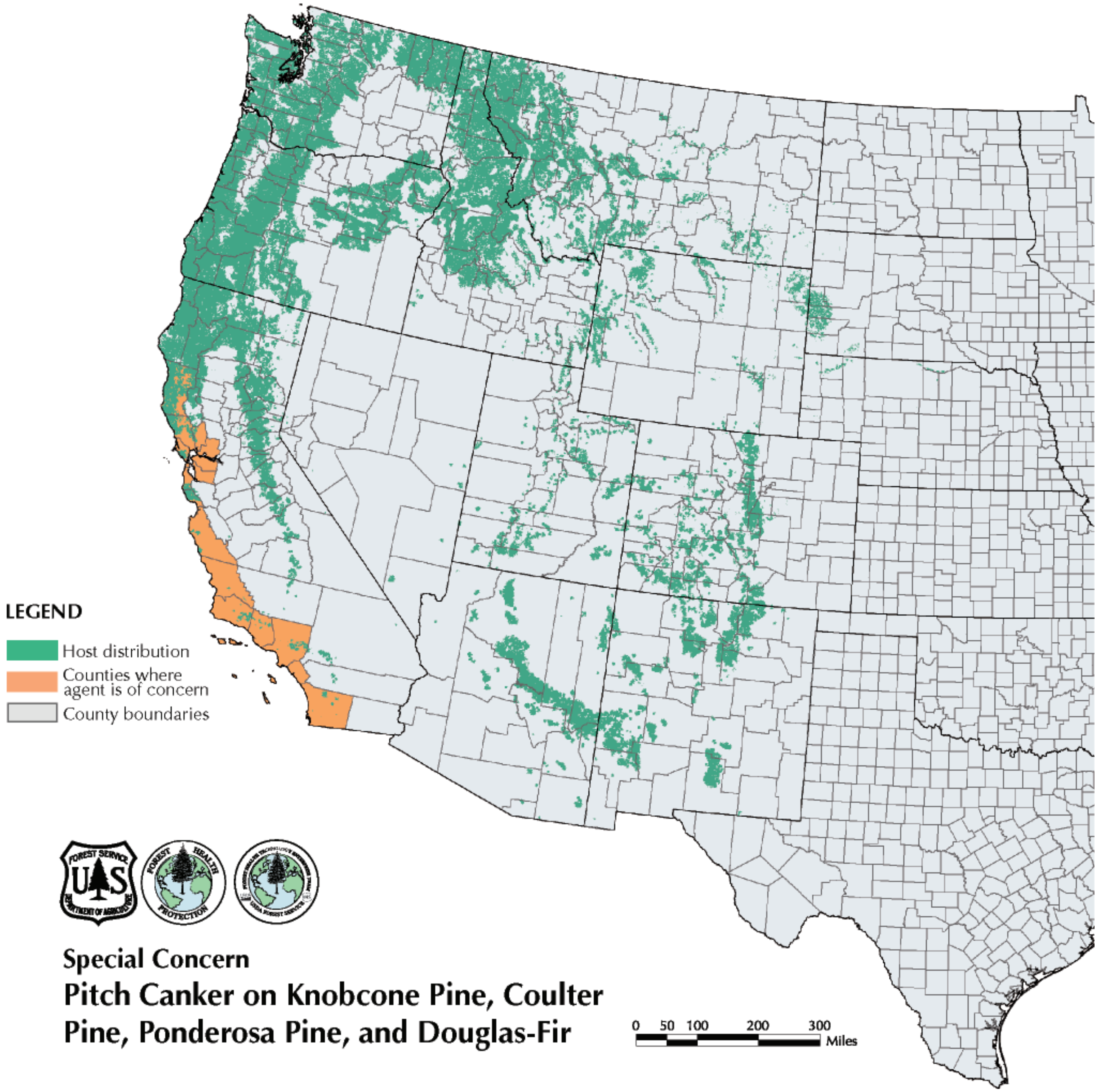
Pacific Madrone Decline on Pacific Madrone

Figure 38



Special Concern
Pinewood Nematode on Eastern Larch, Eastern White Pine, and Red Pine

Figure 39



Special Concern

Pitch Canker on Knobcone Pine, Coulter Pine, Ponderosa Pine, and Douglas-Fir

FIGURE 40

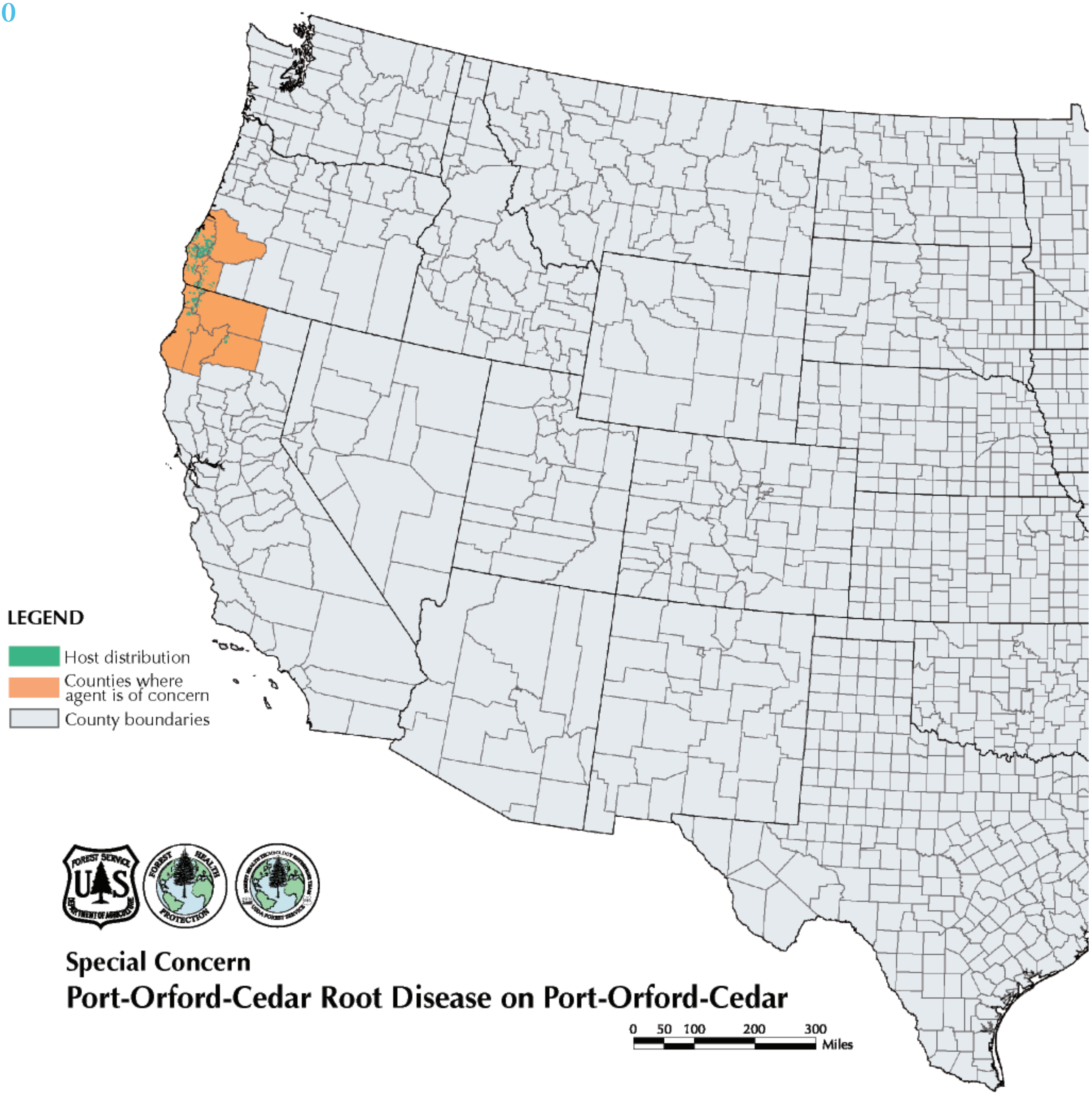

LEGEND
🟩 Host distribution
🟧 Counties where agent is of concern
☐ County boundaries
Special Concern
Port-Orford-Cedar Root Disease on Port-Orford-Cedar
0 50 100 200 300
Miles

Figure 41

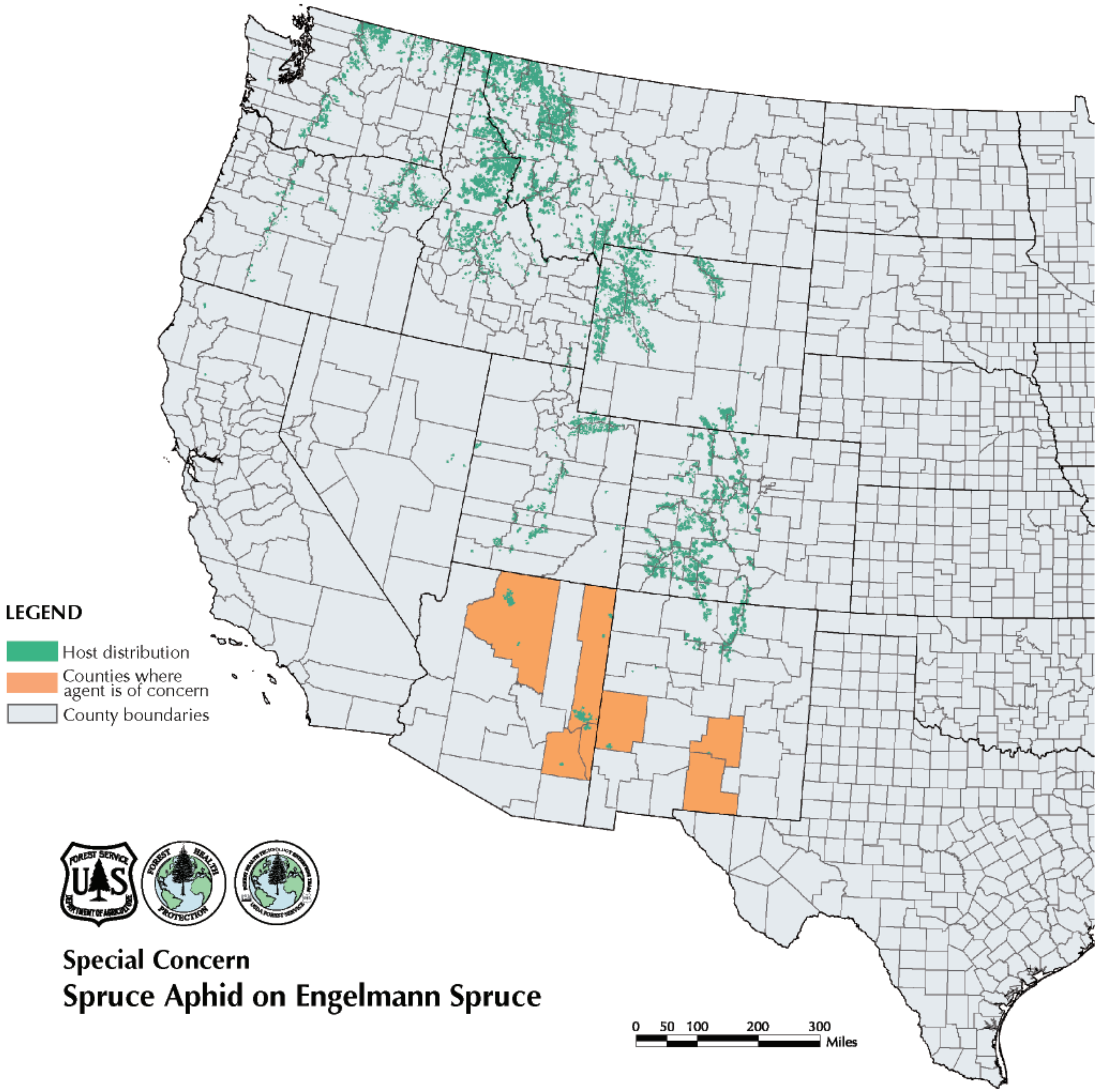
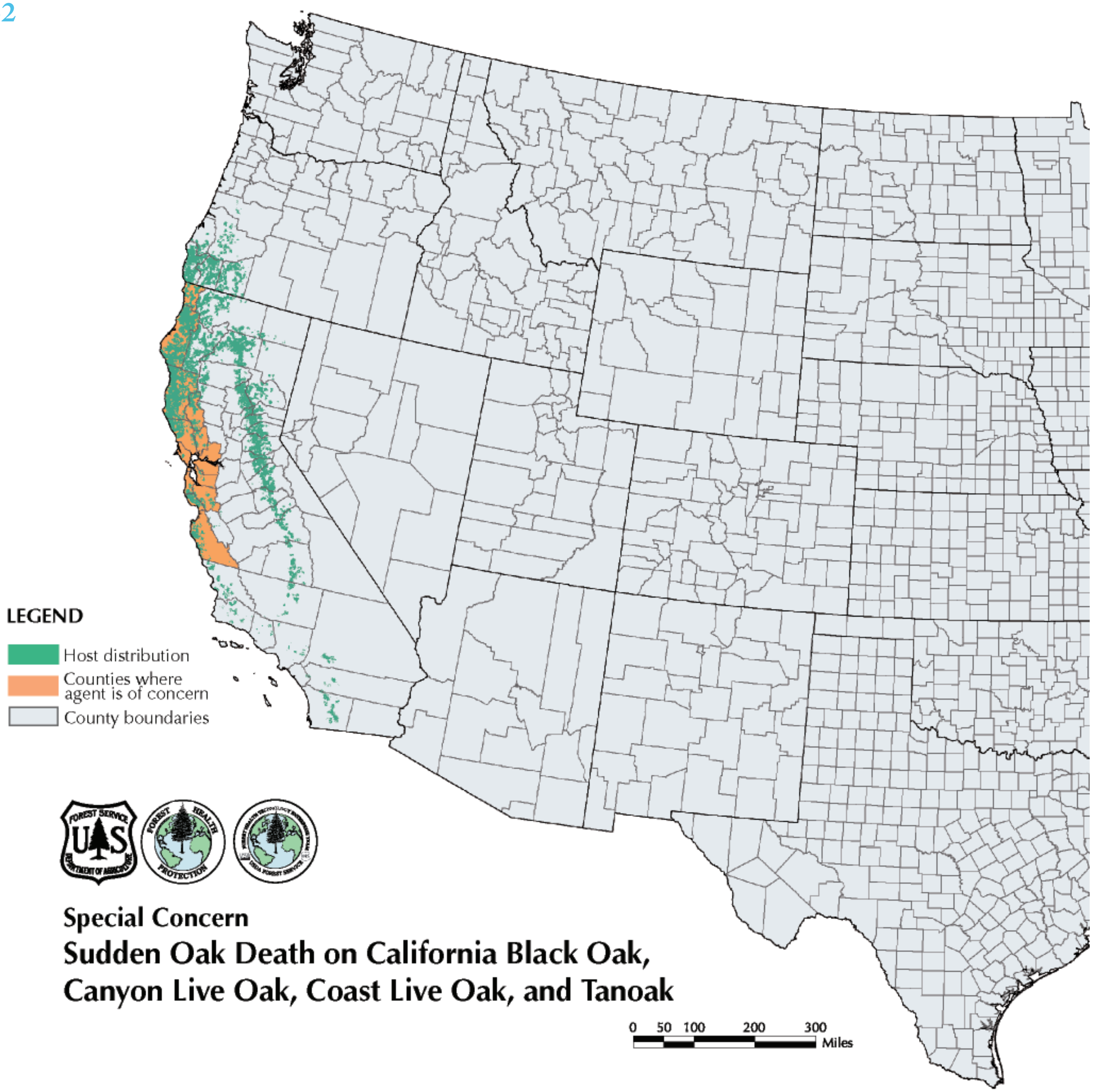
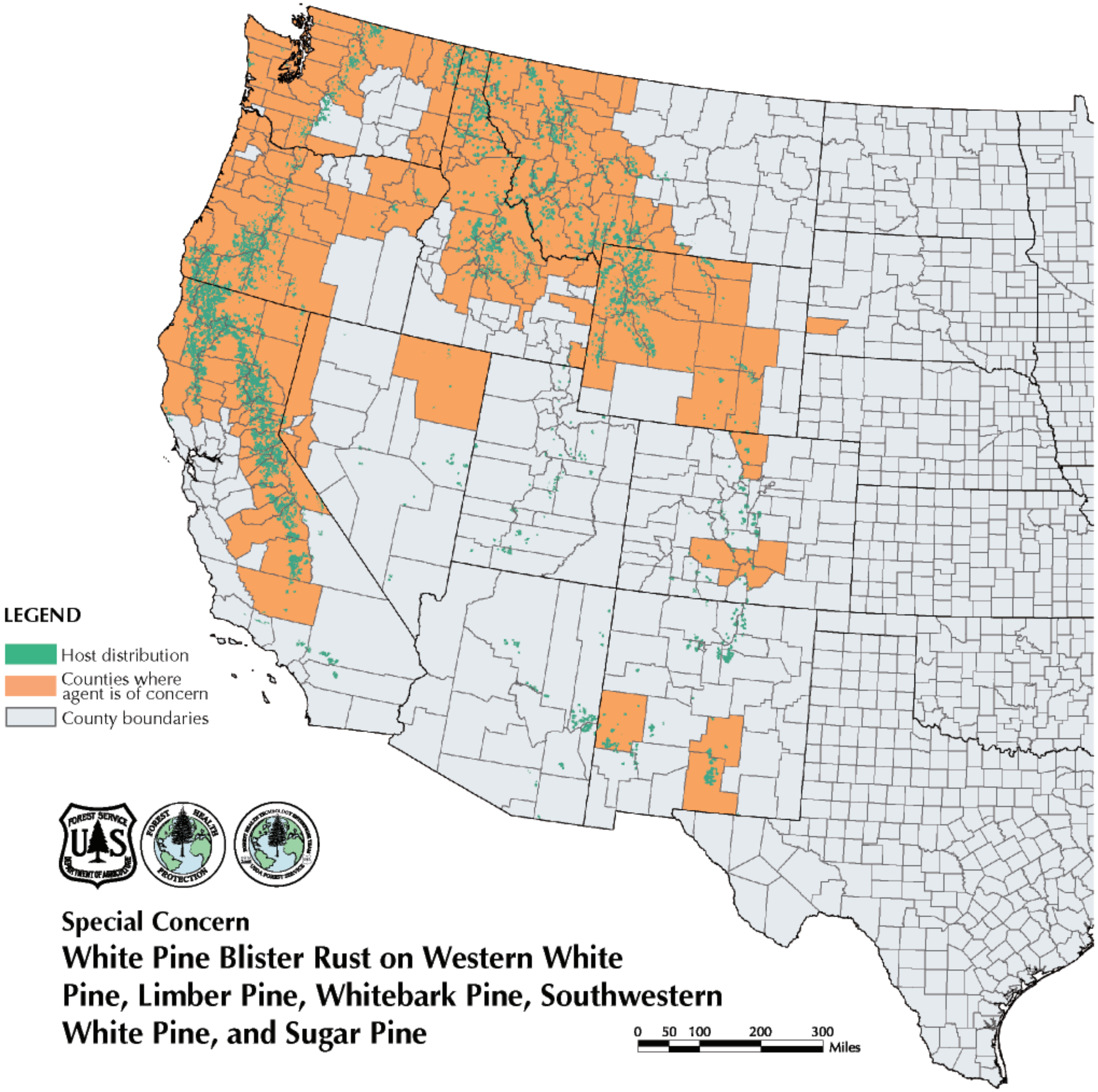

LEGEND
🟩 Host distribution
🟧 Counties where agent is of concern
▭ County boundaries
Special Concern
Spruce Aphid on Engelmann Spruce
0 50 100 200 300
Miles

FIGURE 42



Special Concern
Sudden Oak Death on California Black Oak, Canyon Live Oak, Coast Live Oak, and Tanoak

Figure 43



Special Concern
White Pine Blister Rust on Western White Pine, Limber Pine, Whitebark Pine, Southwestern White Pine, and Sugar Pine

GENERAL TRENDS: IDENTIFYING AREAS AT RISK

A detailed examination of the models used to simulate tree mortality potential for the top 11 risk agents revealed several trends. **TABLE 6** lists the criteria used in modeling, their relative ranking, and their frequency of use. The criteria used most often in all risk models were:

1. *Basal Area/Stand Density.* Host species are at higher risk to tree mortality when stocking levels are at or above 120 to 150 square feet of BA and/or 200 SDI, depending on host type and site conditions (**FIGURE 44**). Over-stocked conditions, particularly in regions where trees are subject to a lack of moisture or to low nutrients, result in stressed trees that are less able to survive attacks from insects or diseases. Basal area/SDI was the most frequently-cited criterion (at over 30 percent of total times cited) and was weighted as the primary criterion over 70 percent of the time.
2. *Diameter.* Older and therefore larger trees are usually at a higher risk of mortality, particularly in regions where environmental stress is high and stand conditions are poor. Fifteen percent of the time, diameter (through QMD, the surrogate used in this study for the tree diameter/age) was rated as the primary modeling criterion. Interestingly, diameter was cited almost as many total times (68 vs. 69) as BA/SDI.
3. *Percent Host.* Forest pests are able to become established and sustain higher populations, and are more likely to hit epidemic levels in regions with a high percentage of host material. Many forest pests do not disperse long distances and are geographically concentrated as a result. Percent host was cited 32 times, almost 15 percent of total citings for the top 11 risk agents.
4. *Site Parameters.* Criteria related to soils (*e.g.*, moisture content), climate (*e.g.*, precipitation and temperature), and topography (*e.g.*, slope and aspect) are also important factors for risk of tree mortality, but are always selected less than 10 percent of the time. Regions with little annual precipitation and/or with soils, such as coarse sands, that have little water available for plants are at the highest risk (**FIGURE 4**).

Areas characterized by one or more of the above four conditions are more predisposed to attack by multiple forest pests and are more likely to experience mortality from insects and diseases than other areas. With these high-risk conditions identified, greater focus can be placed on improving the quality of the base GIS layers that depict them, enabling forest-health specialists to better model areas at significant risk of mortality. Land managers can focus prevention strategies on reducing the prevalence of high-risk conditions.

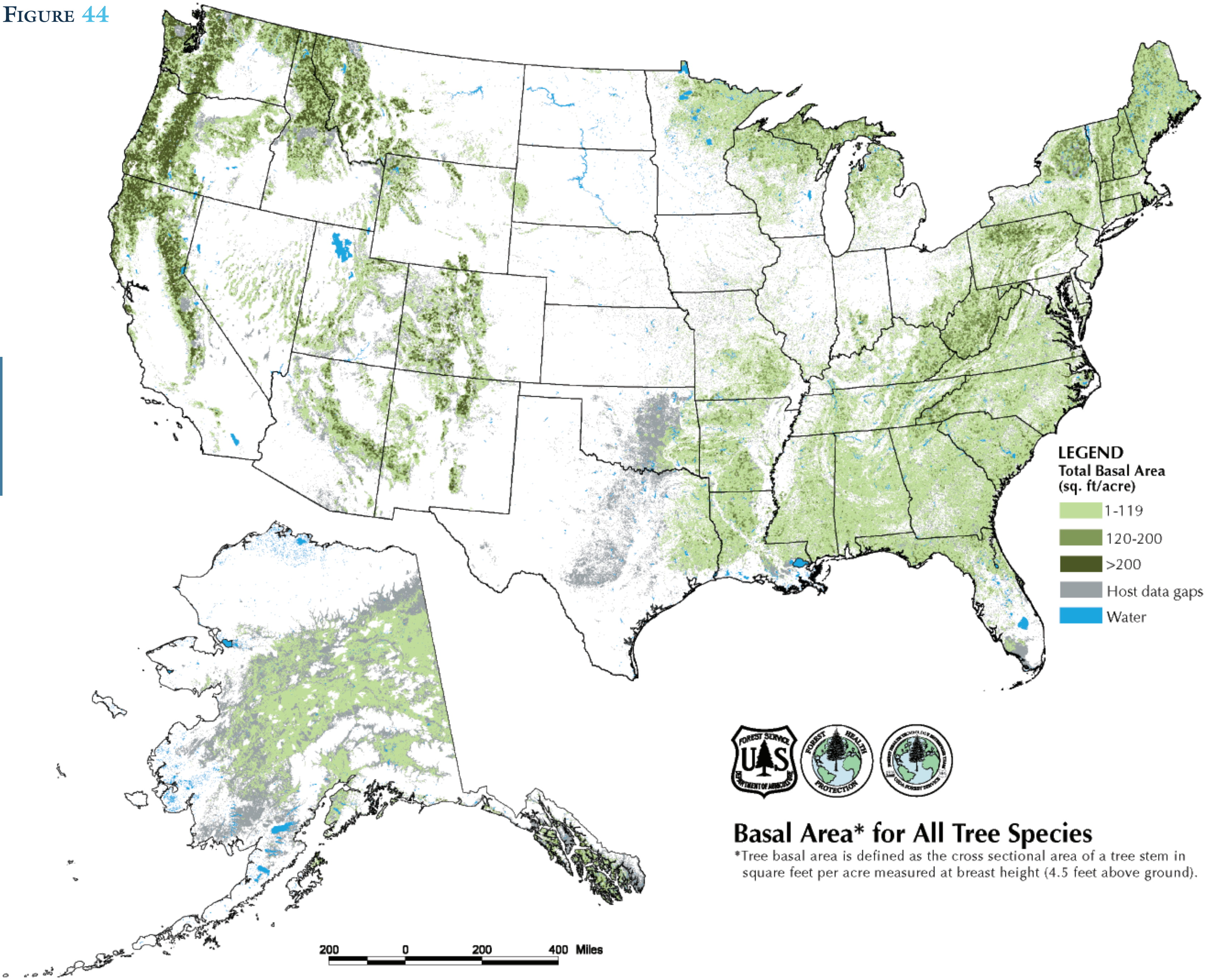
Table 6

KEY INPUT CRITERIA* FOR MODELING PRIMARY AGENTS OF MORTALITY

Criterion	Weighted as Primary Criterion	Percent of Time	Weighted as Secondary Criterion	Percent of Time	Weighted as Third or Lower	Percent of Time	Total Times Cited	Percent of Total
Basal Area/Stand Density*	58	71.6	11	14.9	0	0.0	69	31.5
Diameter*	12	14.8	33	44.6	23	35.9	68	31.1
Percent Host*	10	12.3	21	28.4	1	1.6	32	14.6
Soil Characteristics	0	0.0	1	1.4	16	25.0	17	7.8
Climate	0	0.0	1	1.4	11	17.2	12	5.5
Topography	1	1.2	4	5.4	3	4.7	8	3.7
Proximity to Infestations	0	0.0	2	2.7	4	6.3	6	2.7
Other	0	0.0	1	1.4	6	9.4	7	3.2
Total Citings/Total Percentage	81	100.0	74	100.0	64	100.0	219	100.0

*Derived from FIA forest parameters

FIGURE 44



Basal Area* for All Tree Species

*Tree basal area is defined as the cross sectional area of a tree stem in square feet per acre measured at breast height (4.5 feet above ground).

COMPARISON WITH THE 2002 NATIONAL RISK ASSESSMENT AND OTHER DATA

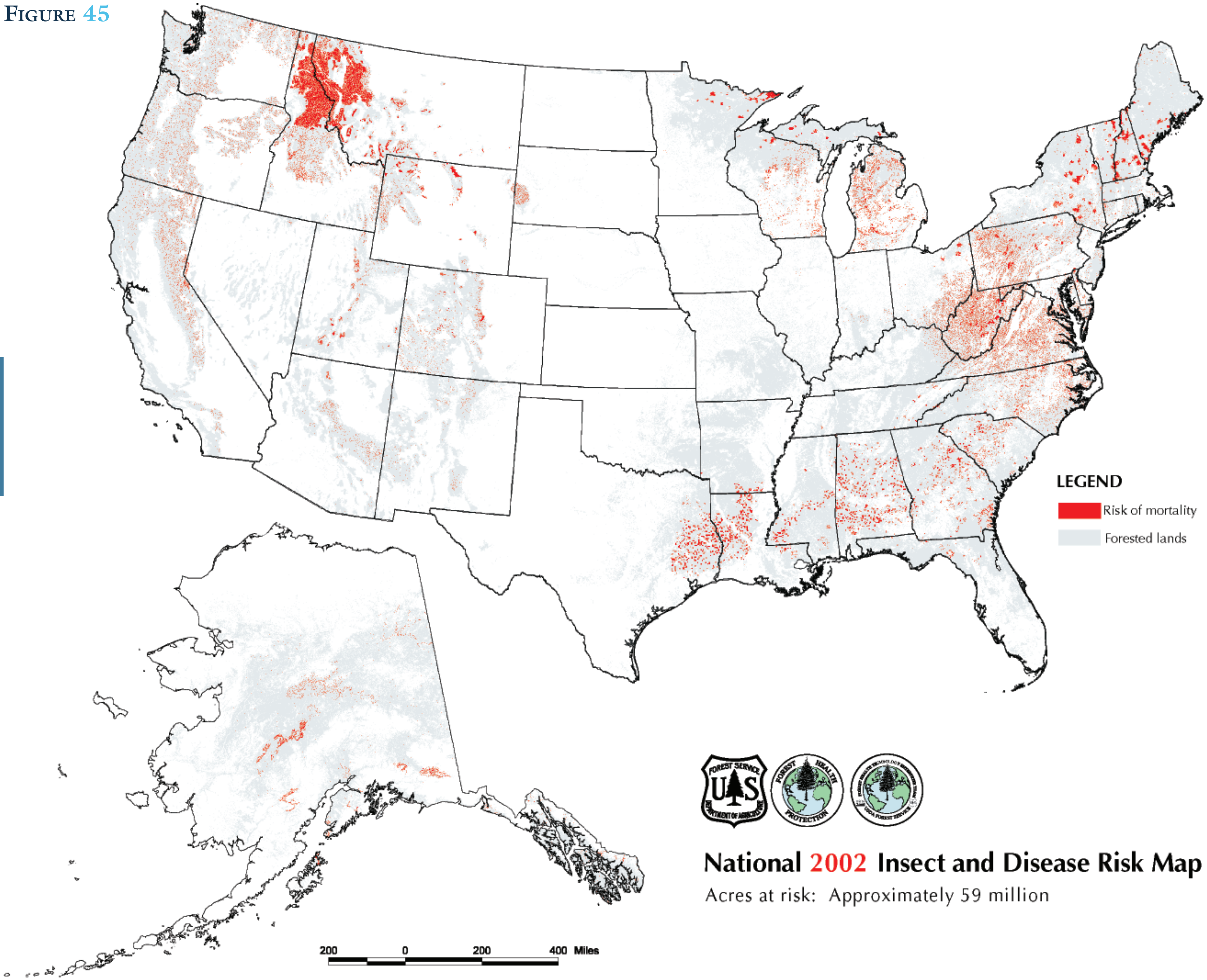
The 2002 risk assessment (Lewis 2002) identified 59 million acres of forest land at or above the 25-percent-mortality threshold, with 2.6 million and 56.4 million acres in Alaska and the contiguous United States, respectively. The 2006 assessment yielded a similar acreage in Alaska (a 5-percent increase) and a 1.2-million-acre (2.2 percent) decrease in the contiguous United States. Although the numbers are close and seem to suggest similar rates of pest activity, a close comparison of the 2006 location and severity (**FIGURE 6**) with that of the 2002 risk assessment (**FIGURE 45**) shows this not to be the case.

Although valuable when assessing regional and national changes in risk, direct comparison of the 2002 (Lewis 2002) and 2006 risk assessments, is complicated by several differences in the way the projects were undertaken:

- In 2002, mortality agents were represented as acting on one of three Alaskan forest types, one of 11 western forest types, or one of 10 eastern forest types (Zhu and Evans 1994). In 2006, each risk-agent/host pair was represented by at least one of 188 models, all of which were compiled to form a national composite (NIDRM) representing mortality potential. These models were all run on a central server and documented using a standard spreadsheet template (see **Appendix C**).
- In 2002, the affected areas of many mortality agents began as hand-drawn polygons, which:
  - » were rasterized and assigned a random placement of pixels to achieve a desired mortality percentage, or
  - » were tested for coincidence with other attribute layers, such as forest types, ecoregions, FIA stand characteristics, and historic insect and disease survey records.

  In 2006, a standard set of GIS data layers was used to construct the multi-criteria models built by regional specialists.
- More risk agents and host species were examined in the 2006 risk assessment than in 2002.
- For the earlier report, forest-health specialists used a variety of strategies to delineate areas at risk across a forest-type map. The standard multi-criteria modeling process was used in 2006 to assess potential mortality for each risk agent/host species pair.
- In 2002, areas at risk tended to conform to national forest and regional boundaries. In 2006, Bailey's (2004) ecoregional provinces and section boundaries, rather than regional or political boundaries, were used to define different geographies within which models were applied.

FIGURE 45


LEGEND
🟥 Risk of mortality
⬜ Forested lands
National 2002 Insect and Disease Risk Map
Acres at risk: Approximately 59 million
200
0
200
400 Miles

- The definition of risk in the current risk assessment applies only to trees of greater than 1 inch in diameter; the 2002 assessment included all trees.

Because the 2002 risk assessment used fundamentally different modeling processes and data, the location and severity of areas at risk from the two projects should not be directly compared. We believe the 2006 risk assessment is an improvement and a benchmark for future comparisons of risk.

Of primary significance—the 2006 risk map created a standardized process. Now in place, the new interactive framework will facilitate periodic re-assessments as data quality and models improve through time.

EVALUATING INDIVIDUAL MODELS

Two output maps for each of the 188 models and the model documentation in the form of a spreadsheet can be viewed at the FHTET website, (see FIGURES 46 AND 47 for examples). These data are provided online so that the quality of every model and its resultant maps can be evaluated. In addition, the host distribution is depicted on each map so that the quality of the host surfaces can also be examined.

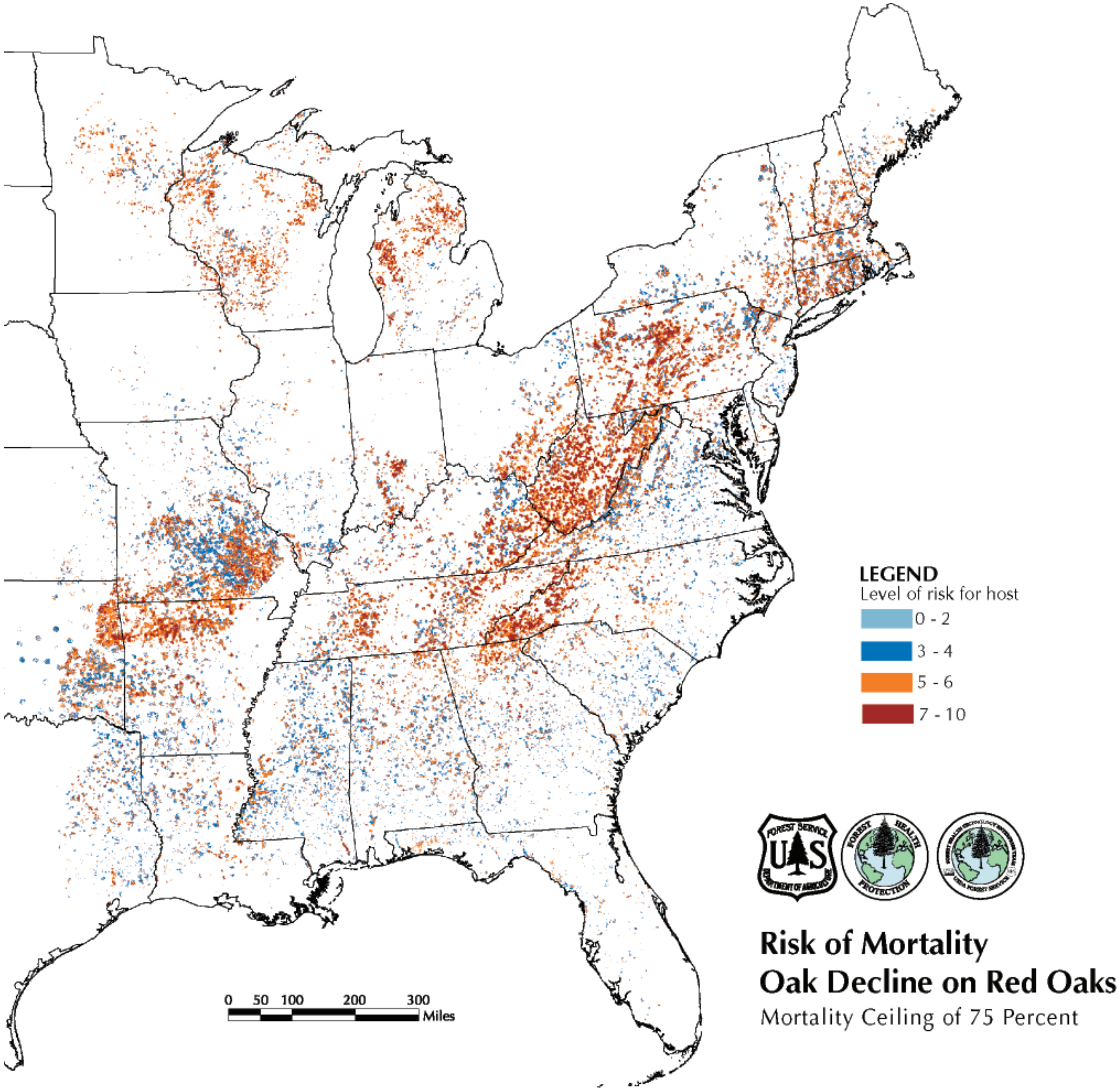
Errors in either a model or the host distribution can result in significant inaccuracies in the final composite risk map. Feedback on the quality of models and host distributions is critical for the continued development and improvement of NIDRM.

The first of the two maps for each model at the risk map website represents the likelihood, or potential, for a tree species to experience mortality over the next 15 years (see FIGURE 46, presented here so that the viewer can evaluate the quality of the risk models). Because the first map is a direct output from a multi-criteria model (see Methods, page 7, Step 2), values range from 0 to 10. Locations depicting high risk represent areas where all or nearly all of the criteria for a model were met.

Depending on the mortality ceiling, the amount of host in an area, and the number of risk agents modeled in that area, a pixel may or may not meet the 25-percent threshold depicted on the national composite map, no matter how high the potential for mortality loss is.

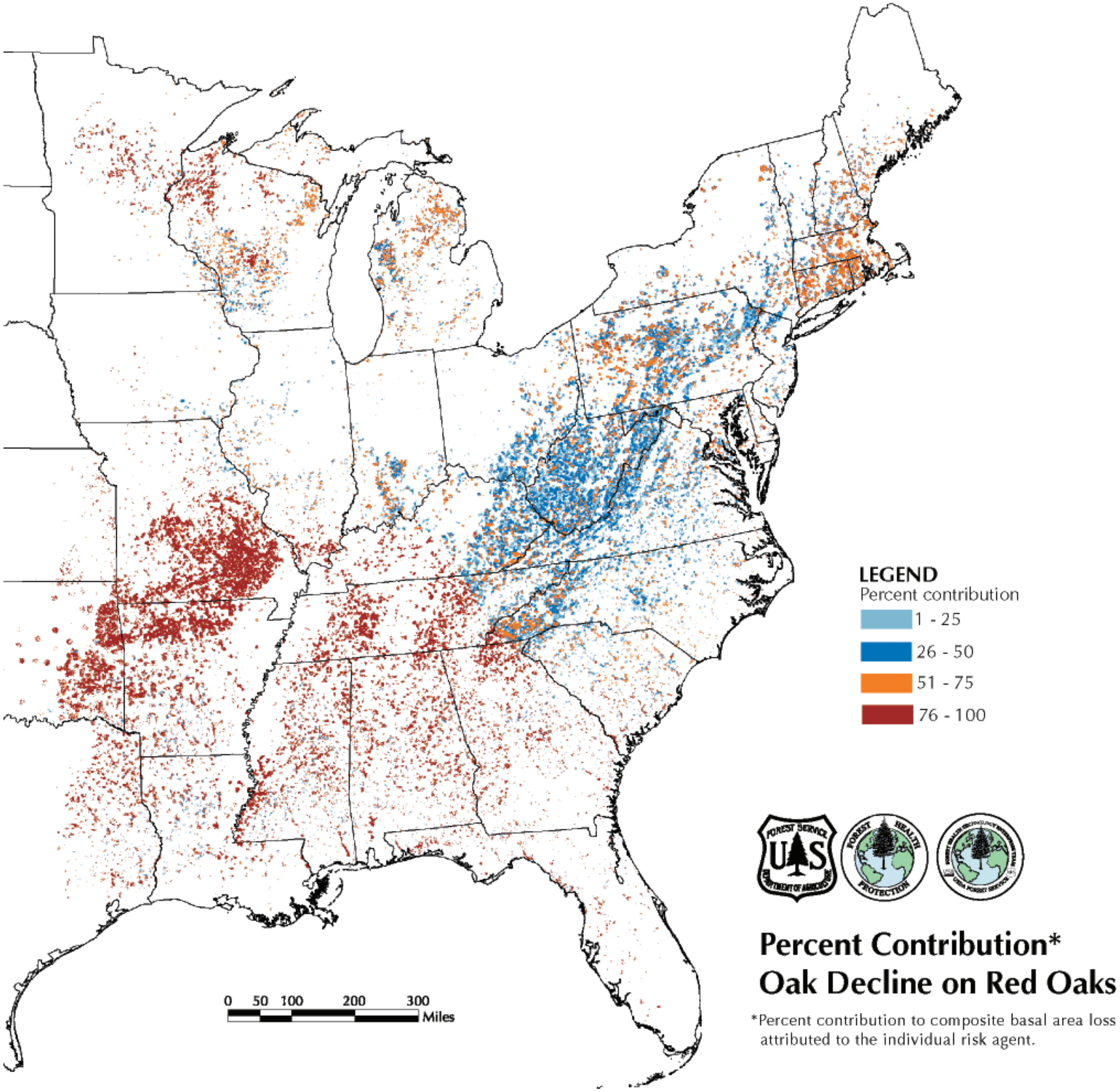
The second map of the pair (FIGURE 47) shows how much an individual model contributes to the national risk map composite and may be used to determine which risk agents are contributing to the basal area loss on NIDRM. Values in the second map depict the percent of the total BA loss potential represented by the particular model.

Figure 46



Risk of Mortality
Oak Decline on Red Oaks
Mortality Ceiling of 75 Percent

FIGURE 47



Percent Contribution*
Oak Decline on Red Oaks

*Percent contribution to composite basal area loss attributed to the individual risk agent.

CONCLUSIONS

Future Data and Model Development

Undertaking a national risk assessment has helped to define data and model development needs for future work. Several weaknesses in data availability and quality and in model availability and scope were identified during this study, and we encourage further development in two areas:

- Nationwide forest parameter layers, and
- Broad-scale studies aimed at ascertaining variations in insect and pathogen behavior.

The lack of spatially explicit nationwide forest parameter layers, such as BA, QMD, and SDI provided significant impediments during this project. Without adequate host species information, spatially based risk assessments are unattainable even with very accurate models of risk agent behavior. In order to complete NIDRM, the RMIT developed a set of surfaces depicting various forest attributes. Although adequate, these data were less than optimal in terms of accuracy and precision.

We recommend the development of a complete set of national 30-meter resolution layers representing BA, QMD, and SDI for all the tree species[16] examined in this report. High-resolution data provides the opportunity to generate risk assessments at multiple scales, ensuring consistency among future NIDRM products, local risk maps, and pest trends.

Unfortunately, the current trend has been to produce more generalized forest-type maps in the belief that these maps would serve a greater variety of potential clients (Brohman and Bryant 2005). In actuality, generalized forest cover information is rarely useful for predicting pest behavior because the density and distribution of individual host species are required but not available (see Table 6). Greater detail would be more applicable for forest insect and pathogen predictions where the location, density, and condition of individual tree species are most important.

Many of the models brought into the 2006 risk assessment rely on a limited set of data and likely do not fully capture interactions and/or variations in forest pest behavior. As a result, regional studies and assessments of pest behavior are needed. With the availability of GIS and spatially enabled statistical packages, large landscape-level assessments can now be efficiently conducted.

In order to facilitate access to risk assessment products, FHTET has begun development on multiple interactive web pages that will be accessible from the FHTET website.

To increase participation and expedite future model development, FHTET is developing a custom toolset that will allow seamless transfer of GIS technology to resource managers engaged in risk assessments. Updates on the development of

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[16] See Appendix B: Risk Agent and Host Species List

this and other tools are available at the FHTET website.

The 2006 risk assessment is based on current or past climatic conditions. The authors recommend that future enhancements include potential impacts of climate change on host-pest interactions as well.

RISK ASSESSMENT VALIDATION APPROACH

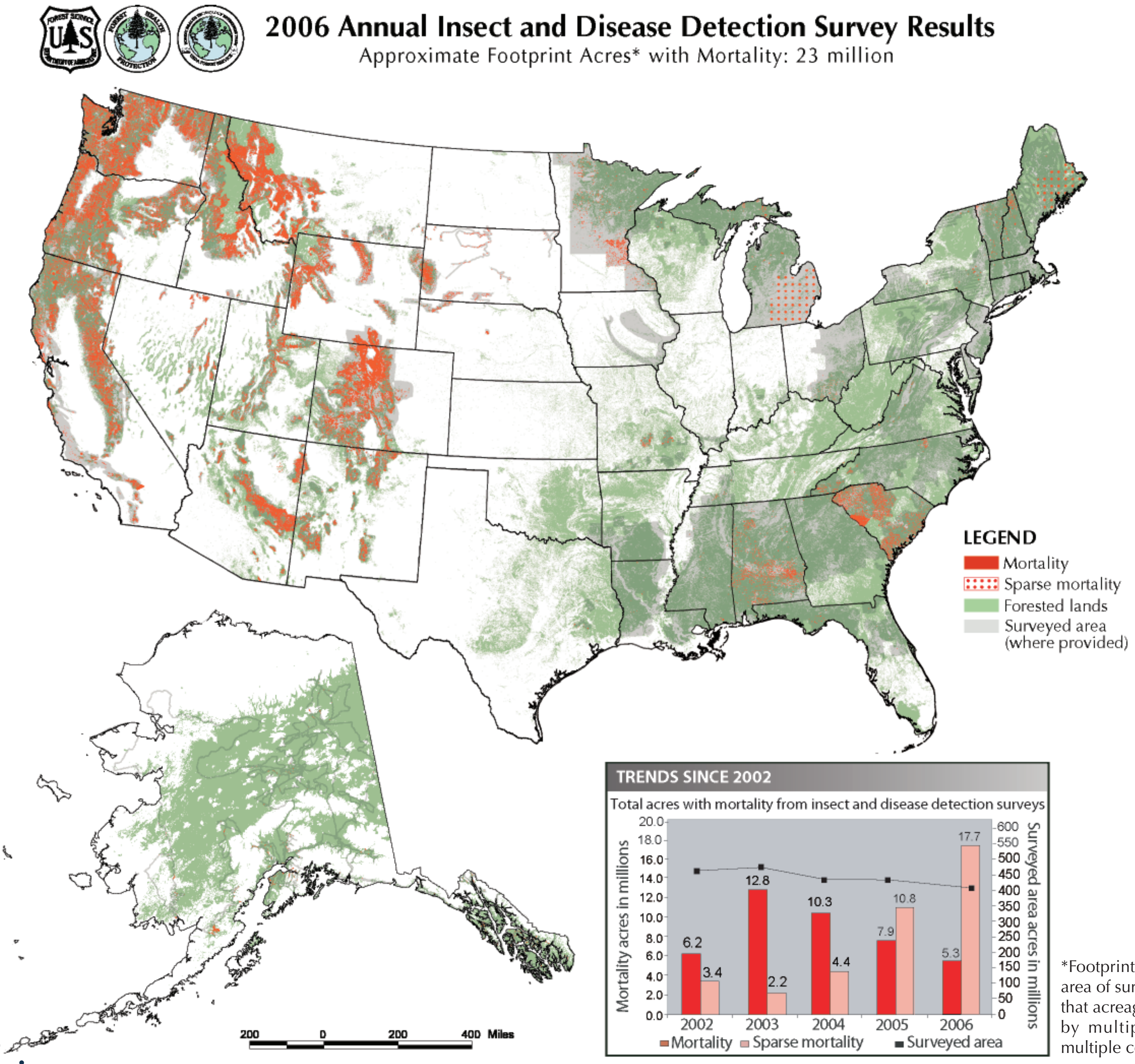
With the 2006 risk assessment complete, the RMIT hopes to begin work on validating and updating models in anticipation of future risk assessments. Currently, the Forest Service and its partners collect a wide range of data on forest pest impacts and behavior. These data provide various opportunities to evaluate the process and quantify errors. Validation studies would also provide greater quantitative insight into the spatial scale at which NIDRM products may be used with confidence. Three datasets have the potential to provide the bulk of the information needed to evaluate NIDRM: annual insect and disease surveys, permanent plot data, and FIA data.

Each year, the Forest Service and other cooperating state and federal agencies conduct insect and disease detection surveys to collect and compile data on forest insect damage and disease activity nationally. These data provide an overview of annual forest pest activity (FIGURE 48) and may be used to test the predictive capability of NIDRM. In some regions, insect and disease detection survey results are available as far back as the 1940s, providing a detailed historic account of forest pest activity that can be overlaid with NIDRM. While the insect and disease detection survey data can be used to evaluate temporal trends over large areas, direct comparisons between these data and NIDRM will be difficult due to differences in scale and precision.

The Forest Service has installed a series of permanent plots for the Pest Trend Impact Plot System (PTIPS), on which data are collected regarding pest trends, impacts, and behaviors. Although mostly located in the western United States, these plots are situated in a diverse set of forest types, providing a broad overview of forest pest behavior in a wide range of ecosystems. Despite the scale differences between NIDRM and the PTIPS data, the plot system will provide information about broad regional trends. In addition, plots can be intersected with or overlaid onto GIS layers to identify correlations between risk agent behavior and site conditions.

FIA plot data also can be used to validate the accuracy and precision of NIDRM as tree mortality is measured on FIA plots. Like the PTIPS plots, broad trends in mortality patterns can be discerned and GIS analysis can be performed to identify relationships between pest activity and site parameters.

FIGURE 48



*Footprint acres: A measure of the area of surveyed mortality, including that acreage simultaneously affected by multiple agents, but without multiple counting of acres.

Conclusions

DID NIDRM MEET THE DESIRED OBJECTIVES?

The 2006 risk assessment effort met most of the project's intended objectives. First, it is an *integrating* process. Various types of models—some empirical, others based on expert opinion, and some derived from ecological principles—reside within the same framework. Although the final output is indeed a map, the GIS-based framework represents a *fully transparent and repeatable* process for conducting national insect and disease risk assessments. The models and framework provide an *interactive* and accessible environment so that changes can be rapidly incorporated into the composite product. The process is also *scalable*, as several regional higher-resolution efforts that have spun off from the 2006 risk assessment have shown (Krist et al. 2007). Finally, this report and the previously mentioned website provide a concise set of information that can be used in future strategic planning efforts.

The framework inherently allows for comparability across broad geographic regions, though model development requires seamless coordination among Forest Service Regions. Future iterations of the National Insect and Disease Risk Map will include stronger oversight on selection, coordination and implementation of regional models.

IMPLICATIONS OF NIDRM: MONITORING, EVALUATION, AND PLANNING

Despite the relatively coarse resolution and (currently) non-validated precision of NIDRM, the framework and map are useful tools for describing broad landscape-level patterns of potential future forest insect and pathogen activity. Together, NIDRM and the risk assessment framework presented in this report should guide the selection of locations for future monitoring and the evaluation of prevention strategies.

With a standard interactive modeling framework in place, the 2006 risk assessment can now serve as a standard process for projecting the impact of insects and diseases on America's forests. The interactive nature of the modeling process enables forest-health specialists to update models and data, introduce new information (*e.g.*, climatic trends), and produce updated projections of risk.

ACRONYMS

AML	Arc Macro Language®
AVHRR	Advanced Very High Resolution Radiometer, a satellite-based sensor
AWC	Available Water holding Capacity
BA	Basal Area
DBH	Diameter at Breast Height
DCW	Digital Chart of the World
DEM	Digital Elevation Model
DI	soil Drainage Index
DLG	Digital Line Graph
FHM	Forest Health Monitoring
FHP	Forest Health Protection
FHTET	Forest Health Technology Enterprise Team
FIA	Forest Inventory and Analysis
GIS	Geographic Information System
IDW	Inverse Distance Weighting
NIDRM	National Insect and Disease Risk Map
NLCD	National Land Cover Data
NRCS	Natural Resources Conservation Service
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PTIPS	Pest Trend Impact Plot System
QMD	Quadratic Mean Diameter
R&D	Research & Development
RMIT	Risk Map Integration Team
RMOT	Risk Map Oversight Team
RRMT	Regional Risk Mapping Team
RSAC	Remote Sensing Applications Center
RSB	Remote Sensing Band (an FIA working group)
SCAS/OSU	Spatial Climate Analysis Service at Oregon State University
SDI	Stand Density Index
STATSGO	STATe Soil GeOgraphic database

GLOSSARY

The following definitions were taken from various publications, including Minami (2000), the State of Maryland/DNR (2007) and Canadian Ministry of Forests and Range (2007).

accuracy	The degree of conformity of a measured or calculated quantity to its actual (true) value. Also see 'precision'.
basal area	The cross-sectional area of a tree stem taken at breast height (4.5 feet) and typically measured in square feet per acre. Similar to stand density index (SDI).
diameter at breast height	Tree diameter including bark, where breast height is taken to be 4.5 feet. Similar to quadratic mean diameter (QMD).
drainage index (also soil drainage index)	An ordinal measure of long-term natural soil wetness. A GIS surface used as a criterion in several risk models.
ecoregion	An area defined by environmental conditions and natural features. Commonly, a hierarchical order (Bailey 2004) defined by successively smaller ecosystems within larger ecosystems; more specifically, provinces within divisions within domains. For example, within the contiguous United States, there are three domains, 19 divisions, and 35 provinces. Provinces are in turn divided into sub-regional sections.
endemic	Normal or native to a place. Endemic growth can be at a relatively high, although constant rate. Also see 'epidemic' and 'exotic'.
epidemic	Epidemic growth is at a rate substantially above what is expected. Also see 'endemic' and 'exotic'.
exotic	Moved beyond its natural range as a result of human activity. Also see 'endemic' and 'epidemic'.
FIA plots	Proprietary locations of FIA's database of forest parameter plot centers. Each plot in the array represents about 6,000 acres. Plot intensity and record dates vary by state and FIA Region.

Forest Health Monitoring	A USDA Forest Service national program designed to determine the status, changes, and trends in indicators of forest condition on an annual basis.
Forest Health Protection	A USDA Forest Service unit that is primarily responsible for minimizing the spread of established invasive species and lessening the damages caused by native insects and diseases.
Forest Inventory and Analysis	USDA Forest Service unit that collects, analyzes, and reports information on the status and trends of America's forests.
Forest Health Technology Enterprise Team	A USDA Forest Service unit in Fort Collins, Colorado, FHTET's mission is to develop and deliver forest health technology services to field personnel in public and private organizations. A unit of Forest Health Protection.
forest/non-forest mask	A GIS layer of forest presence/absence. This layer was developed by RSAC for this project to portray the current extent of forested lands by removing areas of recent catastrophic mortality from fires or insects and diseases.
forest parameters	Forest attributes, such as BA, QMD, and SDI, that are essential to the construction of models used in assembling the NIDRM composite. These attributes are either components of or calculated from FIA plot data. Also see 'site parameters'.
forest types	The classification or label given to a forest stand, usually based on its tree species composition. Pure spruce stands and spruce-balsam stands are two examples.
geographic information system	A computer system capable of integrating, storing, editing, analyzing, sharing and displaying geographically referenced information.
grid	In a GIS, a geographical representation of the world as an array of equally sized square cells (pixels) arranged in rows and columns. Each grid cell is referenced by its geographic x,y location.

host data gaps	Areas on the national risk map where forest parameters could not be mapped due to a lack of FIA and other plot data sources. These gaps typically occur within national parks, urban areas, and some wilderness areas.
inverse distance weighting	An interpolation process for estimating values in unsurveyed areas using known values. The influence of each survey point decreases as the distance to the unsurveyed point increases.
layer	In a GIS, a collection of similar geographic features representing a particular theme — such as roads, streams, or city boundaries — for display on a map. Also see 'surface'.
maximum appropriate scale	The largest scale at which the risk map or any of its components should be displayed. For NIDRM, this was determined with reference to pixel size and discernible pixel colors, among other considerations. For this project the maximum appropriate scale is within the range of 1:2,000,000 – 1:4,000,000.
minimum analysis unit	The smallest area in which analysis should be conducted and results accumulated and reported. For NIDRM, the minimum analysis unit is generally established as a multi-state region. NIDRM inquiries regarding individual states or their constituent areas should be referred to regional experts.
mortality ceiling	The maximum realizable mortality rate that can be achieved by a specific risk agent acting on a specific forest host species in a defined area. Expressed as a percentage, the values range from 0 to 100 percent of total host species BA when all criteria are met for a given risk agent model.
mortality threshold	The minimum percentage of BA loss over an area required to meet the definition of mortality risk. For this project, the mortality threshold for mapping risk is defined as *25 percent* or more of the standing live basal area on trees greater than 1 inch in diameter.

multi-criteria modeling	A modeling process run in a GIS that allows for the combination and weighting of multiple factors. It provides a common framework for combining dissimilar information while resulting in a single index of evaluation.
perturbed and swapped (also ‘fuzzed and swapped’)	The process of intentionally obscuring the location of proprietary FIA plots by moving the point randomly within a 5,000-meter buffer area (perturbing) and switching the attributes (swapping) among plots with similar characteristics.
pixel	A discretely uniform unit of an area (1,000 meters by 1,000 meters for this project)that represents a portion of the earth. Each pixel (or grid cell) has a value that corresponds to a feature or characteristic at that site, such as elevation, temperature, tree species, or soil drainage index.
precision	The degree to which measurements or calculations show the same or similar results. Also called ‘reproducibility’ or ‘repeatability’. If measurements are tightly clustered but distant from the true value, they are deemed to be precise but not accurate. Also see ‘accuracy’.
quadratic mean diameter	Similar to DBH, a parameter of tree girth that is used as a surrogate for tree diameter or age for this project.
raster	In a GIS, when spatial data is represented by a matrix of cells or pixels called a grid. Also see ‘grid’.
rasterize	In a GIS, to convert geographic information from another method of depiction (*e.g.*, polygon) to a regular grid structure. Also see ‘grid’.
remediation (also ‘controls’)	Management measures applied to a condition (presence of a mortality-causing insect or disease) that threatens tree health. In this report, the modeled scenarios assume that no future remediation is applied. If remediation is undertaken by federal, state, or other land managers, modeled risks may be less likely to occur.

Remote Sensing Applications Center	A USDA Forest Service unit in Salt Lake City, Utah, that provides assistance to agency field units in applying the most advanced geospatial technology toward improved monitoring and mapping of natural resources.
Remote Sensing Band	An FIA working group whose charge is to engage all FIA work units in the efficient development of national remote sensing procedures and applications.
resolution	A level of precision in the data. Also see 'spatial resolution'.
review (also 'peer review')	For the risk map project, a formal appraisal conducted by those in the industry who are acknowledged to have sufficient education and experience to be able to give critical comment and recommendations as to the completeness and accuracy of a paper.
risk of mortality	For this project the expectation that, without remediation, 25 percent or more of the standing live basal area greater than 1 inch in diameter will die over the next 15 years (starting from 2005) due to insects and diseases. The potential for risk of mortality is assumed to be a function of the interaction between susceptibility and vulnerability. Also see 'susceptibility' and 'vulnerability'.
scalability	The ability to use a single modeling process with multi-resolution datasets to produce accurate and consistent results. For example, the same model can be run nationally with 1-kilometer data or locally with 30-meter data.
scale	The ratio of the distance on a map as related to the true distance on the ground or the cell size. For the 2006 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 1 kilometer.

sensitivity analysis	A process used to examine how uncertainties about data and management practices could affect the model's results. Inputs to an analysis are changed, and the results are compared to a baseline or base case. This was accomplished in the 2006 risk assessment by re-ranking or re-weighting the model criteria and then observing the results.
site parameters	Those attributes of an area related to or defined by its biotic, climatic, soil, and topographic conditions. Also see 'forest parameters'.
spatial resolution	A measure of the smallest object that can be detected. Or: the area on the ground represented by each pixel (for this project, 1000 meters x 1000 meters). Also see 'scale'.
special concern agents	Risk agents are of special concern when they are considered to have a high ecological, economic, or aesthetic impact.
stand density index	The equivalent total number of 10-inch diameter trees per acre. Similar to basal area (BA).
surface	In a GIS, a geographic phenomenon represented as a set of continuous data, such as elevation or air temperature over an area. Also see 'layer'.
susceptibility	The potential for establishment, over a 15-year period (for this project), of a forest pest within a tree species. Also see 'vulnerability'.
vulnerability	The potential for experiencing mortality of a tree species at a given threshold (stated as a percentage) over a 15-year period (for this project) *if* a forest pest were to become established. Also see 'susceptibility'.

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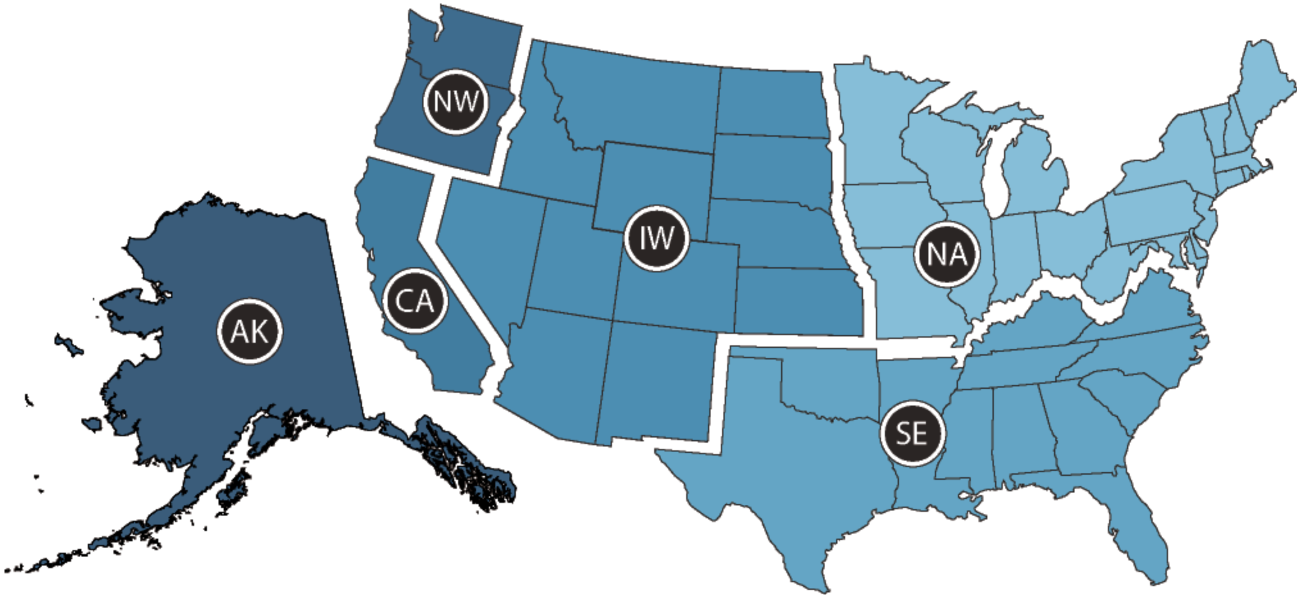
APPENDIX B: MODELS BY REGION

Modified Forest Health Monitoring Regions



Risk Agent and Host Species List (by region)

West Coast-Alaska

Tree Species/Groups	Risk Agent	Number of Models
Alaska-Yellow-Cedar	Alaska Yellow-Cedar Decline	1
Paper/Gray Birch	Heart Rot/Root Rot	1
White Spruce	Northern Spruce Engraver Beetle	1
Sitka Spruce	Spruce Aphid	1
Sitka Spruce	Spruce Beetle	1
White Spruce	Spruce Beetle	1

West Coast-California

Tree Species/Groups	Risk Agent	Number of Models
Coulter Pine	Annosus Root Disease	1
Jeffrey Pine	Annosus Root Disease	1
Ponderosa Pine	Annosus Root Disease	1
Red Fir	Annosus Root Disease	1
White Fir	Annosus Root Disease	2
Douglas-Fir	Black Stain Root Disease	1
Jeffrey Pine	Black Stain Root Disease	1
Pinyon Pine	Black Stain Root Disease	2
Ponderosa Pine	Black Stain Root Disease	1
White Fir	Douglas-Fir Tussock Moth	1
Douglas-Fir	Dwarf Mistletoe	1
Jeffrey Pine	Dwarf Mistletoe	2
Lodgepole Pine	Dwarf Mistletoe	1
Pinyon Pine	Dwarf Mistletoe	1
Ponderosa Pine	Dwarf Mistletoe	2
Red Fir	Dwarf Mistletoe	1
White Fir	Dwarf Mistletoe	1
Red Fir	Fir Engraver Beetle	4

West Coast-California continued

Tree Species/Groups	Risk Agent	Number of Models
White Fir	Fir Engraver Beetle	4
Knobcode Pine	Ips Engraver Beetle	2
Pinyon Pine	Ips Engraver Beetle	2
Jeffrey Pine	Jeffrey Pine Beetle	2
Coulter Pine	Mountain Pine Beetle	1
Lodgepole Pine	Mountain Pine Beetle	2
Ponderosa Pine	Mountain Pine Beetle	3
Sugar Pine	Mountain Pine Beetle	2
Western White Pine	Mountain Pine Beetle	1
California Black Oak	Sudden Oak Death	1
Canyon Live Oak	Sudden Oak Death	1
Coast Live Oak	Sudden Oak Death	1
Tanoak	Sudden Oak Death	1
Coulter Pine	Western Pine Beetle	1
Ponderosa Pine	Western Pine Beetle	3

West Coast-Northwest

Tree Species/Groups	Risk Agent	Number of Models
Sitka Spruce	Armillaria Root Disease	1
Pacific Silver Fir	Balsam Woolly Adlegid	1
Subalpine Fir	Balsam Woolly Adlegid	1
Douglas-Fir	Defoliators	1
Grand Fir	Defoliators	1
White Fir	Defoliators	1
Douglas-Fir	Douglas-Fir Beetle	2
Douglas-Fir	Dwarf Mistletoe	2
Grand Fir	Dwarf Mistletoe	1
Lodgepole Pine	Dwarf Mistletoe	1

West Coast-Northwest continued

Tree Species/Groups	Risk Agent	Number of Models
Mountain Hemlock	Dwarf Mistletoe	1
Western Larch	Dwarf Mistletoe	1
White Fir	Dwarf Mistletoe	1
Whitebark Pine	Dwarf Mistletoe	1
Grand Fir	Fir Engraver Beetle	1
Red Fir	Fir Engraver Beetle	1
White Fir	Fir Engraver Beetle	1
Western Hemlock	Hemlock Looper	1
Ponderosa Pine	Ips Engraver Beetle	1
Mountain Hemlock	Laminated Root Rot	1
Western Redcedar	Miscellaneous Mortality	1
Lodgepole Pine	Mountain Pine Beetle	1
Ponderosa Pine	Mountain Pine Beetle	1
Sugar Pine	Mountain Pine Beetle	1
Western White Pine	Mountain Pine Beetle	1
Whitebark Pine	Mountain Pine Beetle	1
Pacific Madrone	Pacific Madrone Decline	1
Port-Orford-Cedar	Port-Orford-Cedar Root Disease	1
Red Fir	Red Fir Dwarf Mistletoe	1
Douglas-Fir	Root Diseases	2
Grand Fir	Root Diseases	1
Lodgepole Pine	Root Diseases	1
Pacific Silver Fir	Root Diseases	1
Ponderosa Pine	Root Diseases	1
Red Fir	Root Diseases	1
Subalpine Fir	Root Diseases	1
Western Hemlock	Root Diseases	1
White Fir	Root Diseases	1

West Coast-Northwest continued

Tree Species/Groups	Risk Agent	Number of Models
Pacific Silver Fir	Silver Fir Beetle	1
Engelmann Spruce	Spruce Beetle	1
Sitka Spruce	Spruce Beetle	1
Tanoak	Sudden Oak Death	1
Engelmann Spruce	Tomentosus Root Disease	1
Ponderosa Pine	Western Pine Beetle	1
Whitebark Pine	White Pine Blister Rust	1

Interior West

Tree Species/Groups	Risk Agent	Number of Models
Aspen	Aspen Decline	2
Douglas-Fir	Douglas-Fir Beetle	1
Lodgepole Pine	Dwarf Mistletoe	1
Ponderosa Pine	Dwarf Mistletoe	1
White Fir	Fir Engraver Beetle	1
Pinyon Pine	Ips Engraver Beetle	1
Ponderosa Pine	Ips Engraver Beetle	4
Limber Pine	Mountain Pine Beetle	1
Lodgepole Pine	Mountain Pine Beetle	1
Ponderosa Pine	Mountain Pine Beetle	4
Southwestern White Pine	Mountain Pine Beetle	1
Western White Pine	Mountain Pine Beetle	1
Whitebark Pine	Mountain Pine Beetle	1
Douglas-Fir	Root Diseases	1
Grand Fir	Root Diseases	1
Mountain Hemlock	Root Diseases	1
Subalpine Fir	Root Diseases	1
Western Larch	Root Diseases	1

Interior West continued

	Tree Species/Groups	Risk Agent	Number of Models
	Ponderosa Pine	Roundheaded Pine Beetle	3
	Spruce	Spruce Beetle	1
	Subalpine Fir	Western Balsam Bark Beetle	1
	Ponderosa Pine	Western Pine Beetle	6
	Douglas-Fir	Western Spruce Budworm	1
	Grand Fir	Western Spruce Budworm	1
	Subalpine Fir	Western Spruce Budworm	1
	White Fir	Western Spruce Budworm	1
	Limber Pine	White Pine Blister Rust	1
	Western White Pine	White Pine Blister Rust	1
	Whitebark Pine	White Pine Blister Rust	1

Northeastern Area

	Tree Species/Groups	Risk Agent	Number of Models
	Ash	Ash (Hardwood) Decline	1
	Red and Sugar Maple	Asian Longhorned Beetle	1
	Balsam and Fraser Fir	Balsam Woolly Adlegid	1
	American Beech	Beech Bark Disease	1
	Paper/Gray Birch	Bronze Birch Borer	1
	Butternut	Butternut Canker	1
	Basswood	Basswood (Hardwood) Decline	1
	Red Oaks Group	Oak Decline	1
	Sugar Maple	Sugar Maple (Hardwood) Decline	1
	Elm	Dutch Elm Disease	1
	Tamarack	Eastern Larch Beetle	1
	Ash	Emerald Ash Borer	1
	Aspen	Forest Tent Caterpillar	1
	Red Oaks Group	Gypsy Moth	1

Northeastern Area continued

Tree Species/Groups	Risk Agent	Number of Models
White Oaks Group	Gypsy Moth	1
Carolina/Eastern Hemlock	Hemlock Woolly Adelgid	1
Red Pine	Ips Engraver Beetle	1
Jack Pine	Jack Pine Budworm	1
Red Oaks Group	Oak Wilt	1
White Oaks Group	Oak Wilt	1
Balsam Fir	Spruce Budworm	1
Spruce	Spruce Budworm	1
Eastern White Pine	White Pine Blister Rust	1

South

Tree Species/Groups	Risk Agent	Number of Models
Eastern White Pine	Annosus Root Disease	1
Loblolly Pine	Annosus Root Disease	1
Longleaf Pine	Annosus Root Disease	1
Shortleaf Pine	Annosus Root Disease	1
Virginia Pine	Annosus Root Disease	1
Loblolly Pine	Fusiform Rust	1
Slash Pine	Fusiform Rust	1
Carolina/Eastern Hemlock	Hemlock Woolly Adelgid	1
Eastern White Pine	Southern Pine Beetle	1
Loblolly Pine	Southern Pine Beetle	1
Longleaf Pine	Southern Pine Beetle	1
Pitch Pine	Southern Pine Beetle	1
Shortleaf Pine	Southern Pine Beetle	1
Slash Pine	Southern Pine Beetle	1
Table Mountain Pine	Southern Pine Beetle	1
Virginia Pine	Southern Pine Beetle	1

APPENDIX C: SUSCEPTIBILITY AND VULNERABILITY CONTRIBUTIONS TO MORTALITY MODELS

Risk Model Worksheet - Interior West

Risk Agent(s):	Mountain Pine Beetle	**Host(s):**	Lodgepole Pine
Model Extent:	Interior West	**Mortality Ceiling:**	70%

Susceptibility

Rank/Weight		Criterion	Risk Begins (a)	Risk Peaks (b)	Risk Decreases (c)	Risk Ends (d)	Curve	Rank	Weight
	0%								
Criteria 1									
Criteria 2									
Criteria 3									
Criteria 4									
Criteria 5									
Criteria 6									
Criteria 7									
Criteria 8									
Criteria 9									
Criteria 10									

Vulnerability

Rank/Weight		Criterion	Risk Begins (a)	Risk Peaks (b)	Risk Decreases (c)	Risk Ends (d)	Curve	Rank	Weight
1	100%								
Criteria 1		Host QMD (Inches)	6	8	8	8	Linear	1	30%
Criteria 2		Percent Basal Area Host	25	50	50	50	Linear	1	30%
Criteria 3		Total Basal Area (Sq. Ft. /Acre)	80	120	160	250	S-4	1	30%
Criteria 4		Elevation/Latitude Zones	1	3	3	3	Linear	1/3	10%
Criteria 5									
Criteria 6									
Criteria 7									
Criteria 8									
Criteria 9									
Criteria 10									

Constraints		**Comments**	
Citations	Amman et al. 1977, Hagle et al. 2000, Randall and Tensmeyer 2000, and Steele et al. 1996	**Model Certainty**	2 - Literature/Research Based

Risk Model Worksheet - Interior West

Risk Agent(s): White Pine Blister Rust

Host(s): Limber Pine

Model Extent: Central Rocky Mountains

Mortality Ceiling: 10%

Susceptibility

Rank/Weight		Criterion	Risk Begins (a)	Risk Peaks (b)	Risk Decreases (c)	Risk Ends (d)	Curve	Rank	Weight
1	100%								
Criteria 1		May Relative Humidity	45	54	54	54	Linear	1	60%
Criteria 2		May Minimum Temperature (F)	28	34	34	34	Linear	1/3	20%
Criteria 3		May Precipitation (mm)	45	45	45	87	Linear	1/5	12%
Criteria 4		August Minimum Temperature (F)	37	48	53	63	Linear	1/7	9%
Criteria 5									
Criteria 6									
Criteria 7									
Criteria 8									
Criteria 9									
Criteria 10									

Vulnerability

Rank/Weight		Criterion	Risk Begins (a)	Risk Peaks (b)	Risk Decreases (c)	Risk Ends (d)	Curve	Rank	Weight
	0%								
Criteria 1									
Criteria 2									
Criteria 3									
Criteria 4									
Criteria 5									
Criteria 6									
Criteria 7									
Criteria 8									
Criteria 9									
Criteria 10									

Constraints: Restricted to the following ecoregion sections: M331B, M331I, M331F, M33G, M331J, N342F.

Comments:

Citations: Kearns 2005

Model Certainty: 2 - Literature/Research Based

Risk Model Worksheet - Northeastern Area

Risk Agent(s): Gypsy Moth

Host(s): Red Oak Species

Model Extent: Eastern U.S.

Mortality Ceiling: 50%

Susceptibility

Rank/Weight		Criterion	Risk Begins (a)	Risk Peaks (b)	Risk Decreases (c)	Risk Ends (d)	Curve	Rank	Weight
1/2	33%								
Criteria 1		Proximity to Infestation (Miles)	0	30	60	200	S 4	2/5	20%
Criteria 2		Avg Min Jan Temp (F)	5	12	12	12	S 1	2/5	20%
Criteria 3		Slope (0 = Flat, 1 = Hilly)	0	1	1	1	S 1	1/5	10%
Criteria 4		Host Basal Area	10	50	50	50	S 1	1	50%
Criteria 5									
Criteria 6									
Criteria 7									
Criteria 8									
Criteria 9									
Criteria 10									

Vulnerability

Rank/Weight		Criterion	Risk Begins (a)	Risk Peaks (b)	Risk Decreases (c)	Risk Ends (d)	Curve	Rank	Weight
1	67%								
Criteria 1		Site Quality	0	11	11	17	S 5	1	20%
Criteria 2		Host Basal Area	10	50	50	50	S 1	1	20%
Criteria 3		Annual Precipitation	9	9	9	38	S 2	1	20%
Criteria 4		Soil Dryness	0	0	0	34	S 5	1	20%
Criteria 5		Proximity to Infestation (Miles)	0	30	30	200	S 2	1	20%
Criteria 6									
Criteria 7									
Criteria 8									
Criteria 9									
Criteria 10									

Constraints

Comments

Citations

Model Certainty 3 - Informed Professional Judgement