United States
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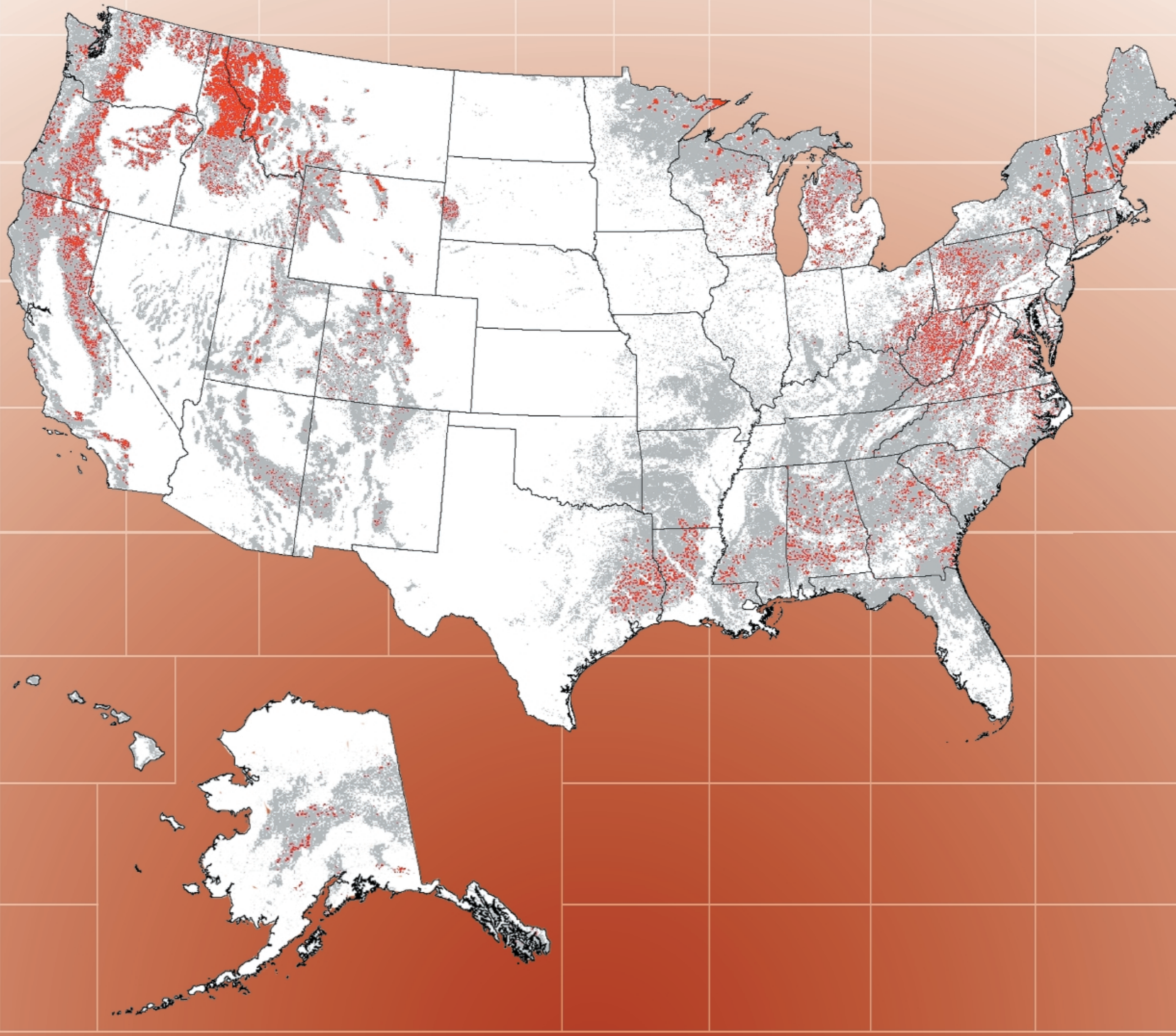
Mapping Risk from Forest Insects and Diseases



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by Joseph W. Lewis

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Summary

The purpose of the risk mapping effort is to develop a geographic information system (GIS) database containing information needed for a strategic evaluation of forest health risk on all forested lands in the United States. This effort is designed to provide managers at the national level with the best currently available information on broad-scale risks pertinent to the health of our Nation's forest.

Risk mapping is an iterative process that revises and fine-tunes the database as more and better information becomes available. Using empirical data, models, and expert judgment, we made projections of risks of tree mortality or growth/volume loss from insects and diseases. These estimates will be modified as more and better information becomes available through the long-term Forest Health Monitoring program and other information sources.

The risk mapping effort described in this paper was undertaken to provide a broad, national-level depiction of risk of tree mortality or growth/volume loss from insects and diseases. As such, it is not to be used for site-specific purposes. However, it does provide a systematic approach for evaluating risk from a national standpoint.

An area is defined to be at risk if 25 percent or more tree mortality (beyond the normal level of approximately 0.6 percent annually), or growth/volume loss, is expected over the next 15 years. Implicit in this definition is a prediction, on an organism-by-organism basis, that insect outbreaks and disease infestations will occur within the next 15 years, and will result in substantial levels of tree mortality or growth/volume loss. The 25 percent level is meant to represent an uncommon, rather extraordinarily high percentage.

Results of the insect and disease risk mapping effort are presented separately for three categories of risk (mortality, growth loss, and organisms of special concern).

Tree mortality risk projections were made for 27 organisms (17 insects and 10 diseases). Approximately 59 million acres were identified as being at risk. Of the 27 insects and diseases evaluated, 4 organisms accounted for more than two-thirds of the acres at risk. They are—gypsy moth (26 percent), root diseases in the West (23 percent), southern pine beetle (13 percent), and mountain pine beetle (7 percent).

Of the 59 million acres at risk, 24 million (41 percent) are on national forests and 34 million (59 percent) are on other lands. This amounts to 12 percent of national forest land being at risk, compared to 6 percent of other lands. Because the underlying acre estimates are not site specific, these percentages are relative indicators only. As this document was being prepared, the mortality risk projections were recently revised to 70 million acres, reflecting additional acres at risk in Washington, Oregon, and California. These additional acres are not reflected in this document.

Growth loss risk projections were made for 12 organisms (8 insects and 4 diseases). Approximately 48 million acres were identified as being at risk. Of the 12 insects and diseases evaluated, 2 accounted for almost three-fourths of the acres at risk. They are—dwarf mistletoes throughout the West (37 percent) and heart rot in Alaska (37 percent).

Twelve organisms were put into a special category because they pose threats in areas where host trees are relatively few in number, or are minor components scattered throughout a more dominant cover type. We did not calculate acres at risk to these organisms because estimates would be highly unreliable, and depiction of acres at risk on a map would greatly overstate the magnitude of the problem. We did, however, identify general areas within which we expect host trees of these organisms to be at risk.

Of the three risk categories examined, risk of tree mortality has the most significant and widespread implications for forest health.

From a strategic standpoint, there is a need to identify where the highest potentials for forest health problems exist. This information is needed for long-range planning, and is essential for identifying priorities when developing policy for the Forest Service. The insect and disease risk projections can be combined with other forest health-related risk estimates to provide critical background information for policymakers at the national level.

From a program management standpoint, information generated from the risk mapping effort can be used, along with other management information, to help determine program priorities and to support budget requests.

Introduction

Purpose

The purpose of the risk mapping effort is to develop a geographic information system (GIS) database containing information needed for a strategic evaluation of forest health risk on all forested lands in the United States. Development of this database, and corresponding coarse filter maps, is the first step in an analysis process designed to help set priorities for addressing forest health problems. See appendix A for a complete description of the priority-setting process. Although this document concentrates on describing the process used to develop the insect and disease GIS layer, note that additional information layers are necessary to provide a more comprehensive picture of risk to forest health. Other layers (fire, threatened and endangered species, and wildland/urban interface) are currently in various stages of development.

The terms "risk" and "forest health" may be expressed in a variety of ways, depending on one's perspective regarding natural resources and natural resource management. For this risk mapping effort, we try to precisely define risk from insects and diseases, so there is no ambiguity in what is being depicted on the maps. We do not, however, attempt to define "forest health." Past attempts at defining forest health have resulted in statements that are complex, vague, and controversial. For purposes of identifying risk from insects and diseases, we identify areas where substantial tree mortality or growth/volume losses are expected to occur in the near future. The effect of that mortality andgrowth/volume loss on forest health and communities (including ecological, social, and economic impacts) will be determined by policymakers and natural resource managers, and will be done most effectively on a more site-specific basis.

Background

Natural resource managers are faced with a variety of issues that are complex and difficult to address. Yet, these issues cannot be ignored. A decision to do nothing has consequences, just as a decision to take action has consequences. Managers need information that is timely and pertinent to the issues at hand to understand the consequences of their decisions. The risk mapping effort is designed to provide managers at the national level with the best currently available information on broad-scale risks pertinent to the health of our Nation's forests.

We began the risk mapping effort in 1995 with the formation of a group of specialists from several disciplines. The group identified information needed to make an initial assessment of forest health risk in the United States. Several "information layers" were identified as being pertinent to forest health. Four layers were deemed to be of particular importance—insects and diseases, fire, threatened and endangered species, and wildland/urban interface. When combined and interpreted, these information layers provide a composite indication of the health risks to our Nation's forested lands.

Using empirical data, models, and expert judgment, we made projections of risks of tree mortality or growth/volume loss from insects and diseases. These estimates will be modified as more and better information becomes available through the long-term Forest Health Monitoring program and other information sources.

Insect & Disease Risk Team

A team of Forest Service specialists was assembled to address the issue of risk to forest health from insects and diseases. The team developed a definition of risk, identified basic data needed to quantify risk, and made individual estimates of areas at risk for a large number of insects and diseases. In addition to the members of the team, many other specialists from Forest Service regions and research stations provided data and developed models for making risk projections. Several specialists in State forestry organizations also provided input. The team greatly appreciates the input provided by these specialists.

The team is composed of the following members:

Joseph W. Lewis, Economist, Team Leader, Washington, DC

Lowell G. Lewis, GIS Specialist, Fort Collins, CO

Kenneth E. Gibson, Entomologist, Region 1

David W. Johnson, Plant Pathologist, Region 2

Bill Schaupp, Entomologist, Region 2

Jill L. Wilson, Entomologist, Region 3

Dayle D. Bennett, Entomologist, Region 4

Richard L. Halsey, GIS Specialist, Region 4

Lisa Levien, Remote Sensing Specialist, Region 5

Sheri Lee Smith, Entomologist, Region 5

David R. Bridgwater, Entomologist, Region 6

Craig L. Schmitt, Plant Pathologist, Region 6

Julie L. Johnson, GIS Specialist, Region 6

Edwin K. Yockey, GIS Specialist, Region 8

Wesley A. Nettleton, Entomologist, Region 8

Kathy M. Matthews, Biological Technician, Region 10

Thomas E. Luther, Forester, Northeastern Area

Bradley P. Onken, Entomologist, Northeastern Area

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Steven A. Katovich, Entomologist, Northeastern Area

Manfred Mielke, Forest Health Specialist, Northeastern Area

Noel F. Schneeberger, Entomologist, Northeastern Area

General Methodology

This section describes the approaches taken to develop the insect and disease "information layer." A general methodology was developed and applied to all insects and diseases, regardless of location or specific situation. However, some of the factors that determine "risk" vary considerably by organism, host, and location. Therefore, the specific technique for modeling risk is potentially different for each insect and disease.

Creating the spatial database required not only a determination of relative susceptibility, but also the delineation of the geographic location of areas at risk. This compounded the task the group faced and increased the potential for inaccuracies. The databases used to identify locations of cover types and forest characteristics were not designed for site-specific interpretation. Thus we can only depict general areas at risk on a map, not pinpoint risk on specific acres or pixels.

The general approach taken in this analysis is as follows: We began the analysis by assembling a team of specialists, composed primarily of entomologists, pathologists, and GIS specialists. The team was asked to answer this question—To what extent are the Nation's forests at risk from insects and diseases?

To answer that question, the following steps were undertaken:
1. Define risk.
2. Identify the insects and diseases to be analyzed.
3. Develop the process to delineate areas at risk.
4. Create maps showing areas at risk to insects and diseases.

Define Risk

There was much discussion about the term "risk." Should we identify several levels of risk (high, moderate, low)? What would be the stochastic nature of the estimates we needed to make? What level of confidence would be acceptable? While initially there were differences of opinion about how to approach "risk," there was unanimous agreement that we needed to define the term, and that the definition should be succinct and universally applicable to all insects and diseases in all locations.

Although the team produced risk estimates for both tree mortality and growth/volume loss, most of the effort (and progress made) has been devoted to mortality. Therefore, this document will concentrate on describing the effort made to estimate the risk of tree mortality.

The team discussed alternative approaches to determining risk. Viewing risk as a continuum, with numerical ratings on a scale of, say, 1 to 100, was dismissed because of lack of data and a feeling that this level of detail would imply a level of precision that did not exist. An approach that defined three levels of risk (high, moderate, and low) with a specific range for each level was discussed at length and rejected for the same reasons. The team leader explored the idea of using the concept of "fuzzy logic" with a colleague, Dr. Guillermo Mendoza, University of Illinois, who is an expert in that area. Fuzzy logic involves comparisons using designations of "more" or "less," rather than specifying numerical values. Dr. Mendoza advised against using this approach, given the team's reluctance to identify multiple levels of risk. There was a good deal of discomfort with identifying multiple levels of risk, but it was generally agreed that a single, relatively high level of risk over a specified time period could be estimated with a reasonable level of comfort.

After much debate, the group decided that an area would be at risk if 25 percent or more tree mortality (beyond the normal background level of approximately 0.6 percent annually) can be expected over the next 15 years. Implicit in this definition is a prediction, on an organism-by-organism basis, that insect outbreaks and disease infestations will occur within the next 15 years, and will result in substantial levels of tree mortality.

The 25 percent level is meant to represent an uncommon, rather extraordinarily high amount of mortality (the team debated higher and lower levels, and reached consensus on 25 percent).

The normal level of mortality is used here as a point of reference, and is applicable only on a national scale. Our estimate of 0.6 percent "normal" mortality represents the percentage of total growing stock in the United States that dies annually from all causes. It is based on statistics from the most recent national inventory titled "Forest Resources of the United States, 1992" (Powell and others 1992). We made the calculation as follows:

857, 565, 000 MCF
(net volume of growing stock from page 47),
+16, 307, 642 MCF
(annual removals from page 109),
+ 5, 481, 004 MCF
(annual mortality from page 109),
divided into 5, 481, 004 MCF = .0062

The 15-year timeframe was reached by consensus to represent 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.

The reader should understand that the risk estimates made in this analysis are not cumulative. That is, an expectation of 25 percent tree mortality over 15 years does not translate to 50 percent mortality over 30 years, or 75 percent over 45 years. Theoretically, risk must be re-evaluated at the end of the 15-year period to determine if the underlying factors have changed. However, given the level of uncertainty and the intended iterative nature of this approach, we would hope that re-evaluations occur more frequently.

Identify the Insects and Diseases To Be Analyzed

The group identified a large number of insects and diseases to be evaluated (see appendix B for a complete list). After the analysis was underway, the group decided to divide these organisms into three risk categories:

1. Risk of tree mortality (27 organisms).
2. Risk of growth loss or volume loss (12 organisms). Growth loss applies to most organisms. Volume loss applies to heart rot because the disease affects the inner fiber of the tree rather than potential tree growth.
3. Risk of tree mortality from organisms of special concern (12 organisms).

The last category represents organisms whose host trees are minor components of a forested area. Broad areas containing host types at risk can be identified, but if these areas were mapped in the same manner as the other two categories, the actual extent of the risk would be greatly overstated. Thus, the map for organisms of special concern indicates only broad areas, within which some susceptible trees exist.

It should be noted that there are areas where risk to mortality and growth/volume loss overlap. There are also areas at risk to more than one organism within the same category. In computing the number of acres at risk, we take precautions to avoid double counting. For example, if the risk of mortality from three different insects coincides on a single pixel, that pixel is counted only once when compiling the total number of acres at risk. Also, an acre at risk from three insects is not determined to be "more at risk" than an acre at risk to only one insect.

Entomologists and plant pathologists from all Forest Service regions determined the category to which a particular insect or disease was assigned. Depending on location, a single insect could fall into different categories. This situation occurred six times. For example, balsam woolly adelgid is in the mortality category for most areas, but it is in the special concerns category in high-elevation subalpine and silver fir in Washington and Oregon.

Develop the Process To Delineate Areas at Risk

The risk mapping process was initiated by creating or acquiring the basic GIS data layers needed by the entomol ogists and pathologists as a starting point for modeling areas at risk. The group identified certain kinds of data that were essential to provide a foundation for identifying areas at risk to all insects and diseases, nationwide. Data layers were digitized at a scale of 1: 2,000,000. Each pixel (the basic unit of resolution) is 1 square kilometer. The following layers were developed:

1. Forest cover types—acquired from satellite imagery (AVHRR).
2. Rivers and lakes—existing data.
3. Ecoregions—existing data (Bailey's Ecoregions).
4. National Forest and Grassland boundaries—existing data.
5. Forest Service Region boundaries—existing data.
6. State and county boundaries—existing data.
7. Grid of longitude/latitude graticules—existing data.

A map (1: 2,000,000 scale) containing all the above information was created for each Forest Service region. Each regional map was overlaid with clear mylar film and longitude/latitude boundaries were marked. If combined, the resulting U.S. map would be approximately 5' x 8' for the contiguous 48 States, and 3' x 4' for Alaska. Entomologists, pathologists, and other specialists within each region used the data on these maps along with Forest Inventory and Analysis (FIA) data, aerial survey data pertaining to insect and disease activity, insect/disease models, and expert judgment to delineate areas at risk. For some insects and diseases, polygons were drawn on the mylar film and then digitized. For others, existing digitized information was used. In several instances, assumptions were made about the percent of acres of host type in a particular geographic area that would be at risk; and those acres were randomly distributed throughout the host type.

More specific data used to model risk for an individual organism is explained in the section on specific methodologies.

Create Maps Showing Areas at Risk to Insects and Diseases

Once all pertinent information was digitized and processed in the GIS, maps of the United States, including Alaska and Hawaii, were made showing areas at risk. These maps were at a scale of 1:6,000,000 (about 2' x 3' in size). Separate maps were made for each of the three risk categories (mortality, growth/volume loss, and special concern). Individual maps (8.5" x 11") for each insect and disease were also made. These maps were distributed to specialists for critique. As mentioned above, most attention has been given to the mortality projections, which have been refined three times after dialogue among a broad group of specialists who have forest health expertise. Each refinement has resulted in a more conservative estimate (i.e., fewer acres at risk).

Also, because the base forest cover-type layer is at a scale of 1:2,000,000, the group felt it would be inappropriate to produce maps at a scale greater than 1:6,000,000. As a further precaution to avoid misinterpretation of a map, we determined that all maps should include the following disclaimer:

> The risk map is a visual representation of projected future tree mortality. The underlying data were compiled from various sources, and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

Specific Methodologies

The specific methodologies used to model risk of tree mortality are described in this section, as well as the two organisms (dwarf mistletoes and heart rot) that accounted for most of the acres at risk to growth/volume loss.

Appendix C contains the mortality risk map for all organisms combined, individual maps for each mortality-causing organism, and the national growth/volume loss risk map.

Organisms Causing Tree Mortality in the Eastern United States

Eastern Diseases

Annosus Root Disease (see risk map, Appendix C, figure 1)
Annosus root disease (*Heterobasidion annosum*) is a common disease of southern pines. This pathogen spreads from tree to tree through the root systems, and can result in substantial amounts of tree mortality over time.

Mapping annosus root disease risk began by delineating broad high-hazard areas identified in the Southern Forest Health Atlas for Insects and Diseases. Professional judgment was then used to determine smaller areas within the broad high-hazard area that were most likely to sustain tree mortality over the next 15 years. Areas with less than 50 percent pine cover type were then screened out based on the East-wide Forest Inventory Data Base (Hansen and others, 1992). The remaining acres were then reduced by 50 percent to provide a conservative estimate of projected acres at risk of 25 percent or more tree mortality over the next 15 years.

Fusiform Rust (see risk map, Appendix C, figure 2)
Fusiform rust (*Cronartium quercuum f. sp. Fusiforme*) is the most damaging pathogen of loblolly and slash pines in the Southern United States. Longleaf and pond pines are susceptible to a lesser degree, while several other southern pines are actually resistant to infection by the fungus that causes fusiform rust.

Mapping fusiform rust risk began by delineating areas in which more than 60 percent of the acres are currently infected with fusiform rust. Of the acres currently infected, those with less than 50 percent loblolly and slash pine cover type were then screened out based on the East-wide Forest Inventory and Analysis (FIA) database (Hansen and others, 1992). The remaining acres were designated as being at risk of 25 percent or more tree mortality over the next 15 years.

Beech Bark Disease (see risk map, Appendix C, figure 3)
Beech bark disease is caused by the interaction between a scale insect (*Cryptococcus fagisuga*) and a fungus (*Nectria sp.*) The beech scale attacks and alters the bark, rendering the tree susceptible to the fungus. The fungus causes abundant cankers, often resulting in tree mortality. In some locations, *Nectria coccinata* var. *faginata* is the primary fungus, while in other areas, *N. galligena* is more prevalent.

The critical area was identified starting with the counties along the advancing front of the disease that are known to have both *Nectria* canker and the insect vector present. The major advancing front of the disease occurs in northern Pennsylvania and two smaller discrete infection centers occur in West Virginia and along the Tennessee/North Carolina border. From these advancing fronts the estimated rate of spread of beech bark disease was plotted over the next 15 years. Within this defined area, acres at risk were determined by examining the East-wide FIA plot data for the relative abundance of beech and plotting a distribution map of the species. The resulting polygons represent a 0.2 or greater probability that more than 25 percent of the basal area per acre is beech. These polygons were further refined based on local information and professional judgment of State and Federal forest health specialists.

Eastern Bark Beetles

Southern Pine Beetle (see risk map, Appendix C, figure 4)
Southern pine beetle (*dendroctonus frontalis*) is the premier mortality-causing insect in the Southern United States. This insect can produce as many as seven generations in a single year; allowing populations to increase dramatically in a short period of time. Infestations occur in "spots" (groups of trees), that often begin with a few or several attacked trees and rapidly grow in size if left unchecked. Spots have been known to grow to thousands of trees within a few weeks.

Mapping southern pine beetle risk began with examining historical data to identify counties that have been in outbreak status for 7 or more years during the period from 1960 to 1996 (Hoffard and others, 1995). Outbreak status is defined as more than one southern pine beetle spot per thousand acres of susceptible host type (predominantly loblolly and shortleaf pines), based on Belanger, 1981. Next, FIA plot data were used to screen out areas having less than 50 percent pine forest types. Within the remaining areas, the high-risk areas were delineated based on stand age greater than 5 years, and basal area greater than 90 square feet per acre (Stephen and Lih, 1985 identified stand age and basal area as susceptibility factors).

Eastern Foliage and Stem Feeding Insects

Gypsy Moth (see risk map, Appendix C, figure 5)
The gypsy moth (*lymantria dispar*) is an exotic insect, introduced into the United States in the 1860s. Since then, it has become established throughout New England and the Middle Atlantic States. It continues to gradually spread south and west in a band that currently stretches from Virginia to Michigan. This band is referred to as the "leading edge" of the insect's spread. The area behind the leading edge (to the northeast) is called the "generally infested area."

Historically, the gypsy moth has done most of its damage as it moves into previously uninfested areas (Herrick and Gansner 1986; Liebhold and others 1992). Thus, over the next 15 years, we expect the greatest levels of gypsy moth-caused tree mortality to occur in areas immediately in front of the leading edge.

Acres at risk to gypsy moth were based primarily on the following model developed by Dr. Andrew Liebhold of the Forest Service's Northeastern Research Station: Areas most at risk were determined by first identifying susceptible host type from the FIA forest cover type database (susceptible types include Oak-pine, Oak-hickory, Oak-gum-cypress, Elm-ash-cottonwood, and Aspen-birch) (Liebhold and others 1997). Next, all counties with less than 10 percent of land area covered by forests that have greater than 20 percent basal area of susceptible species were eliminated. Beginning at the leading edge, gypsy moth spread was modeled at 21 kilometers per year (based on professional judgment). Multipliers were created to select areas at risk in 1-kilometer bands emanating in both directions from the leading edge. In front of the leading edge, the multiplier randomly selected 75 percent of the first 1-kilometer band, and gradually decreased to zero percent of the 315th band. Behind the leading edge, the multiplier decreased to 25 percent of the 250th band, and remained at 25 percent for the remainder of the generally infested area. Fifty percent of the total area selected by the multipliers was then randomly deleted to provide a conservative estimate of the area at risk. We recognize that this random reduction factor is arbitrary and constitutes a weakness in the methodology. However, in the judgment of the analysts involved, it was a prudent step. We are examining various ways to improve gypsy moth risk projections.

Spruce Budworm (see risk map, Appendix C, figure 6)
The spruce budworm (*Choristoneura fumiferana*) is a native insect found in Alaska, the Great Lakes area, New England, and some Mid-Atlantic States. This tree defoliator prefers Balsam fir, but also feeds on several types of spruce.

The area at risk from spruce budworm was derived by examining the East-wide FIA plot data for the relative abundance of balsam fir and/or white spruce and plotting a distribution map of where these species occur in uneven-aged, or 40-year-old or older, stands. The resulting polygons represent a 0.3 or greater probability that more than 25 percent of the basal area of these species occurs in 40-year-old or older, or uneven-aged stands. These polygons were further refined based upon local information and professional judgment of State and Federal forest health specialists. For example, significant harvesting of these species has occurred since the last FIA measurements, so forest health specialists modified the polygons to represent current conditions.

Balsam Woolly Adelgid (see risk map, Appendix C, figure 7)
The balsam woolly adelgid (*Adelges picaea*) is a nonnative insect that attacks several species of fir in western and eastern U.S. forests. While not particularly widespread in the East, the insect has been a recurring problem in coastal areas of Maine and in Fraser fir stands in the Appalachian Mountains.

Mapping balsam woolly adelgid risk began by identifying spruce/fir, Fraser fir, and balsam fir cover types in the Eastern United States. Next, a few small areas in western North Carolina were designated as high risk because they contain pure stands of Fraser fir.

Hemlock Woolly Adelgid (see risk map, Appendix C, figure 8)
The hemlock woolly adelgid (*Adelges tsugae Annand*) is a nonnative insect that attacks forest and ornamental hemlock trees in the Eastern United States. Since it was first observed in Virginia around 1950, this insect has spread north as far as Maine. The hemlock woolly adelgid is expected to eventually spread throughout the entire range of eastern and Carolina hemlocks.

The area at risk from hemlock woolly adelgid was determined by first identifying the counties known to be infested with the insect, and extending outward to accommodate the rate of spread during the next 15 years. Within this defined area, hemlock woolly adelgid acres at risk were derived by examining the East-wide FIA plot data for the relative abundance of eastern hemlock and plotting a distribution map of the species. The resulting polygons represent a 0.3 or greater probability that more than 25 percent of the basal area per acre occurs in hemlock. These polygons were further refined based on local information and professional judgment of State and Federal forest health specialists. For example, several small polygons were removed from southern West Virginia and several pixels were added in northern New Jersey, Maryland, Connecticut, and Massachusetts to reflect known hemlock stands at risk.

Organisms Causing Tree Mortality in the Western United States

Western Diseases

Root Diseases (see risk map, Appendix C, figures 9 and 10)

Areas at risk from root diseases are found in many places in the Western United States, some of which are poorly documented and not fully accounted for in this risk mapping effort. The most prominent root disease-caused mortality risk is attributed to the following pathogens:

1. Armillaria root disease (*Armillaria ostoyae*)
2. Laminated root disease (*Phellinus weirii*)
3. Annosus root disease (*Heterobasidion annosum*)
4. Brown cubical root and butt rot (*Phaeolis schweinitzii*)

Other root diseases account for relatively fewer acres at risk.

Northern Rocky Mountain Area

A particularly large, highly concentrated area of northern Idaho and western Montana accounts for most of the acres identified as being at risk. Mortality projections for this area are based on the following factors:

1. A system of 1,200 permanent plots established to evaluate root disease-caused tree mortality.
2. Root disease severity ratings made on sample stands within several ecosections.
3. Personal experiences of plant pathologists about the distribution of root disease-caused tree mortality within ecosections.

Reports dating back to the early 1900s indicate that root disease-caused tree mortality was common in northern Idaho and western Montana. In addition, we know that over the past century, disease-tolerant species such as western white pine, western larch, and ponderosa pine, that once dominated this area, have decreased significantly. The decline of these species has been attributed to the introduction of white pine blister rust, wildfire suppression, and historical harvesting patterns. The disease-tolerant species have been replaced with Douglas-fir, grand fir, and subalpine fir, all of which are highly susceptible to root diseases, resulting in substantially increased tree mortality rates in today's forests (Byler and others).

Mapping high-risk areas in Idaho and Montana began by identifying areas within three Bailey's Sections where the forest cover types are predominantly Douglas-fir, grand fir, and subalpine fir (based on McNab and Avers 1994), and where root disease-caused tree mortality is known or assumed to be present. Within these areas, samples of stands were rated for root disease severity using aerial photographs and a 0-9 severity rating technique (Hagle 1992). Annual mortality rates (percent per year) for trees larger than 5 inches diameter at breast height (dbh) were calculated by severity class from permanent plot data accumulated over the past 12 years (Hagle 1992; Hagle and others 1994). Areas where severity ratings exceeded those needed to produce annual mortality rates of 1.7 percent were identified as high-risk areas. It should be noted that the areas represented by the plot data are smaller than the 1-km-square resolution used in the risk map. The higher resolution data were extrapolated to 1-km pixels. Thus, each pixel identified as being at risk is expected to incur 25 percent or more tree mortality over the next 15 years, but the mortality will not be evenly distributed within the pixel. This is of little concern for purposes of strategic risk mapping, but would be important for very site-specific analyses.

Southwest

The most common root diseases in the Southwest are armillaria root disease (*Armillaria spp.*) and annosus root disease (*Heterobasidion annosum*). High-risk areas were determined by first delineating areas known to contain significant amounts of spruce-fir and mixed conifer cover types; and then, based on professional judgment, randomly selecting 10 percent of the pixels in that area to represent the portion at high risk.

Pacific Southwest

Most root disease-caused mortality in the Pacific Southwest is caused by annosus root disease (*Heterobasidion annosum*) and black stain root disease (*Leptographium wageneri*). Based on professional judgment, all pine cover types were designated as high risk.

Pacific Northwest
Root diseases in the Pacific Northwest cause mortality primarily in the Douglas-fir and true fir cover types. High-risk areas east of the Cascade Mountains are delineated in Douglas-fir and true firs where root disease is currently active, and where stands have been risk-rated (using a local risk rating model) as moderate or high. High-risk areas west of the Cascade Mountains are delineated in Douglas-fir and true firs where root disease is currently active and trees are less than 80 years old; or in all host types where stands have been risk-rated as severe.

Colorado
High-risk areas were designated using professional judgment based on knowledge of historical annosus root disease activity.

Alaska
Most root disease-caused mortality in Alaska is caused by *Inonotus tomentosus*, affecting spruce trees in the south-central and interior regions. High-risk areas were delineated by first selecting ecosections where tomentosus has been found during ground surveys. Within those ecosections, all cover types except spruce were screened out. Based on professional judgment, 10 percent of the spruce cover type acres were then randomly selected as being susceptible; and 10 percent of those were randomly selected as being at high risk.

Dwarf Mistletoes (see risk map, Appendix C, figure 11)
Dwarf mistletoes (Arceuthobium spp.) are parasitic plants affecting many western conifers. There are several species of dwarf mistletoe throughout the Western United States causing growth loss and tree deformities to a large extent, and tree mortality to a lesser extent. Because mistletoes are so prevalent over a very large area, they can result in significant tree mortality on an annual basis

Pacific Southwest
High-risk areas from dwarf mistletoes were determined by using professional judgment to randomly distribute risk throughout susceptible forested areas in California.

Southwest
High-risk areas from dwarf mistletoes were determined by using professional judgment to randomly select 3 percent of the ponderosa pine cover type.

White Pine Blister Rust (see risk map, Appendix C, figure 12)
White pine blister rust (*Cronartium ribicola*) is an exotic fungal disease that affects all five-needle pines in North America. It was introduced to British Columbia in 1910, and spread to the Western United States. The fungus relies on alternate hosts (*currants and gooseberries*) to spread from one tree to another. Currently, white pine blister rust is active in limber, whitebark, and western white pines in western Montana and northern Idaho; and in limber, whitebark, and bristlecone pines in southern Idaho and Wyoming.

The map depicts those areas with current severe infections in western white pine only.

Commandra Blister Rust (see risk map, Appendix C, figure 13)
Commandra blister rust (*Cronartium comanddrae*) is a fungal disease that infects many pine species throughout Canada and the United States. The fungus relies on alternate hosts (*herbacaeus parasites*) to spread from one tree to another. The disease is most prevalent in lodgepole and ponderosa pine forests in the West. The most recent severe infestations of this disease occur in lodgepole pine stands in northwestern and central Wyoming.

The map depicts the distribution of commandra blister rust where ground surveys have indicated severe losses.

Subalpine Fir Decline (see risk map, Appendix C, figure 14)
Subalpine fir decline is not well understood, but experts believe it is caused by a combination of root diseases and the western balsam bark beetle. In recent years, the decline has been particularly noticeable in Colorado and Wyoming.

The map depicts those areas where aerial surveys over the past several years indicate extensive and continuing tree mortality.

Pinyon Decline (see risk map, Appendix C, figure 15)
Pinion decline is not well understood, but experts believe it is caused by a combination of black stain root disease and bark beetles. Currently, pinyon decline is occurring in Colorado, west of the Continental Divide.

High-risk areas were determined by using professional judgment to randomly select 10 percent of the pinyon/juniper cover type west of the Continental Divide.

Yellow-Cedar Decline (see risk map, Appendix C, figure 16)
Yellow-cedar decline is not well understood, but experts believe it is associated with poorly drained anaerobic soils. The decline is occurring over a large portion of southeast

Alaska. Tree mortality resulting from this decline is believed to be the result of either freezing of the shallow, fine roots, or toxins produced by decomposition in wet, organic soils.

High-risk areas were determined by using professional judgment to randomly select 20 percent of the yellow cedar cover type where the decline has been identified from aerial survey data.

Western Bark Beetles

Mountain Pine Beetle (see risk map, Appendix C, figure 17)

The mountain pine beetle (*Dendroctonus ponderosae*) attacks several species of pine throughout western forests in North America. Mature and overly dense pine forests are especially vulnerable to this bark beetle.

Of the 10 bark beetles evaluated in the Western United States (including Alaska), mountain pine beetle accounted for 30 percent of the total area at risk. Although high-risk areas are found throughout the West, most of the acres at risk are in Washington, Oregon, and Montana.

Specific factors used to map high-risk areas varied by location, but the general approach used in all areas involved use of forest cover type data, FIA stand characteristic data, and/or aerial survey data to identify historical outbreak patterns. Areas dominated by lodgepole or ponderosa pine forests were identified. Within those forest types, areas that exceeded certain thresholds for basal area, age class, and tree size class, were delineated, and, along with historical outbreak data, used to determine areas most susceptible to future outbreaks. Susceptibility factors are based on Amman and others 1977; Bennett and others, 1980; Cole and McGregor, 1983; McGregor and Cole 1985; Schmid and others 1994; and Shore and Safranyik, 1992. Finally, in some areas, a percentage of the susceptible area that would result in 25 percent or more tree mortality over the next 15 years was generated through a consensus of opinions of several entomologists. This percentage was then randomly distributed over the susceptible area to delineate the area at risk.

Pacific Northwest

Mountain pine beetles in the Pacific Northwest cause mortality primarily in ponderosa and lodgepole pine cover types, and other pines to a lesser extent. High-risk areas for ponderosa pine were designated where 70 percent of the cover type is ponderosa pine; average dbh exceeds 8 inches; andbasal area exceeds 200 square feet. High-risk areas for lodgepole pine were designated where 50 percent of the cover type is lodgepole pine; average dbh exceeds 8 inches; and basal area exceeds 150 square feet.

Pacific Southwest

Mountain pine beetles in the Pacific Southwest cause mortality primarily in ponderosa and lodgepole pine cover types, and other pines to a lesser extent. Silvicultural models (Oliver, 1995) and stand density index (SDI) values (Dixon, 1988) created from plot-by-plot analyses were used to determine risk. High-risk areas were designated based on thresholds for cover type, SDI, age, precipitation, and canopy cover. Coefficients for these variables varied by location.

Northern Rocky Mountain Area

Mountain pine beetles in the Northern Rockies cause mortality primarily in lodgepole pine, and other pines to a lesser extent. High-risk areas for lodgepole pine were designated where average dbh exceeds 8 inches; basal area exceeds 120 square feet; trees are over 80 years old; and elevation/latitude is conducive to beetle survival.

Intermountain Area

Mountain pine beetles in the Intermountain area (Idaho, western Wyoming, and Utah) cause mortality primarily in ponderosa and lodgepole pine, and other pines to a lesser extent. Highly susceptible areas for lodgepole pine were designated where average dbh exceeds 8 inches; basal area exceeds 120 square feet; trees are over 80 years old; and elevation/latitude is conducive to beetle survival. Highly susceptible areas for ponderosa pine were designated where average dbh exceeds 10 inches; basal area exceeds 120 square feet; trees are over 80 years old; and elevation/latitude is conducive to beetle survival. Once the highly susceptible areas in the Intermoutain area were identified, aerial survey data of actual tree mortality over a 10-year period were examined to determine how much annual mortality occurred historically in the highly susceptible area. Based on this historical data, 5 percent of the acres in the highly susceptible area were determined to be at risk. The 5 percent was then randomly distributed over the highly susceptible area.

Colorado/Wyoming/Black Hills

Mountain pine beetles in Colorado, Wyoming, and the Black Hills cause mortality primarily in ponderosa and lodgepole pine cover types. Professional judgment was used to designate high-risk acres and then randomly distribute those acres among cover types as follows:

- Colorado—20 percent of ponderosa and lodgepole pine
- Southern Wyoming—10 percent of ponderosa pine
- Shoshone National Forest, Wyoming—5 percent of lodgepole pine
- Bighorn National Forest, Wyoming—5 percent of ponderosa and lodgepole pine

Black Hills National Forest, South Dakota—25 percent of ponderosa pine

Southwest
Mountain pine beetles in the Southwest cause mortality primarily in ponderosa pines, and to a lesser extent white pines. High-risk areas were designated on the Kaibab Plateau in northern Arizona, based on the history of outbreaks in that area.

Douglas-fir Beetle (see risk map, Appendix C, figure 18)
The Douglas-fir beetle (*Dendroctonus pseudotsugae*) primarily affects Douglas-fir throughout Western North America, but will also attack western larch. Outbreaks usually begin in areas where there are significant numbers of felled, injured, or diseased trees. Outbreaks are usually of short duration in the Pacific Northwest, but last longer in the Rocky Mountain forests. In both regions, the insect is capable of causing substantial amounts of tree mortality.

Pacific Northwest
High-risk areas from Douglas-fir beetles were designated where 50 percent of the cover type is Douglas-fir; average dbh exceeds 18 inches; basal area exceeds 150 square feet; slope is less than 15 percent; and aspect is between 45 and 270 degrees

Idaho/Montana/Utah
High-risk areas from Douglas-fir beetles were designated where 50 percent of the cover type is Douglas-fir; average dbh exceeds 16 inches; basal area exceeds 150 square feet; and trees are over 120 years old.

Colorado/Wyoming
High-risk areas from Douglas-fir beetles were designated where aerial surveys over the past several years indicate extensive and continuing mortality.

Fir Engraver Beetle (see risk map, Appendix C, figure 19)
The fir engraver beetle (*Ventralis LeConte*) affects western conifers, particularly Douglas-fir and true firs in the Western United States and Canada.

Pacific Southwest
Fir engraver beetles in the Pacific Southwest cause mortality primarily in white firs, and in red firs to a lesser extent. High-risk areas were designated based on certain thresholds for cover type, SDI, age, precipitation, and canopy cover. Coefficients for these variables varied by location.

Idaho/Montana/Utah
Highly susceptible areas from fir engraver beetles were designated where 50 percent of the cover type is fir; average dbh exceeds 16 inches; basal area exceeds 150 square feet; and trees are over 120 years old.

Based on historical data, 50 percent of the acres in the highly susceptible area were determined to be at risk. The 50 percent was then randomly distributed over the highly susceptible area.

Ips Beetle (see risk map, Appendix C, figures 20 and 21)
Several species of Ips beetles, including *Ips pini, Ips lecontei*, and *Ips perturbatus*, are mortality-causing agents in pine and spruce forests throughout the Western United States.

Southwest
Ips beetles in the Southwest cause mortality primarily in ponderosa pines. Highly susceptible areas were designated based on the history of outbreaks in areas that have sustained significant Ips-related mortality (primarily in central Arizona). Five percent of the acres were determined to be at risk. The 5 percent was then randomly distributed over the highly susceptible areas.

Pacific Southwest
Ips beetle complexes in California cause mortality in mixed conifer cover types. High-risk areas were based on a combination of species mix, SDI, precipitation, and canopy cover.

Alaska
Ips beetles in Alaska cause mortality primarily in white and Lutz spruce in the interior region, and to a lesser extent in the Kenai Peninsula. Highly susceptible areas were delineated by first examining historical aerial survey data to identify areas in the interior region that have been defoliated by spruce budworm infestations for several consecutive years, and areas in the Kenai Peninsula with a residual spruce component following recent harvests. Next, high-risk areas were then determined by randomly selecting 50 percent of the susceptible acres in the interior region, and 10 percent of the susceptible acres in the Kenai Peninsula.

Jeffrey Pine Beetle (see risk map, Appendix C, figure 22)
The Jeffrey pine beetle (*Dendroctonus jeffreyi*) affects only Jeffrey pines. It has been active in California since the early 1900s, causing mortality primarily in overmature, stressed trees.

Pacific Southwest
In California, the Jeffrey pine beetle attacks Jeffrey pines usually in conjunction with other bark beetle infestations. High-risk areas were based on a combination of species mix, SDI, precipitation, and canopy cover.

Roundheaded Pine Beetle (see risk map, Appendix C, figure 23)

The roundheaded pine beetle (*Dendroctonus adjunctus*) causes mortality in ponderosa pine forests in theSouthwest. Highly susceptible areas were designated where historical aerial survey data indicate past mortality caused by roundheaded pine beetle infestations. For most of the highly susceptible area, high-risk areas were determined by randomly selecting 10 percent of the highly susceptible acres. In southwestern New Mexico, where extensive needle cast caused by the Lophodermella cerina fungus has occurred in recent years, 100 percent of the highly susceptible area was designated as high risk.

Larch Beetle (see risk map, Appendix C, figure 24)

The larch beetle (*Dendroctonus simplex*) in Alaska causes mortality primarily in eastern larch in the interior region. Highly susceptible areas were delineated by first examining historical aerial survey data to identify areas in the interior region that have been weakened in recent years by defoliating insects and drought. Next, high-risk areas were then determined by randomly selecting 30 percent of the highly susceptible acres.

Western Balsam Bark Beetle (see risk map, Appendix C, figure 25)

The western balsam bark beetle (*Dryocoetes confusus*) affects western conifers, particularly subalpine fir forests in the Western United States and Canada.

Idaho/Montana

High-risk areas from western balsam bark beetles were designated where 50 percent of the cover type is subalpine fir; average dbh exceeds 16 inches; basal area exceeds 150 square feet; and trees are over 120 years old.

Utah/Wyoming

Highly susceptible areas from western balsam bark beetles were designated where 50 percent of the cover type is subalpine fir; average dbh exceeds 16 inches; basal area exceeds 150 square feet; and trees are over 120 years old. High-risk areas were determined by randomly selecting 5 percent of the highly susceptible acres.

Western Pine Beetle (see risk map, Appendix C, figure 26)

The western pine beetle (*Dendroctonus brevicomus*) affects pine forests throughout the Western United States and British Columbia.

Pacific Northwest

Western pine beetles in the Pacific Northwest cause mortality primarily in ponderosa pines. High-risk areas for ponderosa pine were designated where 70 percent of the cover type is ponderosa pine; average dbh exceeds 8 inches; and basal area exceeds 200 square feet.

Pacific Southwest

Western pine beetles in the Pacific Southwest cause mortality primarily in ponderosa pines. High-risk areas were designated based on certain thresholds for cover type, SDI, age, precipitation, and canopy cover. Coefficients for these variables varied by location.

Intermountain Area

Western pine beetles in the Intermountain area cause mortality primarily in ponderosa pines. Highly susceptible areas for ponderosa pine were designated in even-aged forests, primarily in Idaho, where average dbh exceeds 10 inches, and basal area exceeds 120 square feet. Once the highly susceptible areas were identified, aerial survey data of actual tree mortality over a 10-year period were examined to determine how much annual mortality occurred historically in the highly susceptible area. Based on this historical data, 13 percent of the acres in the highly susceptible area were determined to be at risk. The 13 percent was then randomly distributed over the highly susceptible area.

Southwest

Western pine beetles in the Southwest cause mortality primarily in ponderosa pines. Highly susceptible areas were designated where historical aerial survey data indicate past mortality caused by western pine beetle infestations. High-risk areas were determined by randomly selecting 5 percent of the highly susceptible acres.

Spruce Beetle (see risk map, Appendix C, figures 27 and 28)

The spruce beetle (*Dendoctronus rufipennis*) affects several spruce species in the Western United States and Canada. In recent years, the insect has been particularly destructive in Alaska.

Alaska

In south-central and interior Alaska, highly susceptible areas were delineated by first examining historical aerial survey data to identify areas of hemlock-sitka spruce and other softwood cover types that have been affected by spruce beetle infestations for several consecutive years. Next, aerial survey data was used to eliminate areas of previous spruce mortality. Of the remaining acres, 1.5 million were designated as high-risk acres based on professional judgment.

In southeast Alaska, highly susceptible areas were delineated by first identifying forested acres using a GIS database.

Next, acres of second growth and clearcuts were removed. Then aerial survey data was used to identify areas of current spruce beetle activity. Of the remaining acres, 50 percent were designated as high-risk acres based on professional judgment.

Idaho/Montana/Utah

High-risk areas from spruce beetles were designated where 65 percent of the cover type is spruce; average dbh exceeds 16 inches; and basal area exceeds 150 square feet.

Colorado/Wyoming

High-risk areas from spruce beetles were designated using professional judgment based on knowledge of historical spruce beetle activity.

Southwest

Spruce beetles in the Southwest cause mortality in Engelmann spruce. Highly susceptible areas (a limited number of acres in Arizona) were designated based on knowledge of current spruce beetle activity and expert judgment. High-risk areas were determined by randomly selecting 10 percent of the highly susceptible acres.

Western Foliage and Stem Feeding Insects

Douglas-fir Tussock Moth (see risk map, Appendix C, figure 29)

The Douglas-fir tussock moth (*Orgyia pseudotsugata*) is a defoliator of firs, and ornamental spruce in Western North America. Severe outbreaks have occurred throughout the Western United States and British Columbia. In most years, tussock moth populations remain low and do not cause much tree mortality. But periodically, on approximately 8-to 12-year cycles, tussock moth populations explode and cause extensive tree mortality and growth loss.

Pacific Northwest

High-risk areas from the Douglas-fir tussock moth were designated where at least 80 percent of the cover type is Douglas-fir or true fir in multistoried stands; slope is less than 15 percent; and aspect is between 45 and 270 degrees

Idaho/Utah

High-risk areas from the Douglas-fir tussock moth were designated where at least 60 percent of the cover type is Douglas-fir or grand fir in multistoried stands; average dbh exceeds 9 inches; basal area exceeds 150 square feet; and treesare over 120 years old. Based on historical outbreak data, 30 percent of the acres were determined to be at risk. The 30 percent was then randomly distributed over the area.

Western Spruce Budworm (see risk map, Appendix C, figure 30)

Western spruce budworm (*Choristoneura occidentalis*) is a widespread, chronic defoliator of conifers throughout the Southwest. This insect causes mortality primarily in spruce, Douglas-fir, and true firs.

High-risk areas were designated in very limited areas of New Mexico and Arizona, based on a history of repeated defoliation in those areas in recent years.

Major Organisms Causing Growth/Volume Loss

Dwarf Mistletoes

Dwarf mistletoes are parasitic plants affecting millions of acres of conifer forests throughout the Western United States. Although tree mortality frequently occurs in mistle-toe-infected forests, the pathogen typically causes a slow but steady decrease in the rate of tree growth. In some cases, dwarf mistletoes predispose trees to mortality from bark beetle attacks. While we identified some areas at risk to mortality from dwarf mistletoe, most of the risk is to growth loss.

Much is known about dwarf mistletoes (Hawksworth and Johnson 1989). There are well-developed mistletoe rating models and permanent plot data (Hawksworth 1977). Also, the Forest Service conducts periodic ground surveys of mistletoe-infected areas. Risk estimates are based on information gathered from these existing databases. Infection levels vary throughout host types in most areas. Therefore, a percentage of the susceptible area was projected to be at risk, and that percentage was randomly distributed among susceptible host types.

Heart Rot in Alaska

Heart rot is a fungus that attacks older trees. It is prevalent in Alaska in the south-central and interior hardwood forests, and in the conifer forests in coastal areas. Tree species most affected include aspen, birch, Sitka spruce, hemlock, and western red cedar. In south-central and interior Alaska, the incidence of stem decay fungi in hardwood species is correlated with stand age and can be substantial at stand maturity (Kimmey and Stephenson 1957). A 1967 study indicated that 47 percent of the paper birch and 82 percent of the quaking aspen trees had decay in the merchantable stem (Hutchison 1967). Studies of heart rot in conifer forests indicate that older growth forests are the most susceptible (Kimmey, 1956; Farr and others, 1976; Hennon and McClellan, 1999).

Results

Hardwood forests designated as high risk to heart rot were determined by first selecting the aspen/birch cover type from the forest cover type data set. Within the aspen/birch type, areas recently affected by spruce beetle infestations were removed from consideration (based on the last 10 years of spruce beetle damage as mapped through aerial surveys). By eliminating the areas mapped for spruce beetle from the aspen/birch cover type, the resulting area more accurately represents the aspen/birch forest type. Next, 50 percent of the remaining trees were removed from consideration because they are less than 80 years old. The remaining older growth aspen/birch cover type is expected to be at risk.

Coastal conifer forests designated as high risk to heart rot were determined by first selecting class 4 forested areas from the Tongass National Forest land management plan's cover type data base. From this cover type, clearcuts and trees less than 150 years old were removed, leaving the susceptible older forest. A small proportion (10 percent at most) of unmapped young-growth forests derived from wind disturbance is contained in this area. Thus, 90 percent of the susceptible older forest is expected to be at risk.

Results of the insect and disease risk mapping effort are presented separately for the three categories of risk (mortality, growth loss, and organisms of special concern).

Mortality Risk

Tree mortality risk projections were made for 27 organisms (17 insects and 10 diseases). Approximately 59 million acres were identified as being at risk (25 percent or more tree mortality expected over the next 15 years). Of the 27 insects and diseases evaluated, four organisms accounted for more than two-thirds of the acres at risk. They are—gypsy moth (26 percent), root diseases in the West (23 percent), southern pine beetle (13 percent), and mountain pine beetle (7 percent).

Of the 59 million acres at risk, 24 million (41 percent) are on national forests and 34 million (59 percent) are on other lands. This amounts to 12 percent of national forest land being at risk, compared to 6 percent of other lands. Because the underlying acreage estimates of forested land and ownership designations are not site specific, these percentages are relative indicators only.

Appendix C, Figures 1 through 30 show the mortality risk projections for individual organisms.

Appendix C, Figure 31 shows the combined mortality risk projections for the United States.

Growth/Volume Loss Risk

Growth loss (volume loss in the case of heart rot) risk projections were made for 12 organisms (8 insects and 4 diseases). Approximately 48 million acres were identified as being at risk (25 percent or more growth loss expected over the next 15 years). Of the 12 insects and diseases evaluated, 2 accounted for almost three-fourths of the acres at risk. They are—dwarf mistletoes throughout the West (37 percent) and heart rot in Alaska (37 percent). Because the underlying acreage estimates of forested land and ownership designations are not site specific, these percentages are relative indicators only.

Appendix C, Figure 32 shows the growth/volume loss risk projections.

Organisms of Special Concern

Twelve organisms were put into this special category because they pose threats in areas where host trees are relatively few in number, or are minor components scattered throughout a more dominant cover type. We did not calculate acres at risk to these organisms because estimates would be highly unreliable, and depiction of acres at risk on a map would greatly overstate the magnitude of the threat. We did, however, identify general areas within which we expect host trees of these organisms to incur 25 percent or more mortality or growth/volume loss over the next 15 years.

Appendix C, Figure 33 shows the general areas of susceptibility to organisms of special concern.

Discussion

Of the three risk categories examined, risk of tree mortality has the most significant and widespread implications for forest health. It is our intent to combine insect and disease risk with other risk layers to provide a more comprehensive picture of risk to forest health in the United States. With this objective in mind, we converted the pixel map (where each pixel represents an area of 1 km^2) shown in appendix C, figure 31, to a watershed map (appendix C, figure 34). Watersheds are expressed as fourth level, eight digit, hydrologic unit codes (HUC's). Figure 34 displays the percentage (in range intervals) of each watershed that contains acres at risk of tree mortality from insects and diseases.

Once we have combined several pertinent risk factors for each watershed, we will be able to more comfortably identify those watersheds on which to conduct a more site-specific analysis to determine if, and where, actions to reduce risk are warranted.

Several techniques were used to identify areas at risk. These techniques varied not only among organisms being evaluated, but in some instances, by geographic area for the same organism. Lack of empirical data, insufficient modeling capabilities, and unreliable geographic specificity of cover type data are the primary reasons why estimation techniques varied; and why professional judgment was relied upon in some areas.

Implications

The risk mapping effort described herein was undertaken to provide a broad, national-level depiction of risk of tree mortality or growth/volume loss from insects and diseases. As such, it is not to be used for site-specific purposes. However, it does provide a systematic approach for evaluating risk from a national standpoint.

From a strategic standpoint, there is a need to identify where the highest potentials for forest health problems exist. This information is needed for long-range planning, and is essential for identifying priorities when developing policy for the Forest Service. The insect and disease risk projections can be combined with other forest health-related risk estimates to provide critical background information to policymakers at the national level.

From a program management standpoint, information generated from the risk mapping effort can be used, along with other management information, to determine program priorities and to support budget requests.

The maps produced by this effort depict current risk based on current and historical conditions. Areas that may have been high risk a few decades ago may now be low risk because outbreaks have occurred and susceptible tree species are now gone. Also, not all acres at risk pose problems. Some tree mortality may be considered beneficial to proper functioning of the ecosystem.

The Forest Service Strategic Plan identifies trends in acres at risk from fire, insects, diseases, and invasive plants as outcomes for measuring program performance. We recognize the need to improve procedures for estimating acres at risk. Our intent is to develop estimation techniques that use the best available information, at reasonable cost, in a collaborative manner, to produce credible, timely, understandable information.

Risk mapping is an iterative process that revises and fine-tunes the database as more and better information becomes available. The process takes advantage of sophisticated technology to develop a very versatile database and provide a visual representation to foster clear communication.

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Appendix A—Using Risk Mapping To Set Priorities

The risk mapping effort is a prioritization process. This process begins strategically, and culminates in resource allocation decisions at the watershed or more site-specific level. The Forest Service is proceeding along the following path:

1. Develop Coarse Filter Maps
   The initial risk maps provide the foundation for a strategic evaluation of forest health on all lands. They serve as a coarse filter to focus our attention on broad geographic areas, within which we would want to conduct further, more in-depth, analyses. This first step involves technical specialists with expertise in the factors being evaluated.

2. Foster Dialogue and Solicit Feedback
   The Forest Service will use the initial risk maps at various forums to foster a dialogue on major forest health issues.

3. Modify Risk Estimates and Identify Areas for Further Analysis
   Following a period of discussion and debate, the Forest Service will identify areas to be analyzed in more detail.

4. Determine Actions To Address Forest Health Threats
   Tactical planning on a watershed or more site-specific basis will determine which actions are most appropriate for reducing risk and preventing further adverse effects.

5. Categorize Areas To Determine Priorities
   Risk can be addressed from a management standpoint. Simply knowing that an area is at high risk is not sufficient information to decide if treatment is warranted. This approach classifies high-risk areas into three categories:
   1. No action warranted (risk is tolerable or treatment options are ineffective)
   2. Action constrained (action precluded by legislation, regulation, or policy)
   3. Action warranted (at least one treatment option is effective and efficient)

6. Adjust Forest Service Programs
   The risk mapping effort will help Forest Service managers allocate resources to where the greatest benefits can be achieved in a cost-effective manner.

7. Monitor
   The risk mapping process is iterative. Maps are adjusted as better information becomes available. Actions taken to improve forest health are also monitored to determine program effectiveness.

Appendix B—Insects and Diseases Analyzed

Organisms causing tree mortality

Annosus root disease
Balsam woolly adelgid
Beech bark disease
Douglas-fir beetle
Douglas-fir tussock moth
Dwarf mistletoes
Fir engraver beetle
Fusiform rust
Gypsy moth
Hemlock woolly adelgid
Ips beetle
Jeffrey pine beetle
Larch beetle
Mountain pine beetle
Pinyon decline
Root diseases in the West
Round-headed pine beetle
Subalpine fir decline
Spruce beetle
Spruce budworm
Southern pine beetle
Western balsam bark beetle
Western pine beetle
White pine blister rust
Western spruce budworm
Yellow cedar decline

Organisms causing growth loss

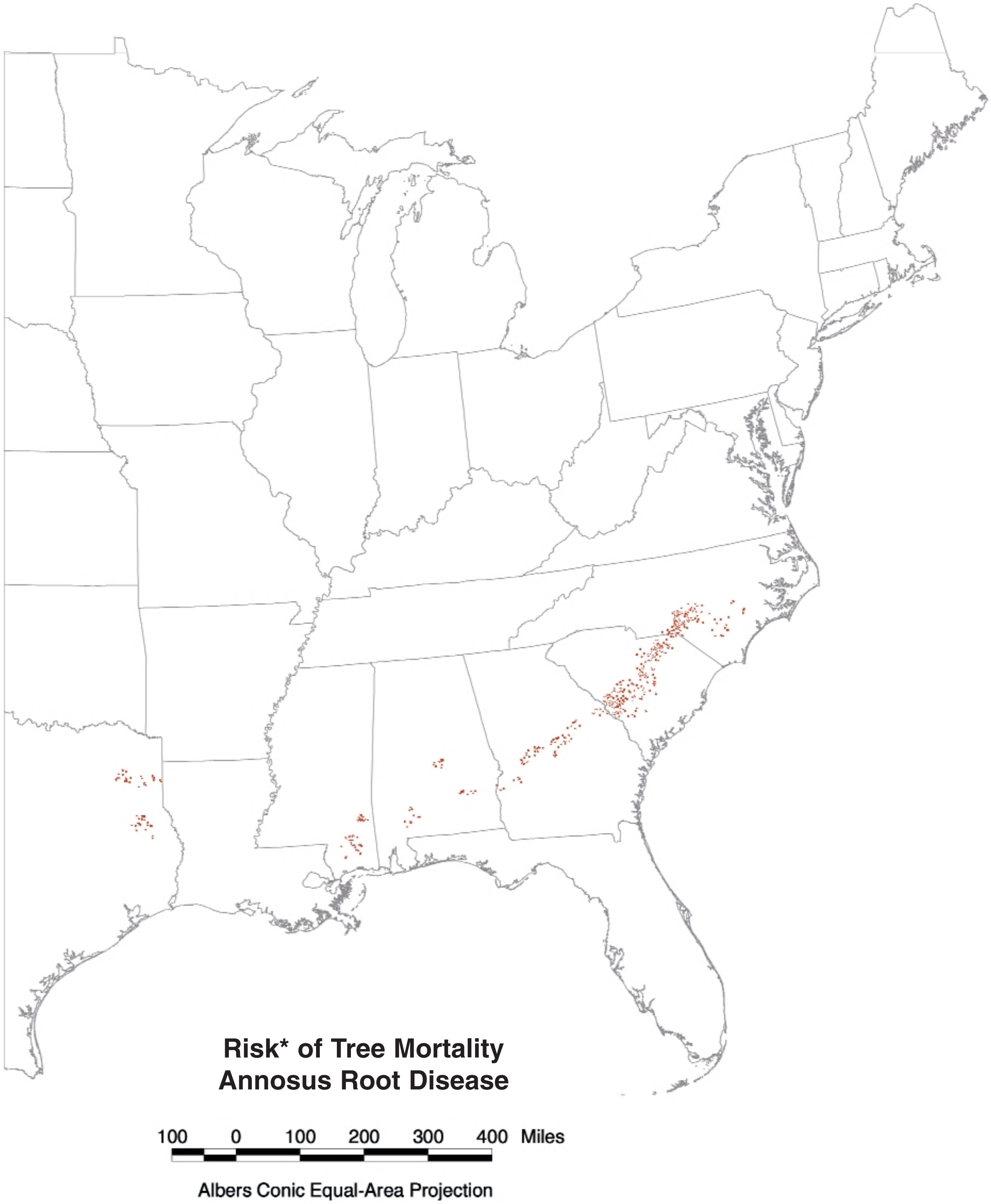
Black-headed budworm
Douglas-fir tussock moth
Dwarf mistletoes
Comandra blister rust
Heart rot
Hemlock sawfly
Lodgepole needle miner
Modoc budworm
Needle casts
Oak decline
Spruce budworm
Spruce needle aphid
Western spruce budworm

Organisms of special concern

Balsam woolly adelgid
Butternut canker
Cercospora blight
Cottonwood decline
Diplodia blight
Dogwood anthracnose
Oak wilt
Pine tip moths
Pinewood nematode
Pitch canker
Port Orford cedar root disease
White pine blister rust

Appendix C—Risk Maps

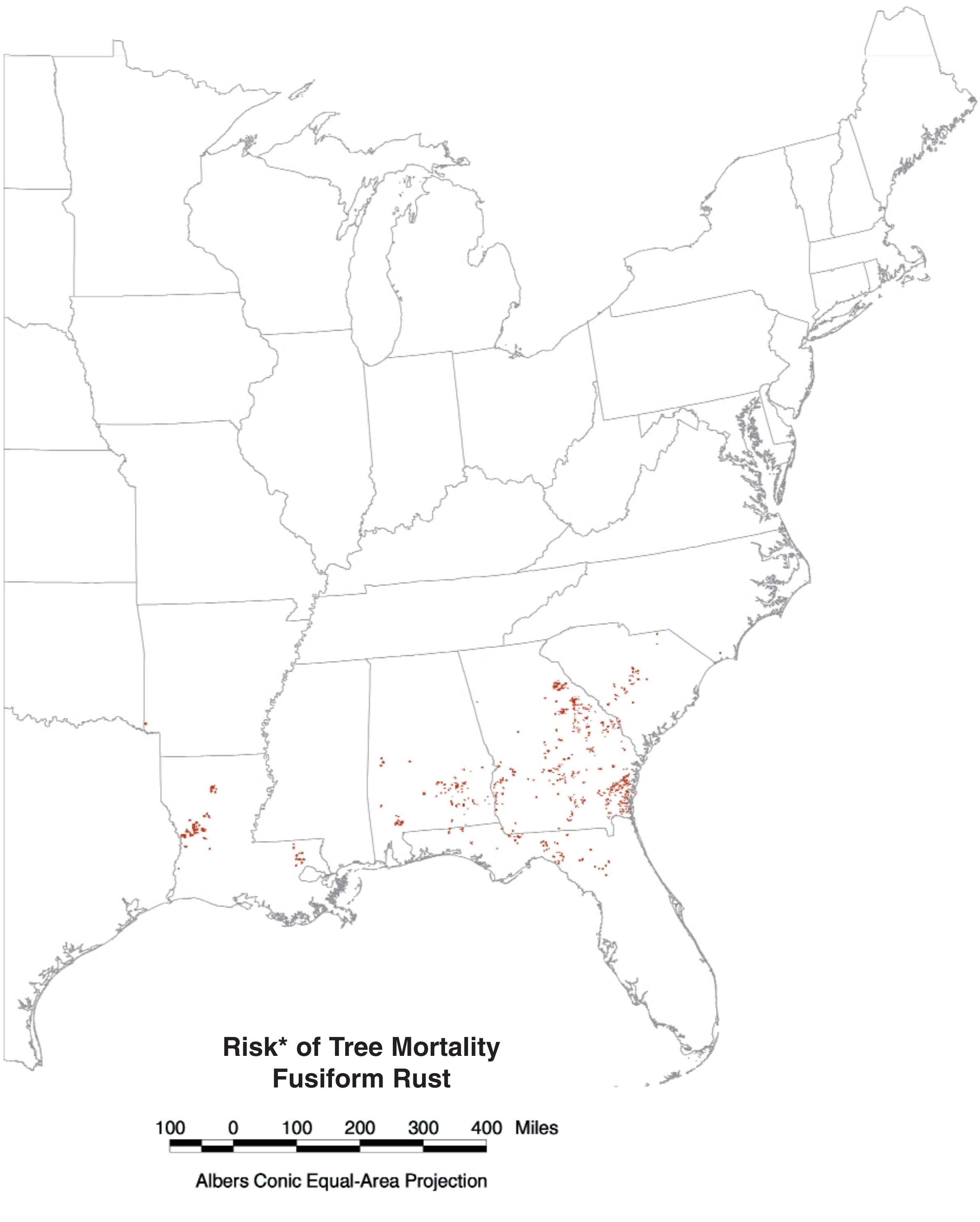
Figure 1



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 2



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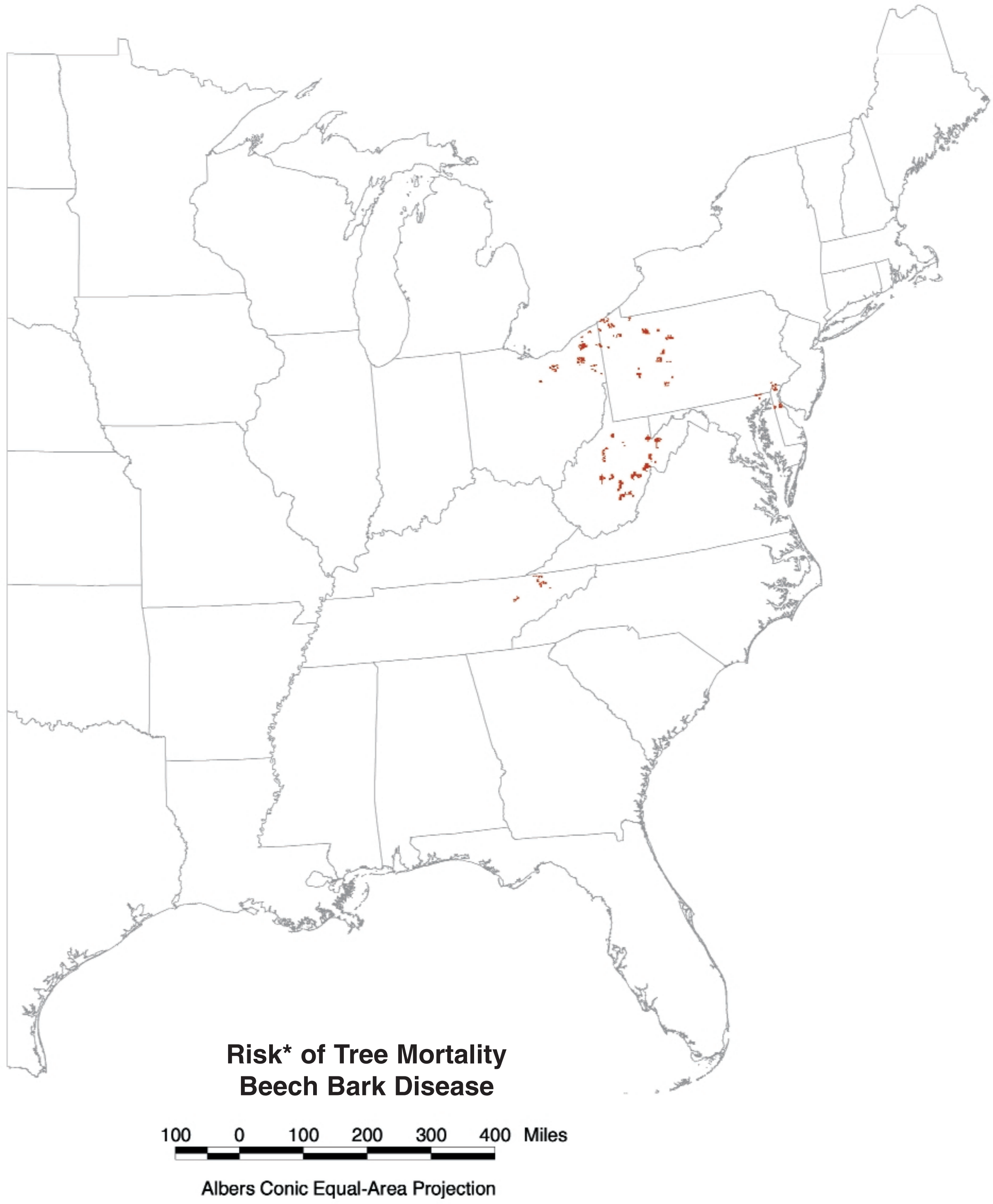
03/15/00

Figure 3



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

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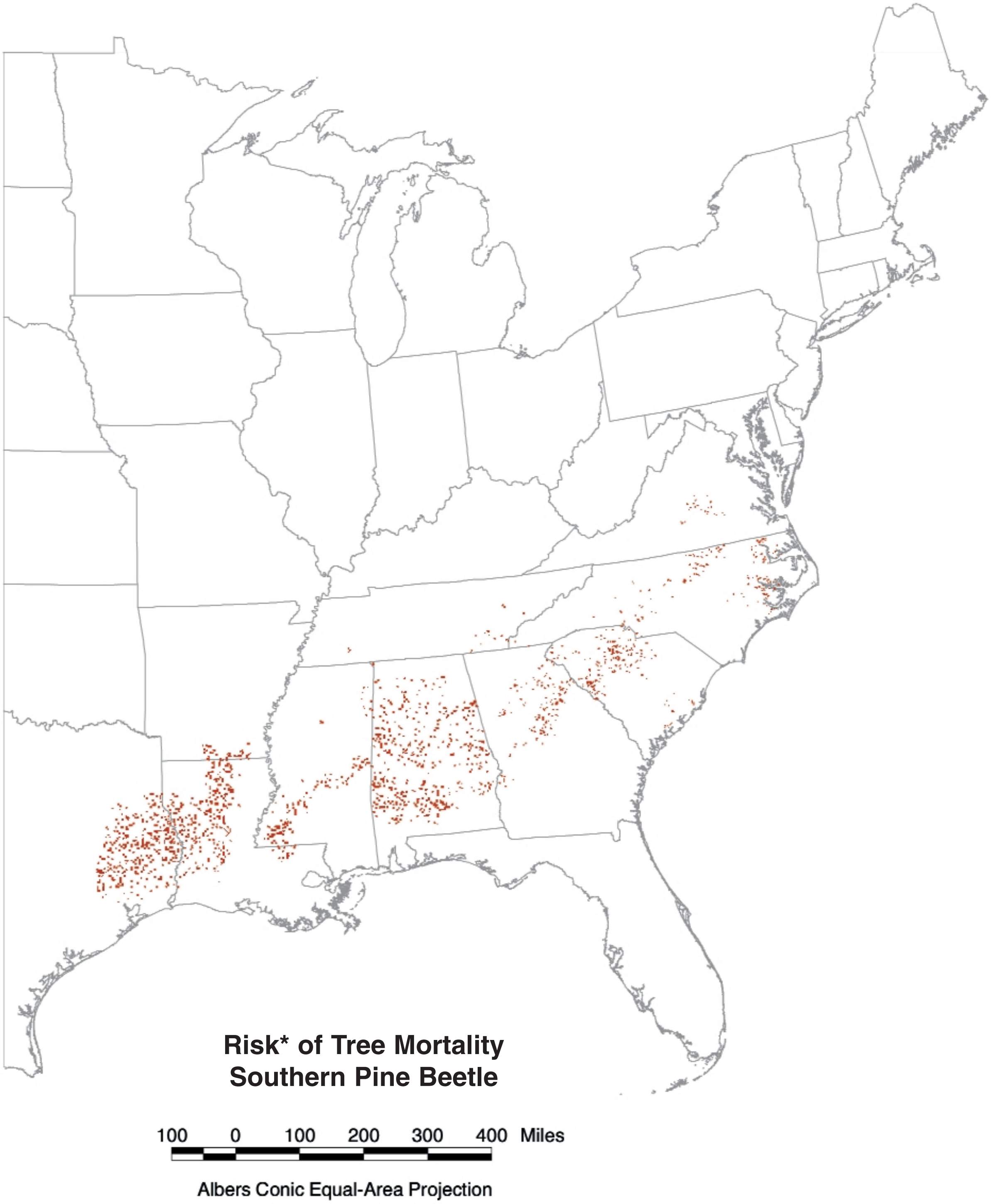
Figure 4

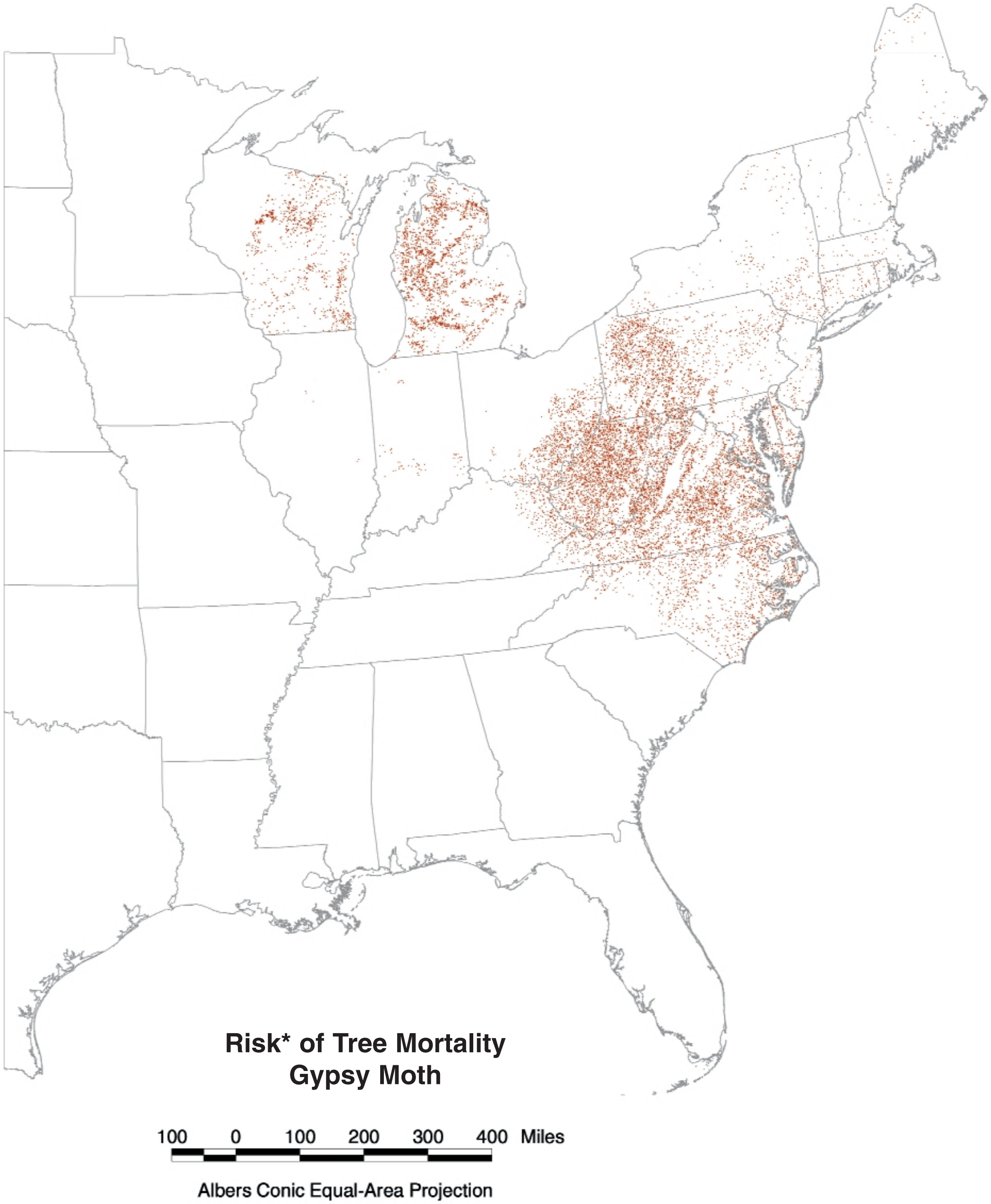


*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

Figure 5



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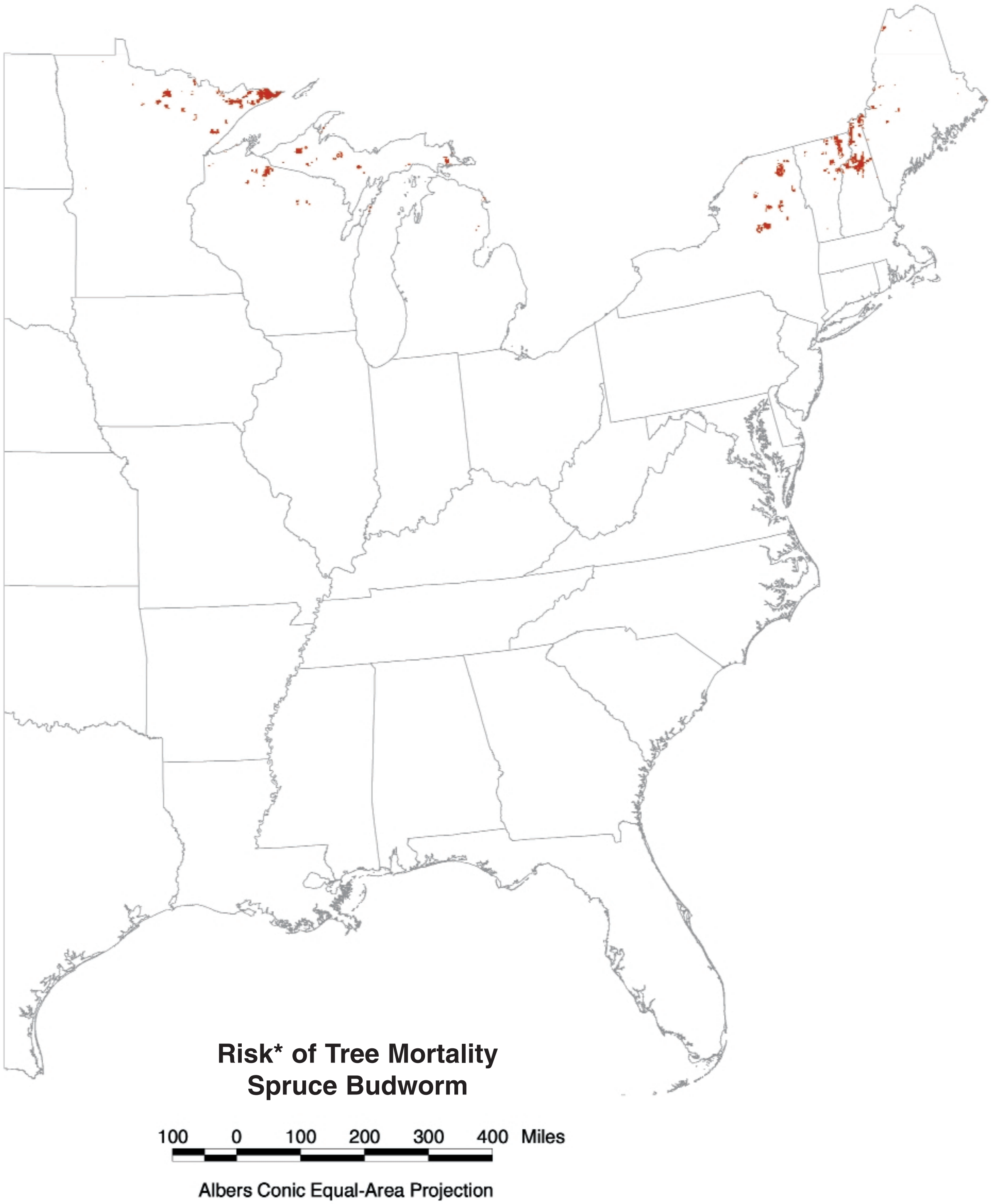
Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 6

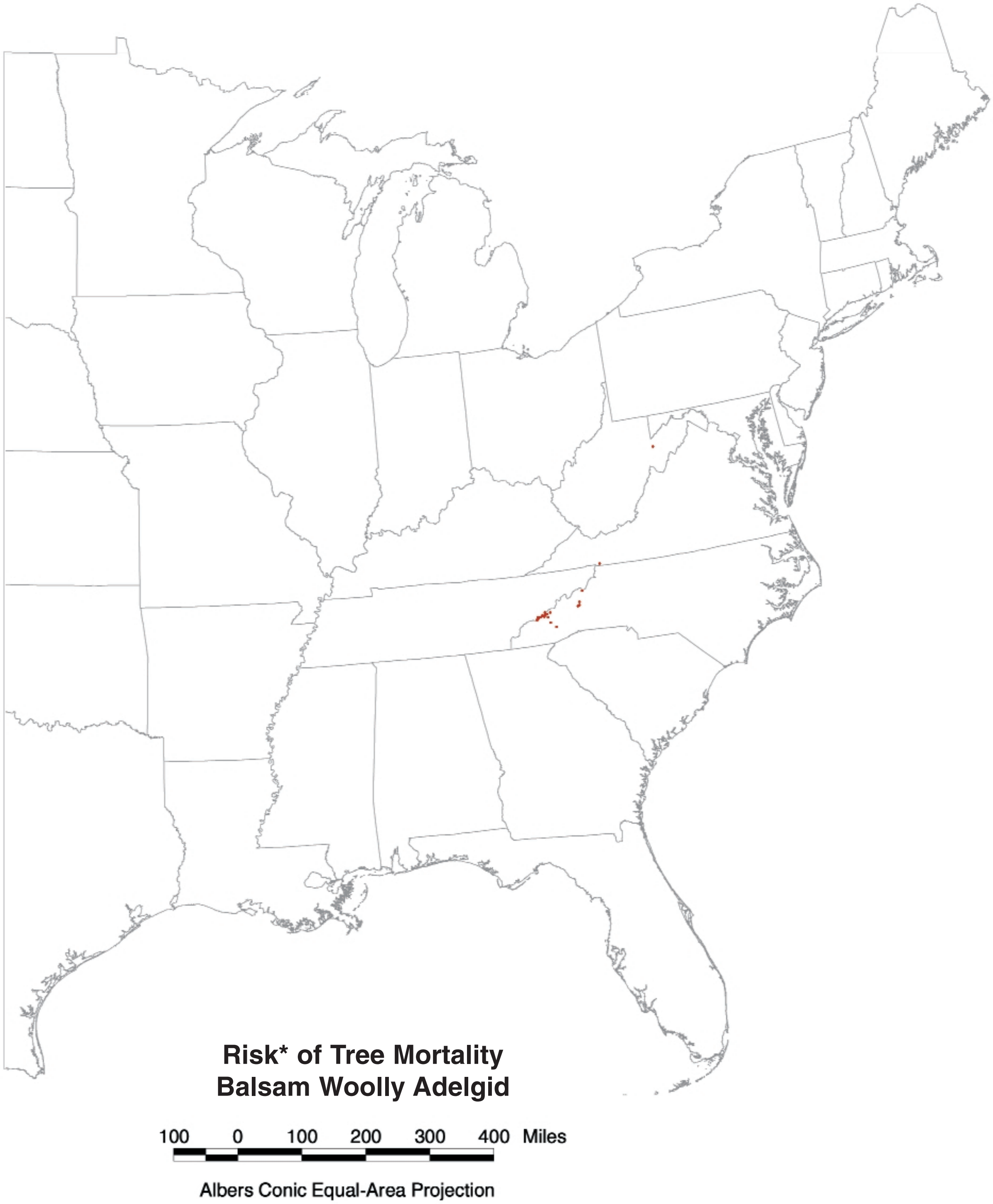


*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

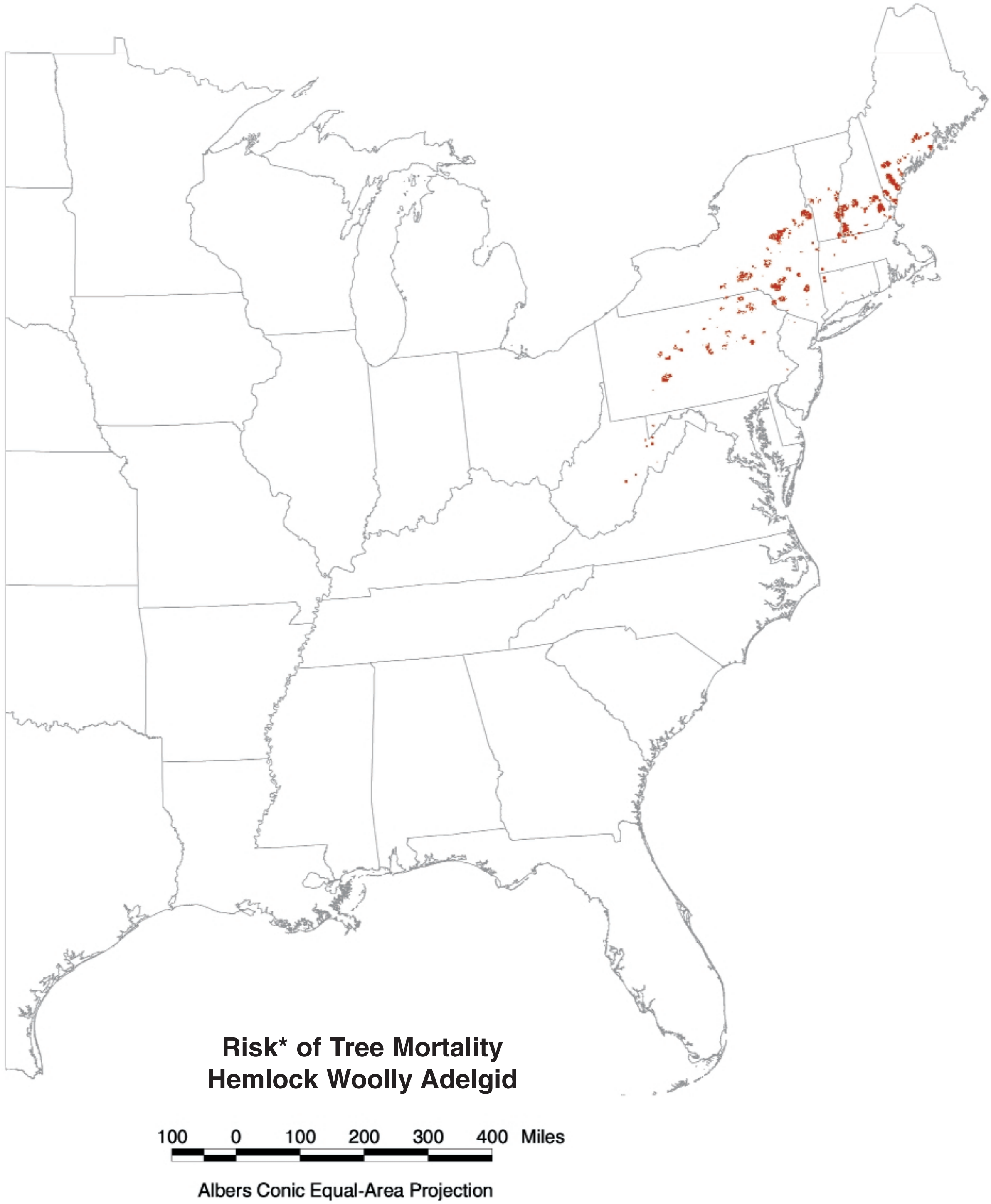
Figure 7



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 8

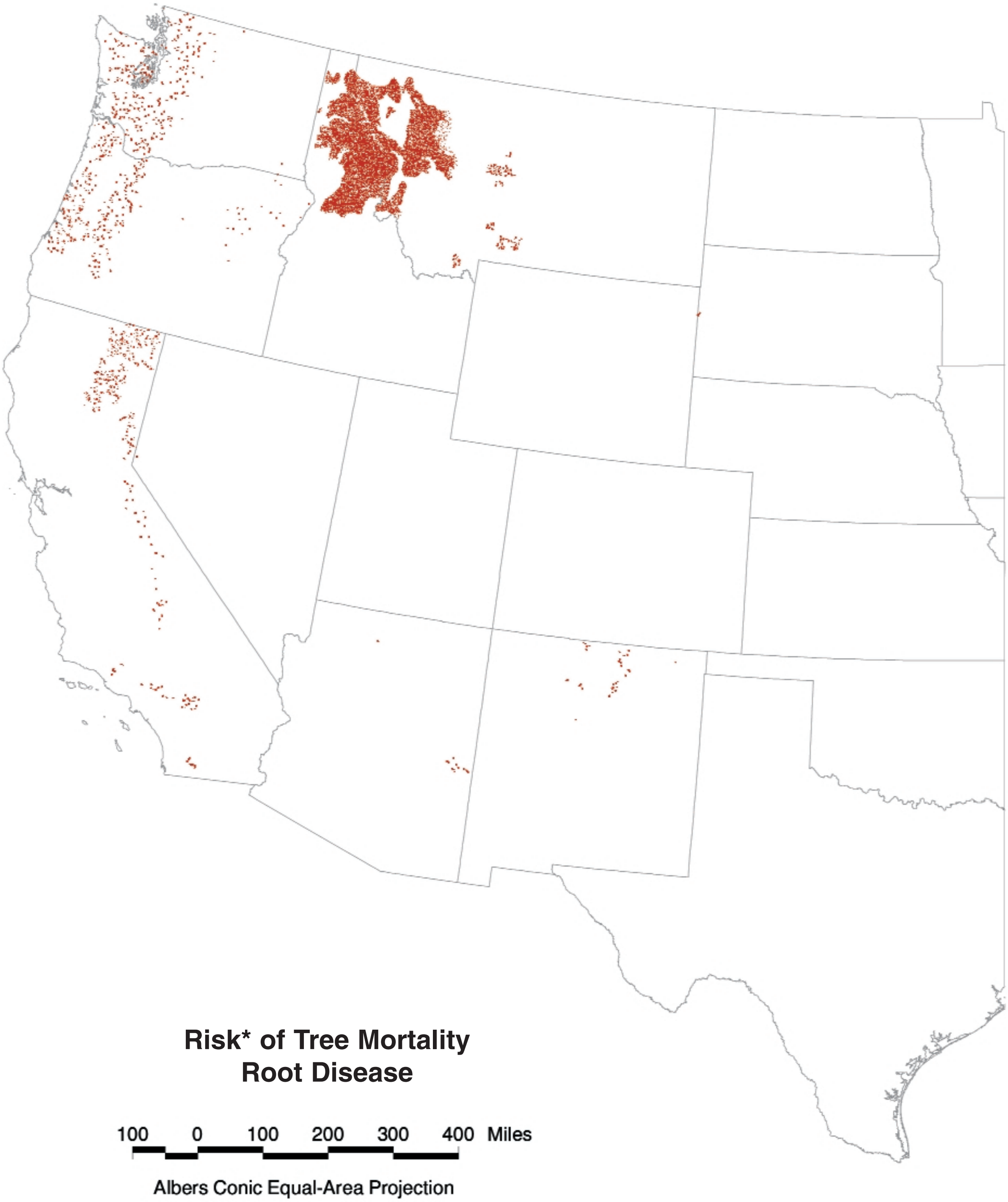


*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

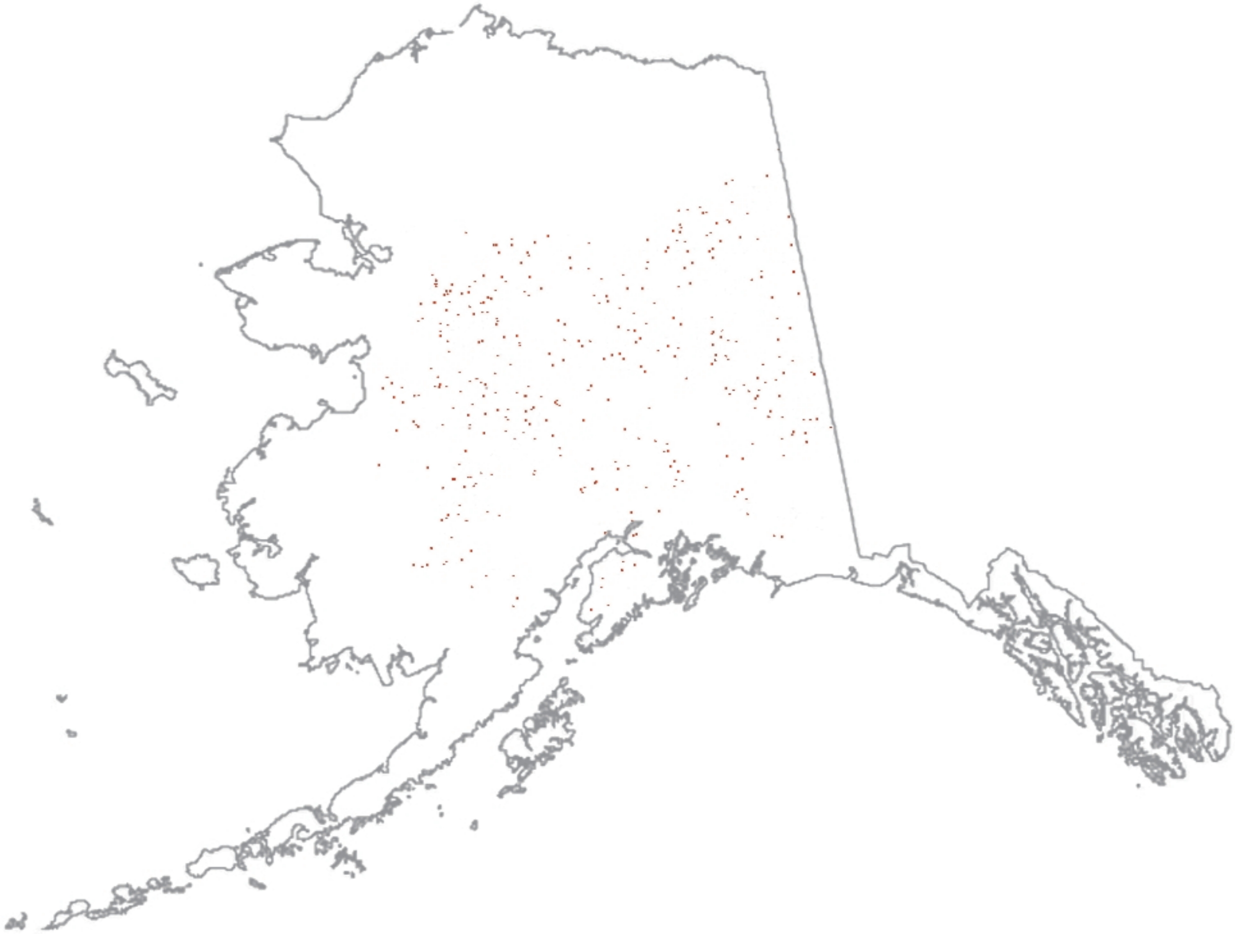
Figure 9



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 10



Risk* of Tree Mortality
Root Disease

100 0 100 200 300 400 Miles

Albers Conic Equal-Area Projection

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

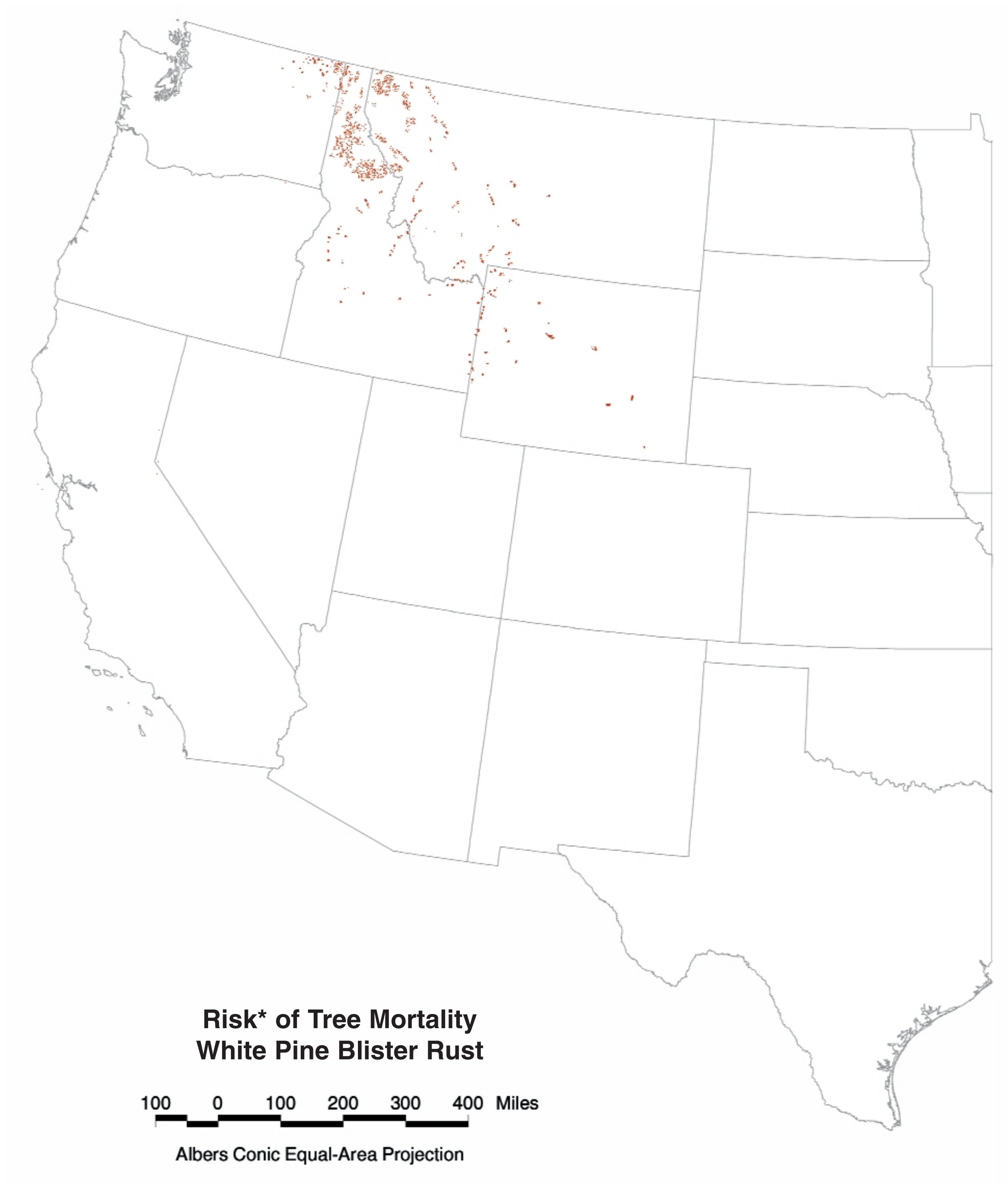
03/15/00

Figure 11

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 12

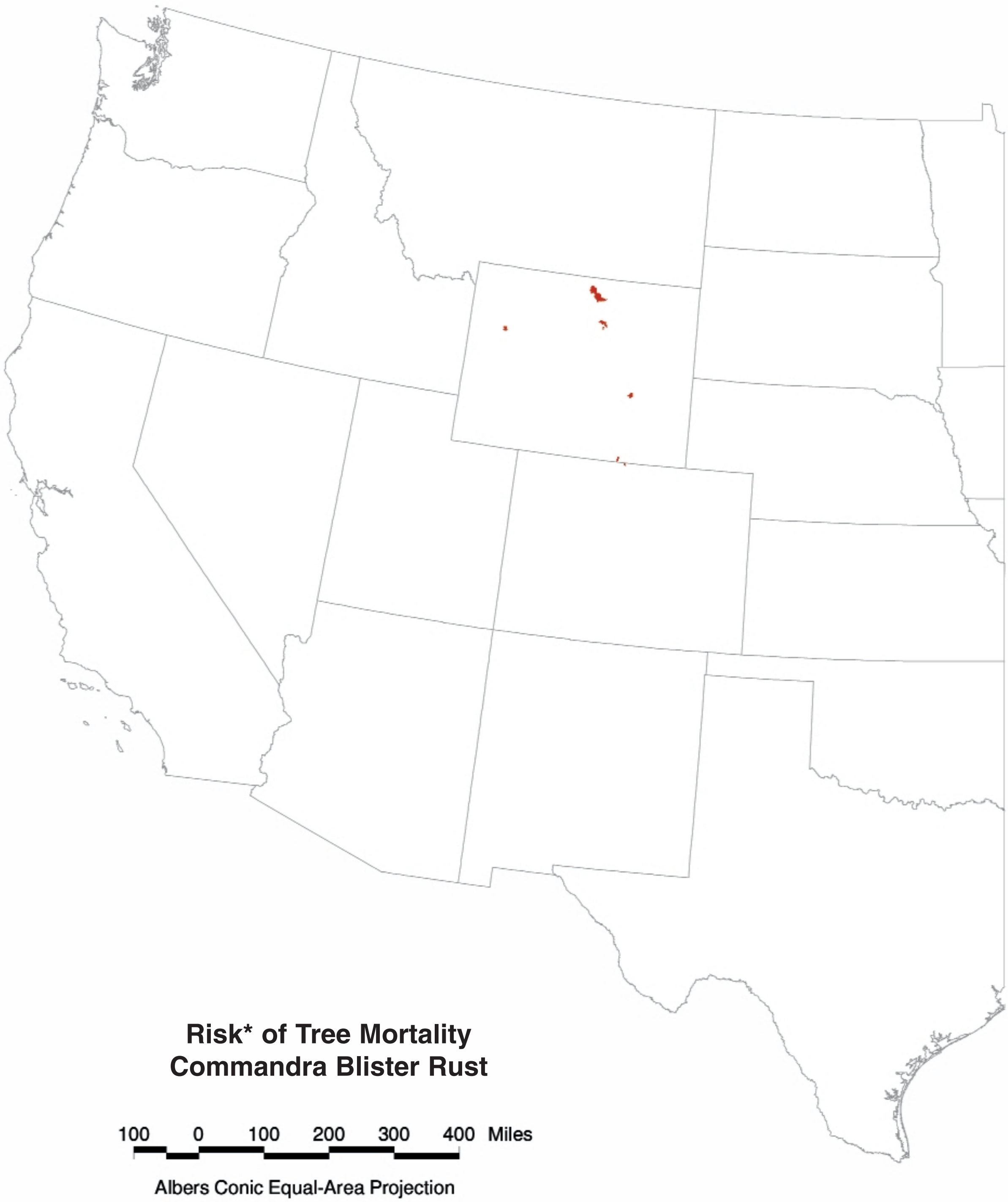


*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

Figure 13



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

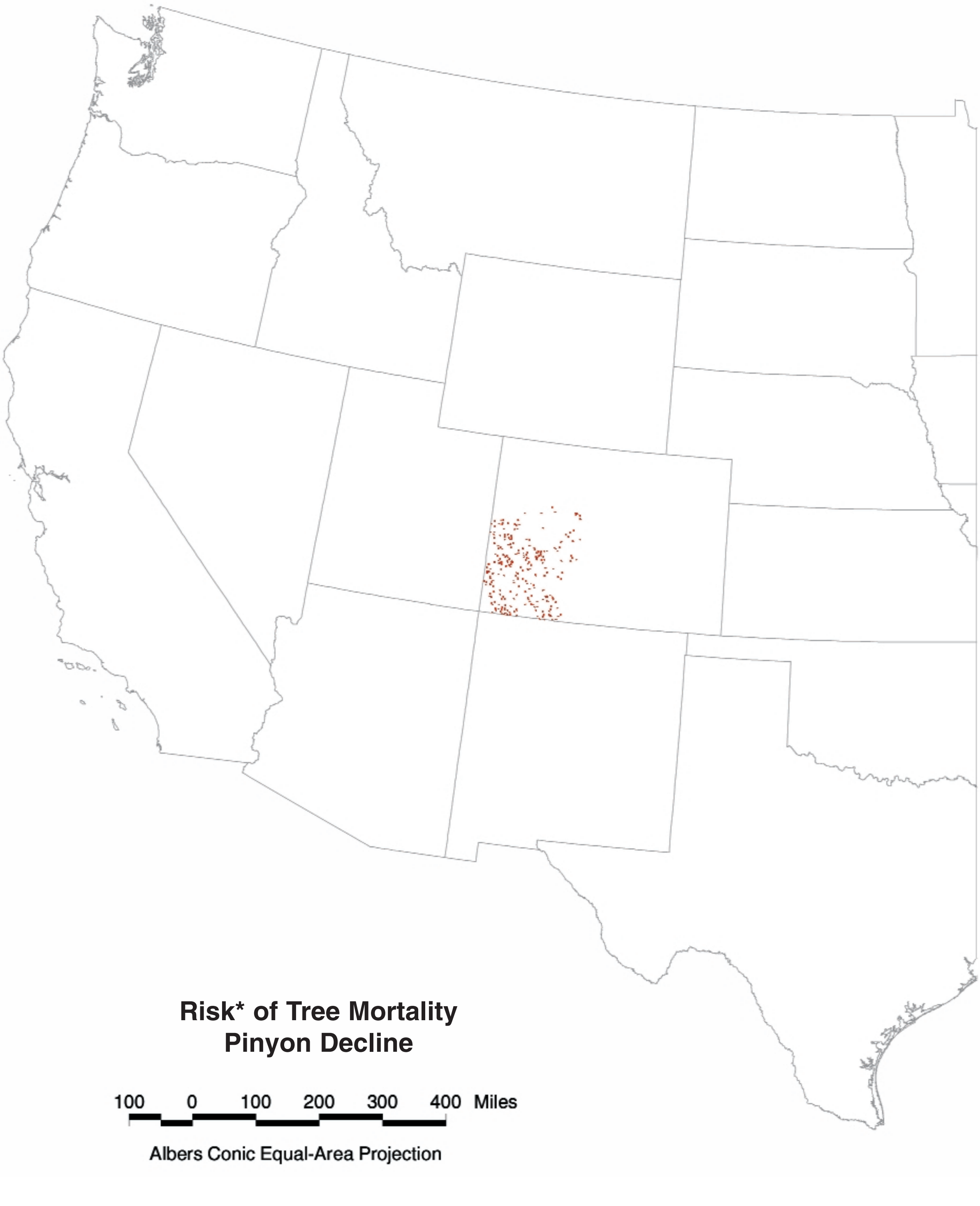
Figure 14

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

Figure 15



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 16

Risk* of Tree Mortality
Yellow Cedar Decline

100 0 100 200 300 400 Miles

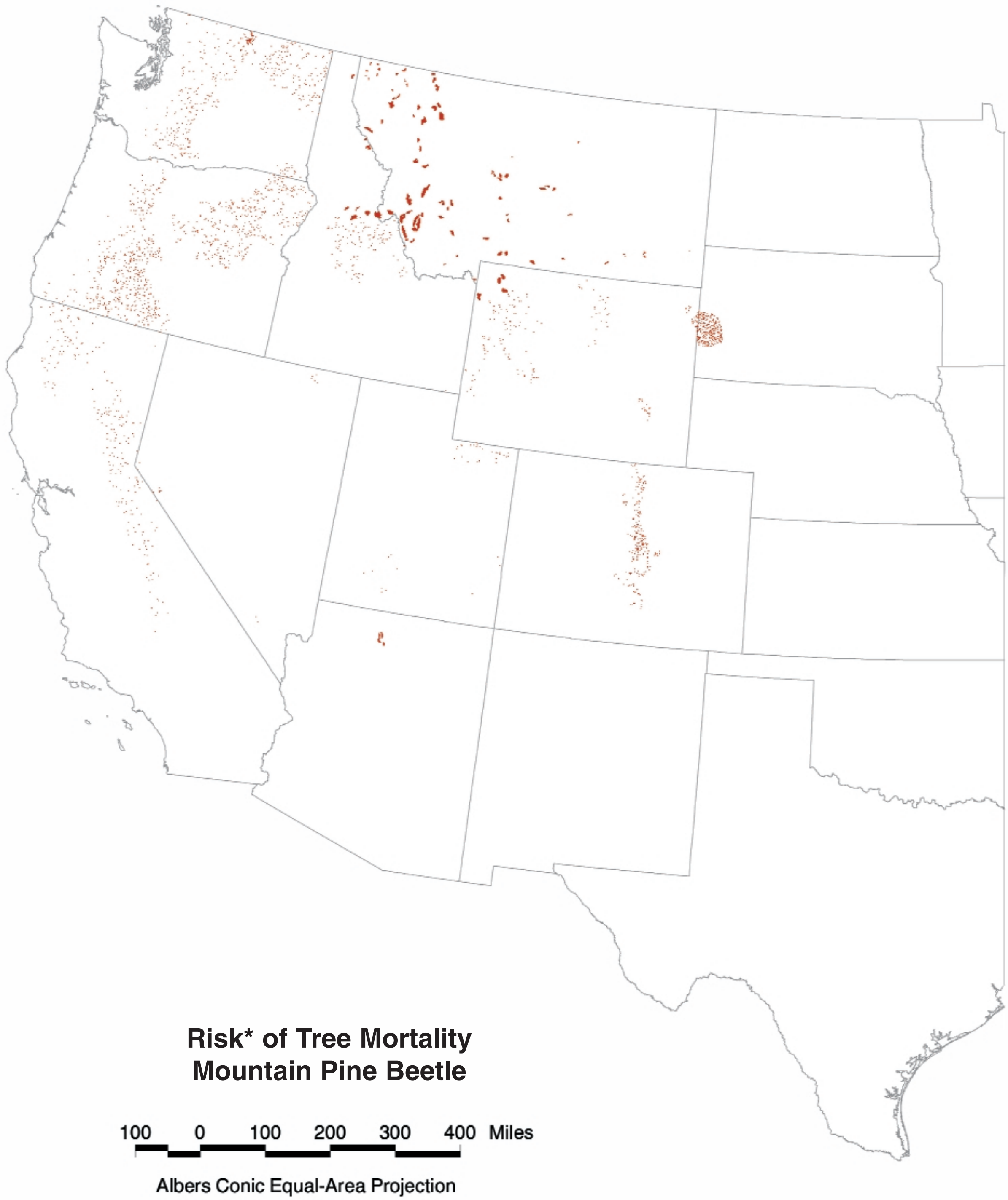
Albers Conic Equal-Area Projection

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

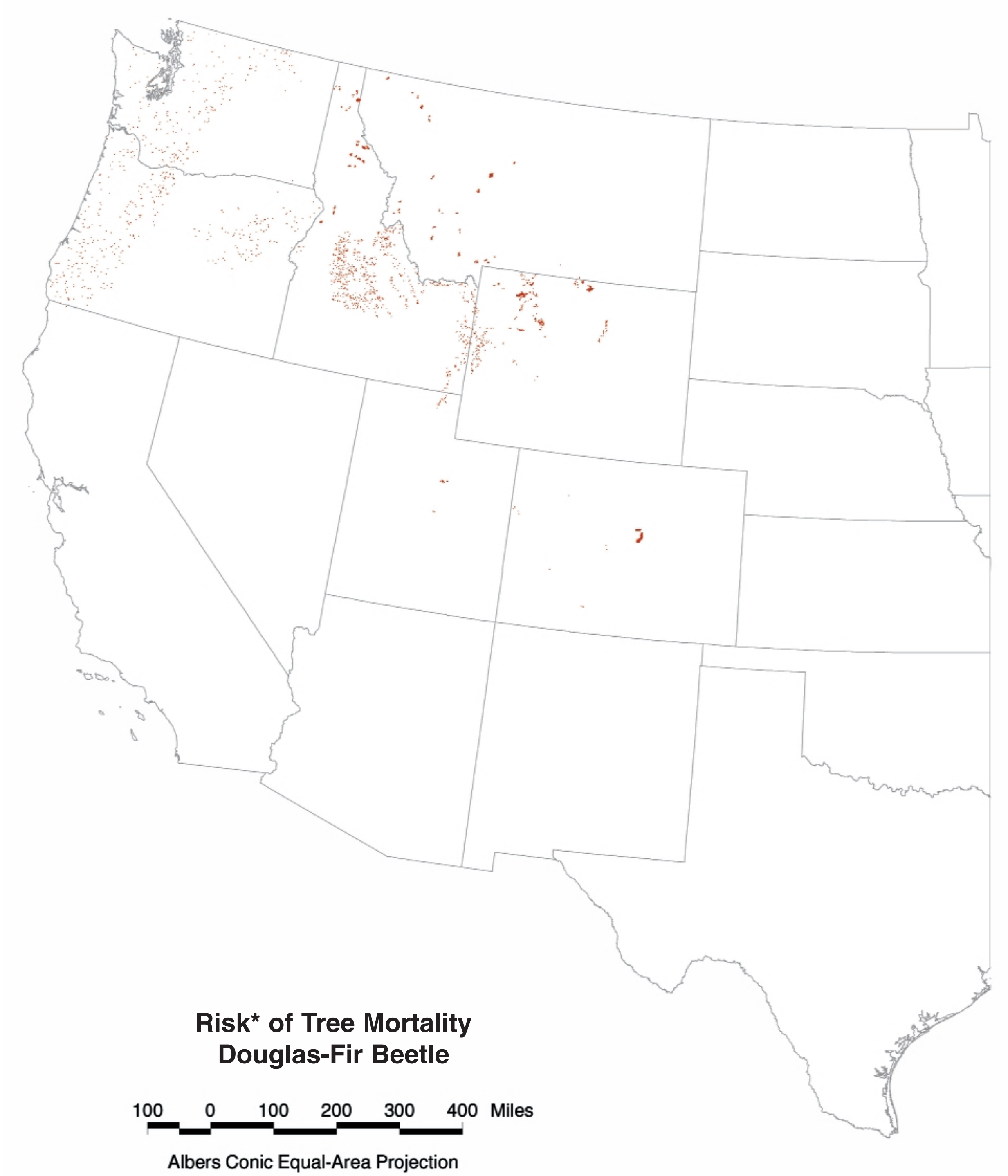
Figure 17



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 18



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

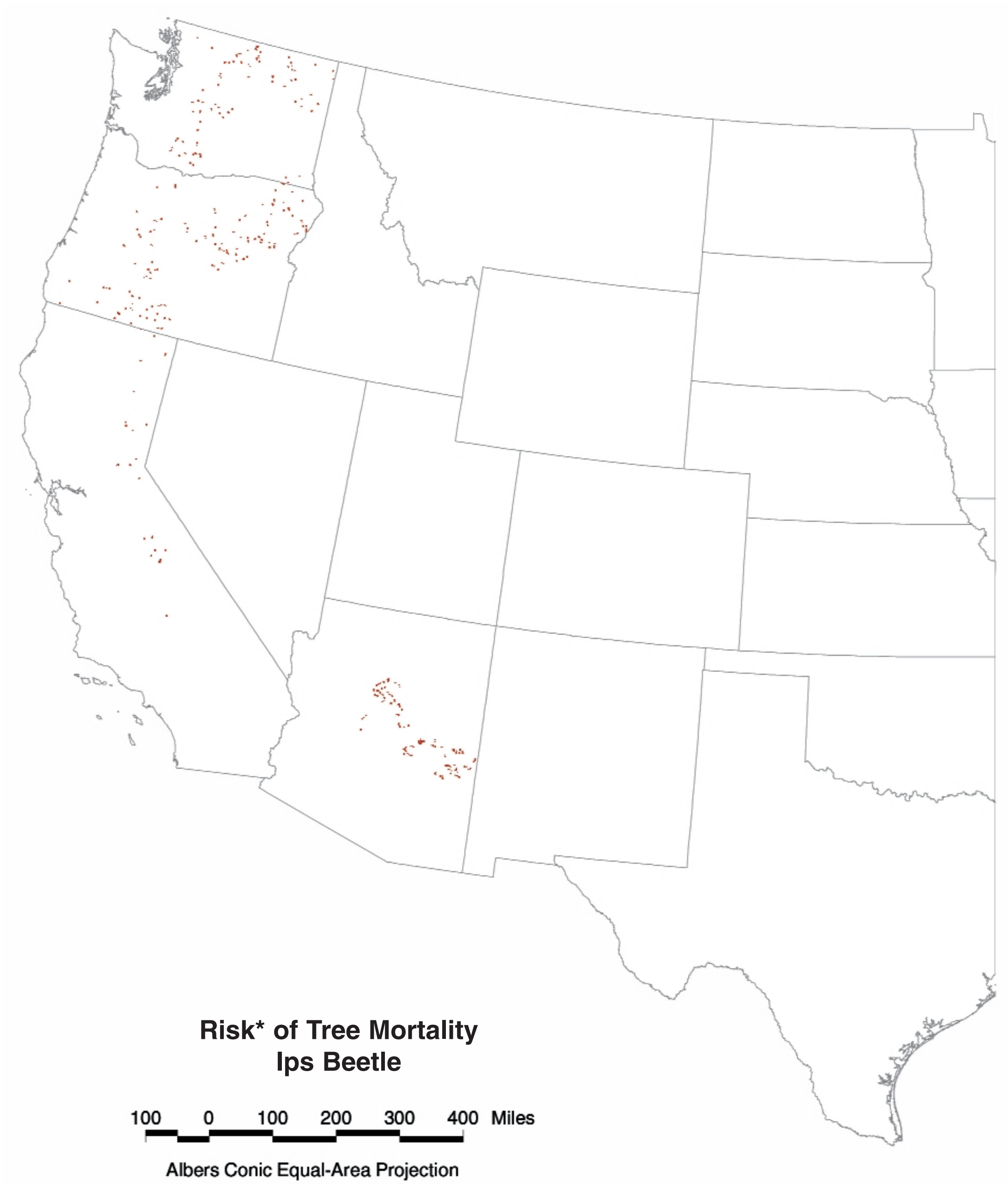
03/15/00

Figure 19

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

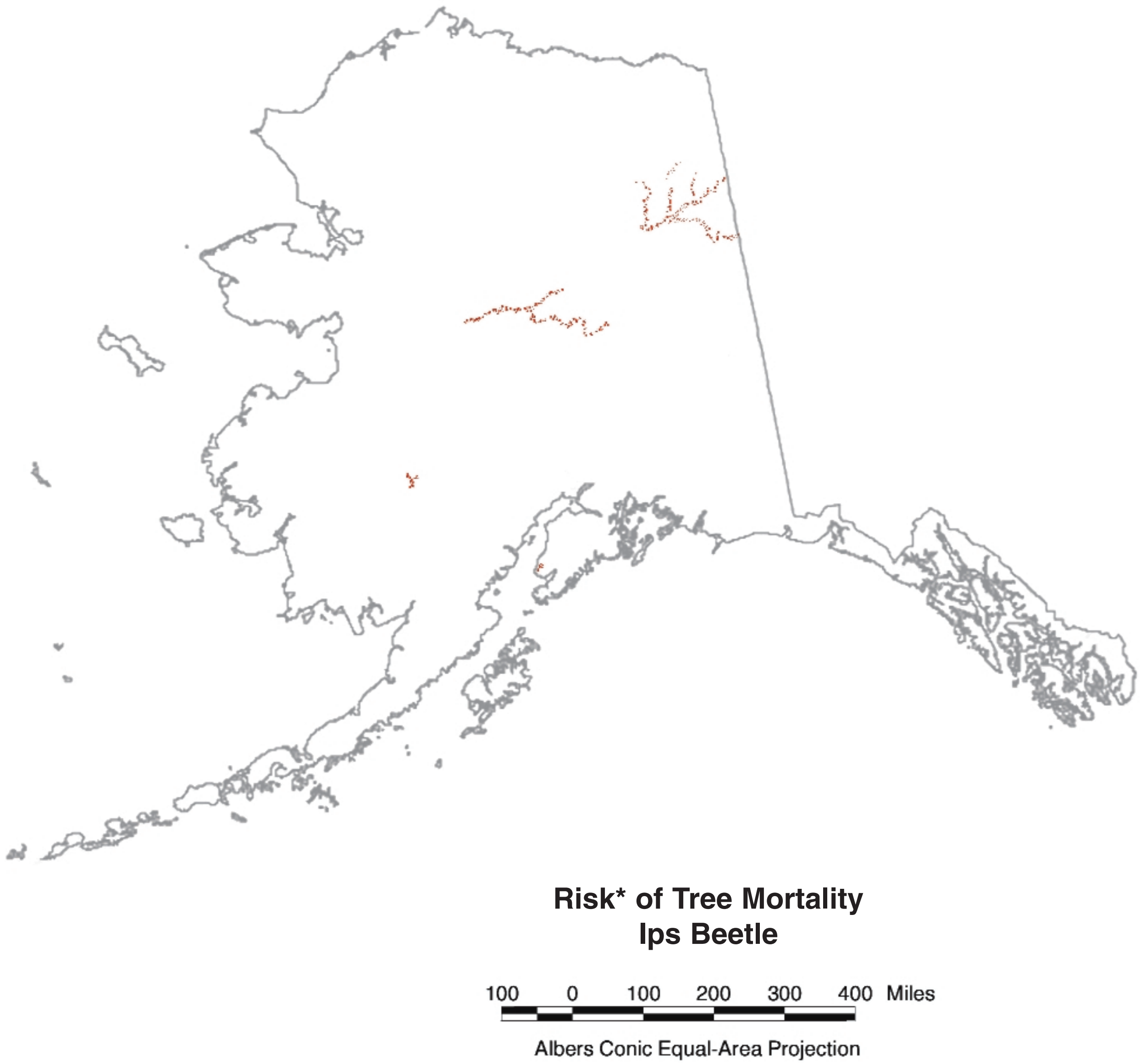
Figure 20



*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 21



*An area is considered to be at risk if 25% or more reduction in volume is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources, and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 22

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

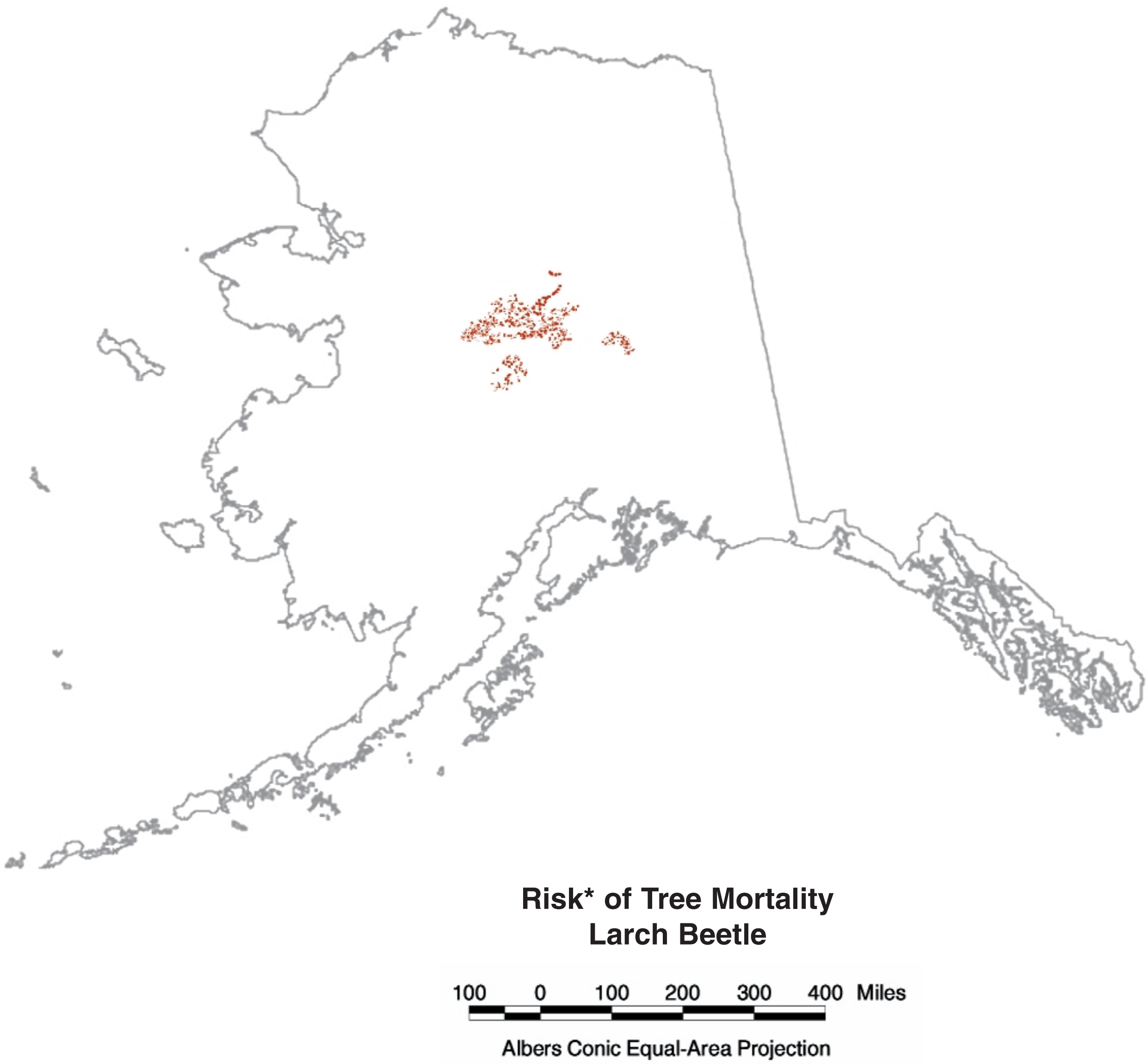
03/15/00

Figure 23

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 24



Risk* of Tree Mortality
Larch Beetle

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

Figure 25

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis. 03/15/00

Figure 26

*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

Figure 27

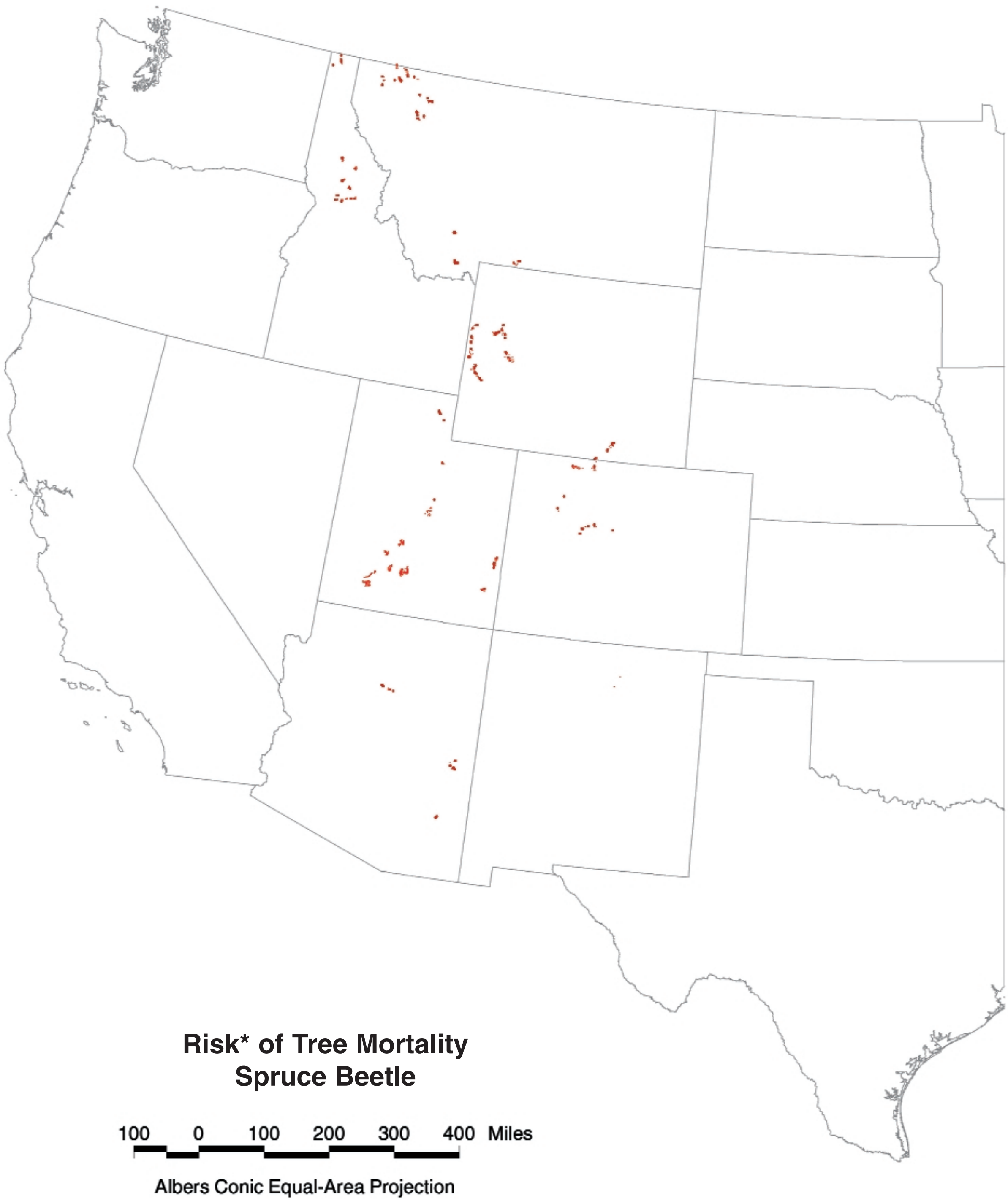


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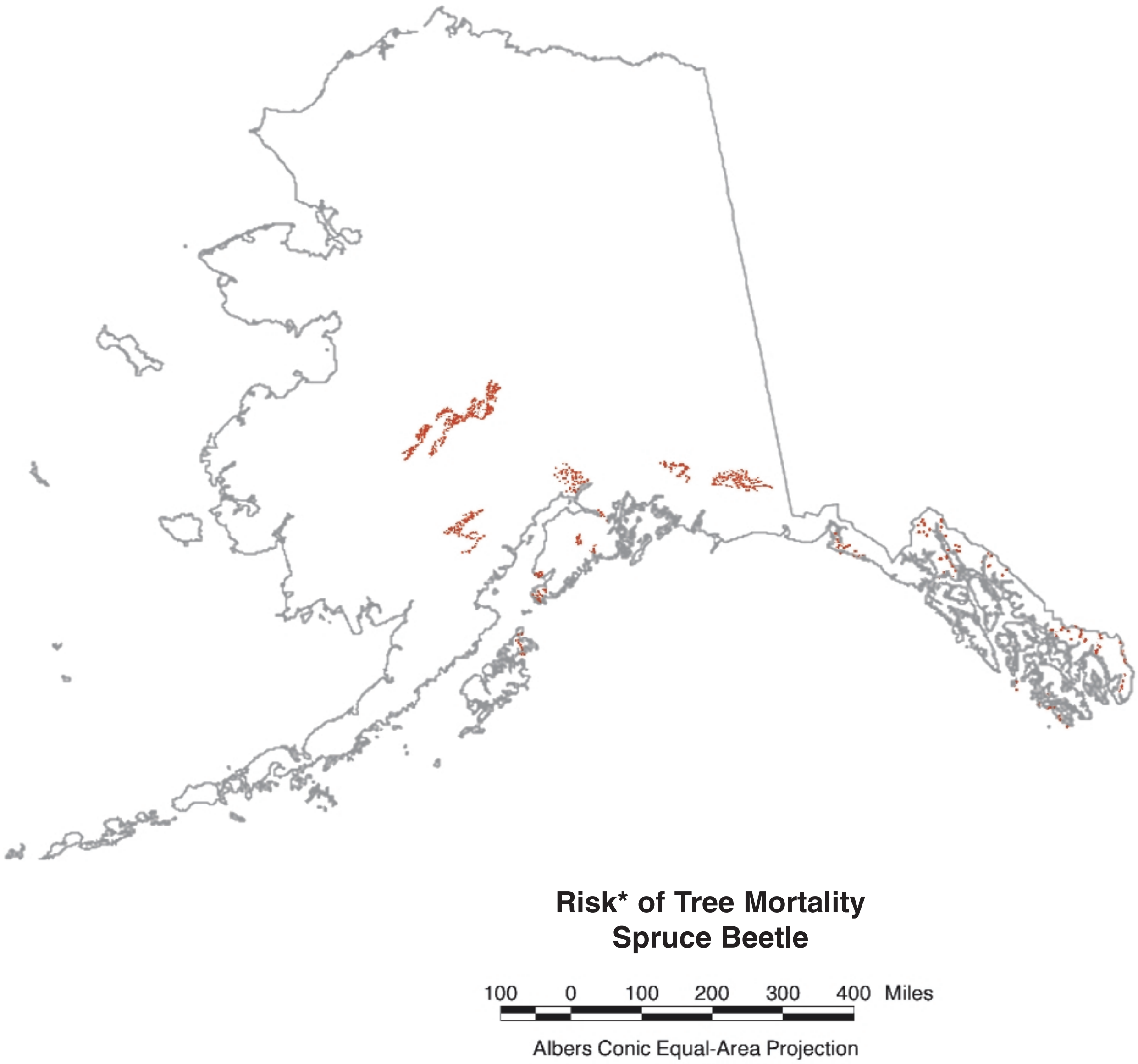
Figure 28



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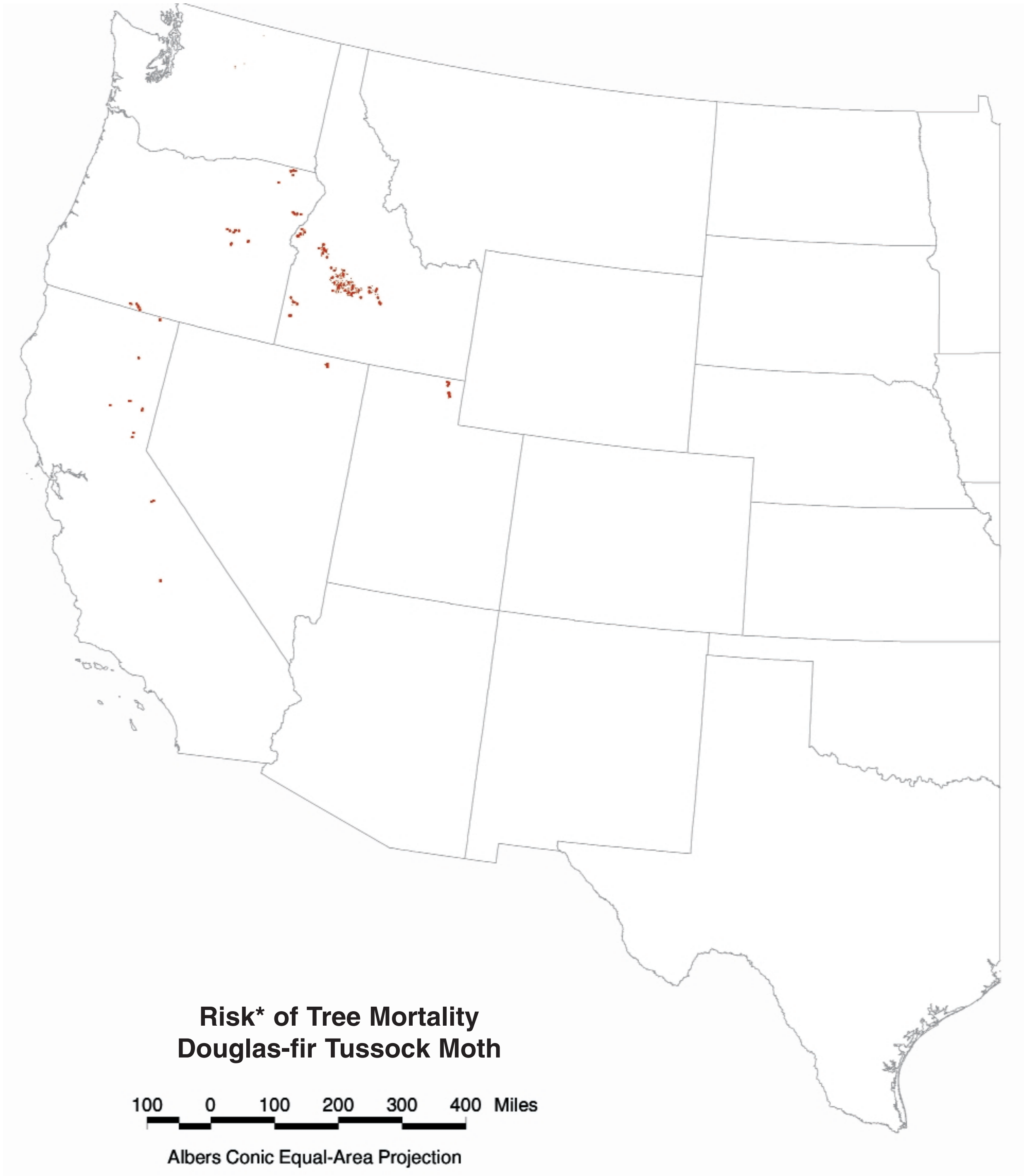
Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

Figure 29



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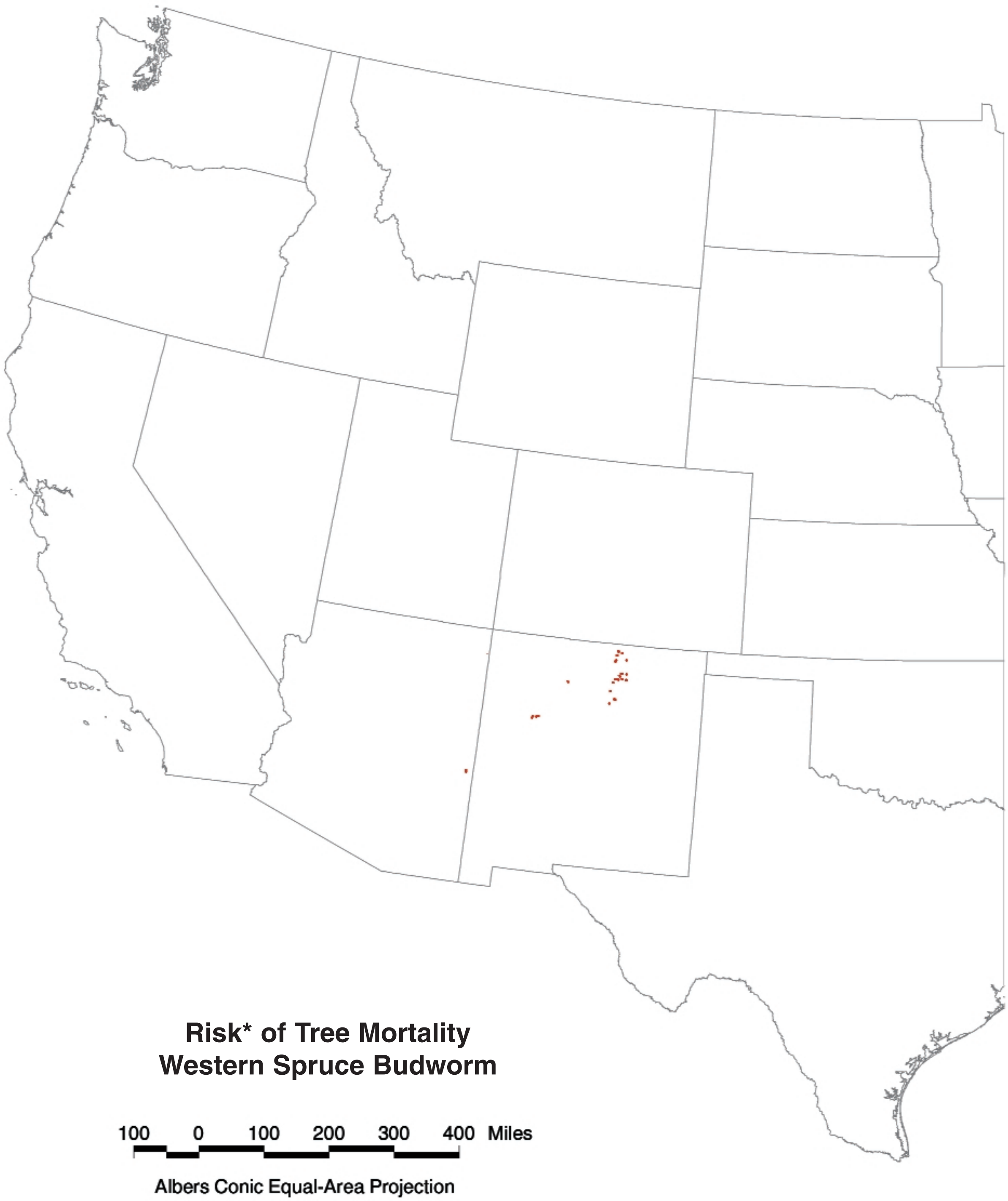
Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

Figure 30



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Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

03/15/00

Figure 31

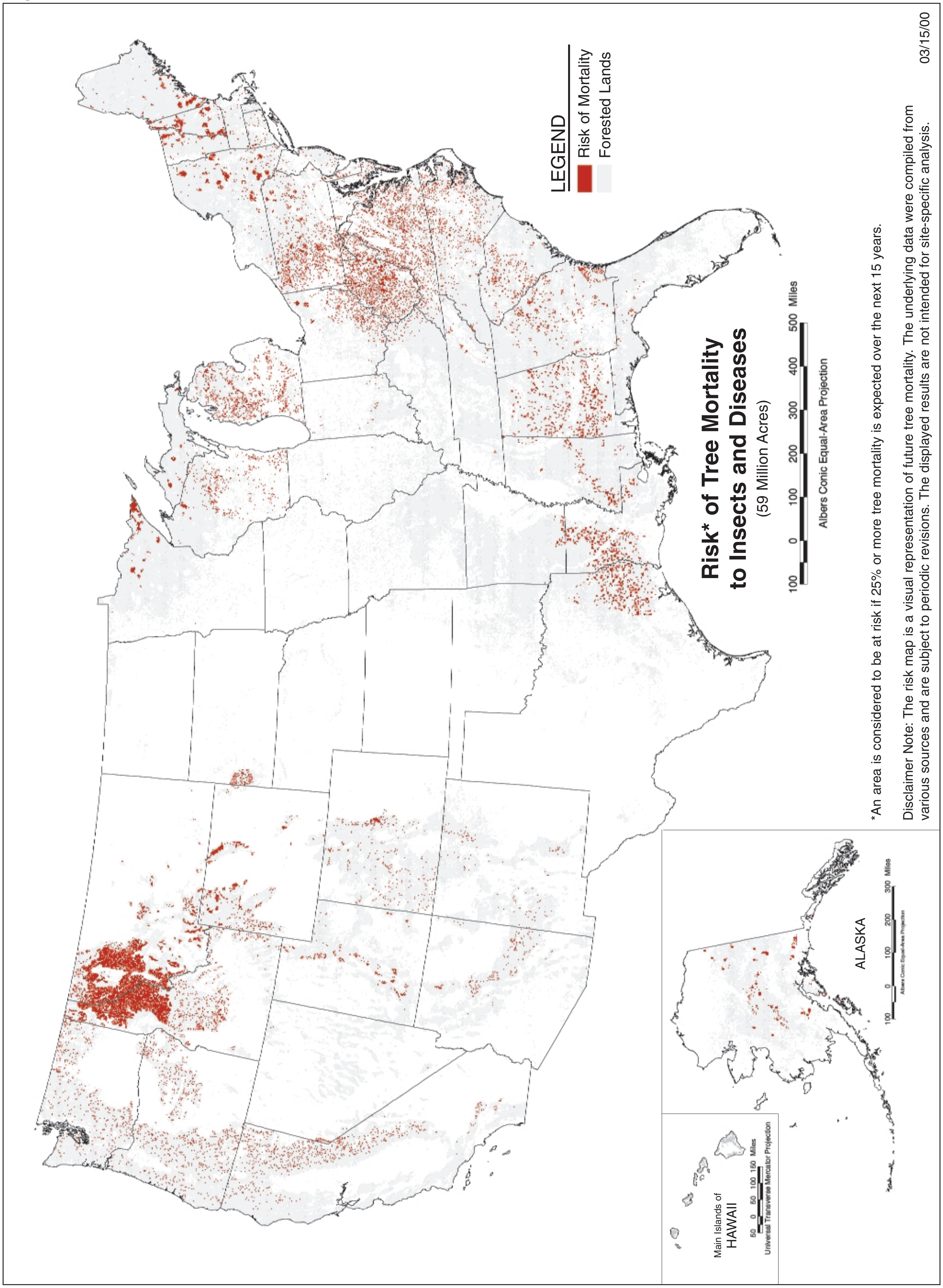
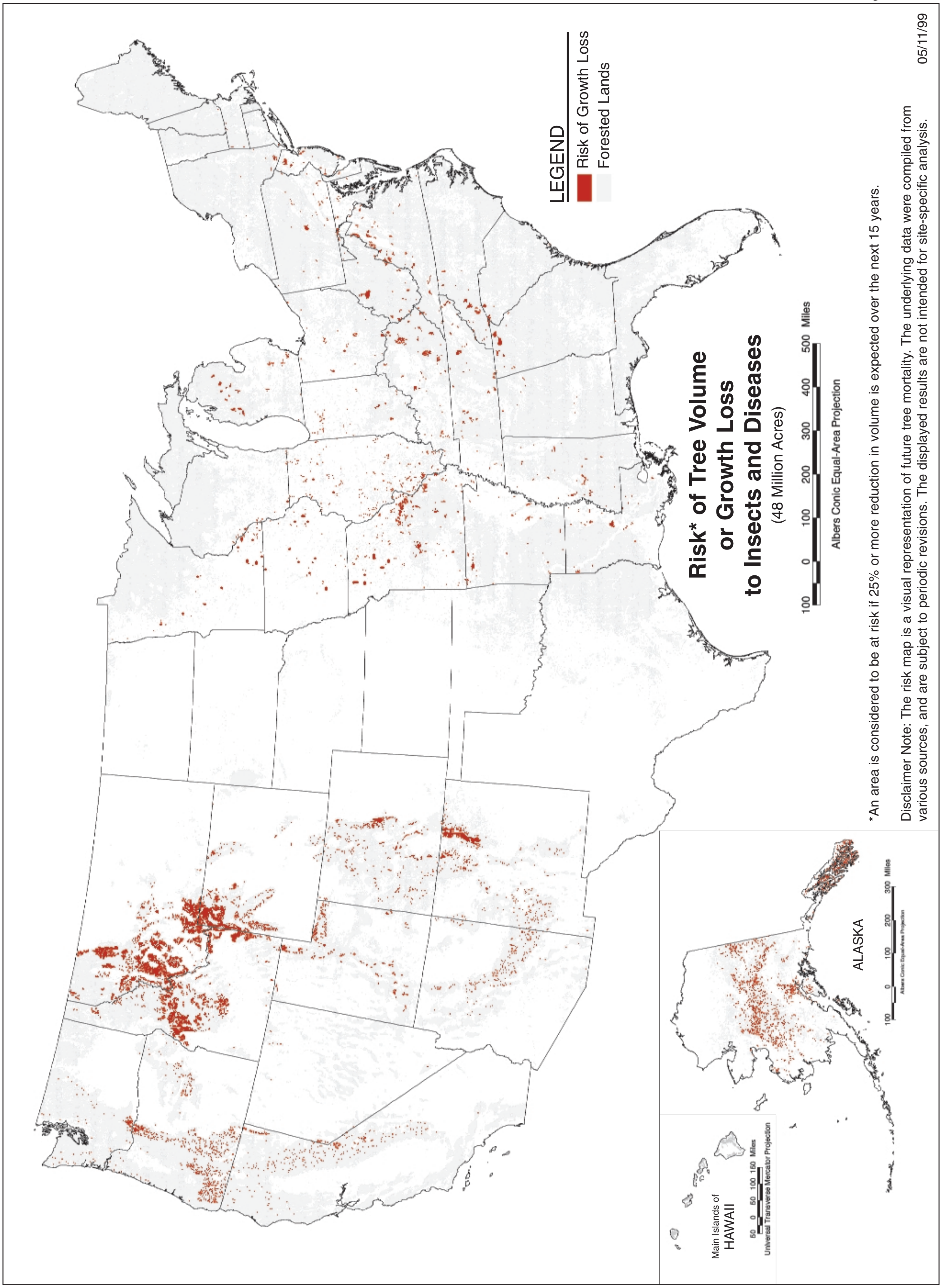

LEGEND
Risk of Mortality
Forested Lands
Risk* of Tree Mortality
to Insects and Diseases
(59 Million Acres)
100 0 100 200 300 400 500 Miles
Albers Conic Equal-Area Projection
ALASKA
100 0 100 200 300 Miles
Main Islands of
HAWAII
50 0 50 100 150 Miles
Universal Transverse Mercator Projection
*An area is considered to be at risk if 25% or more tree mortality is expected over the next 15 years.
Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.
03/15/00

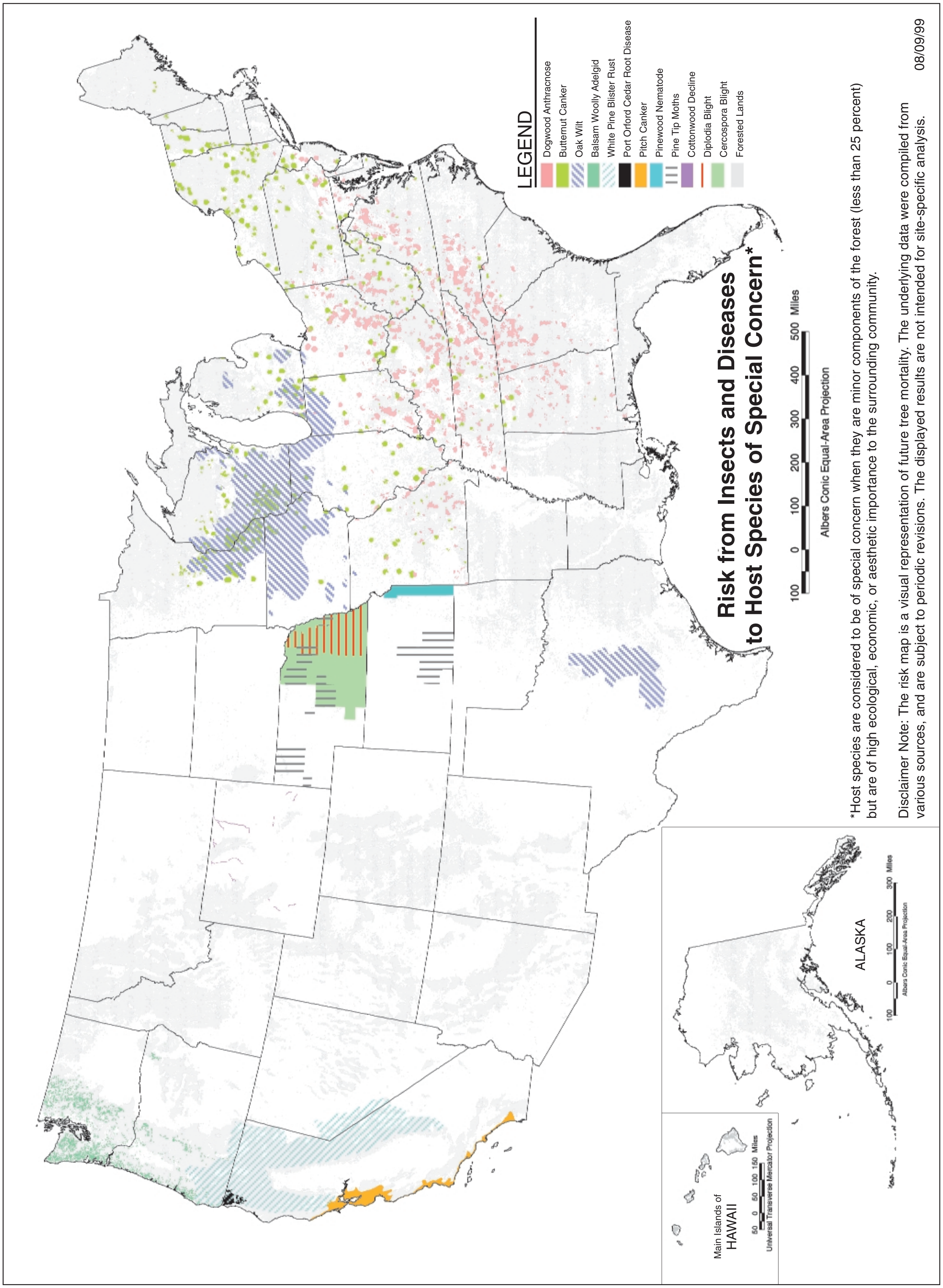
Figure 32



*An area is considered to be at risk if 25% or more reduction in volume is expected over the next 15 years.

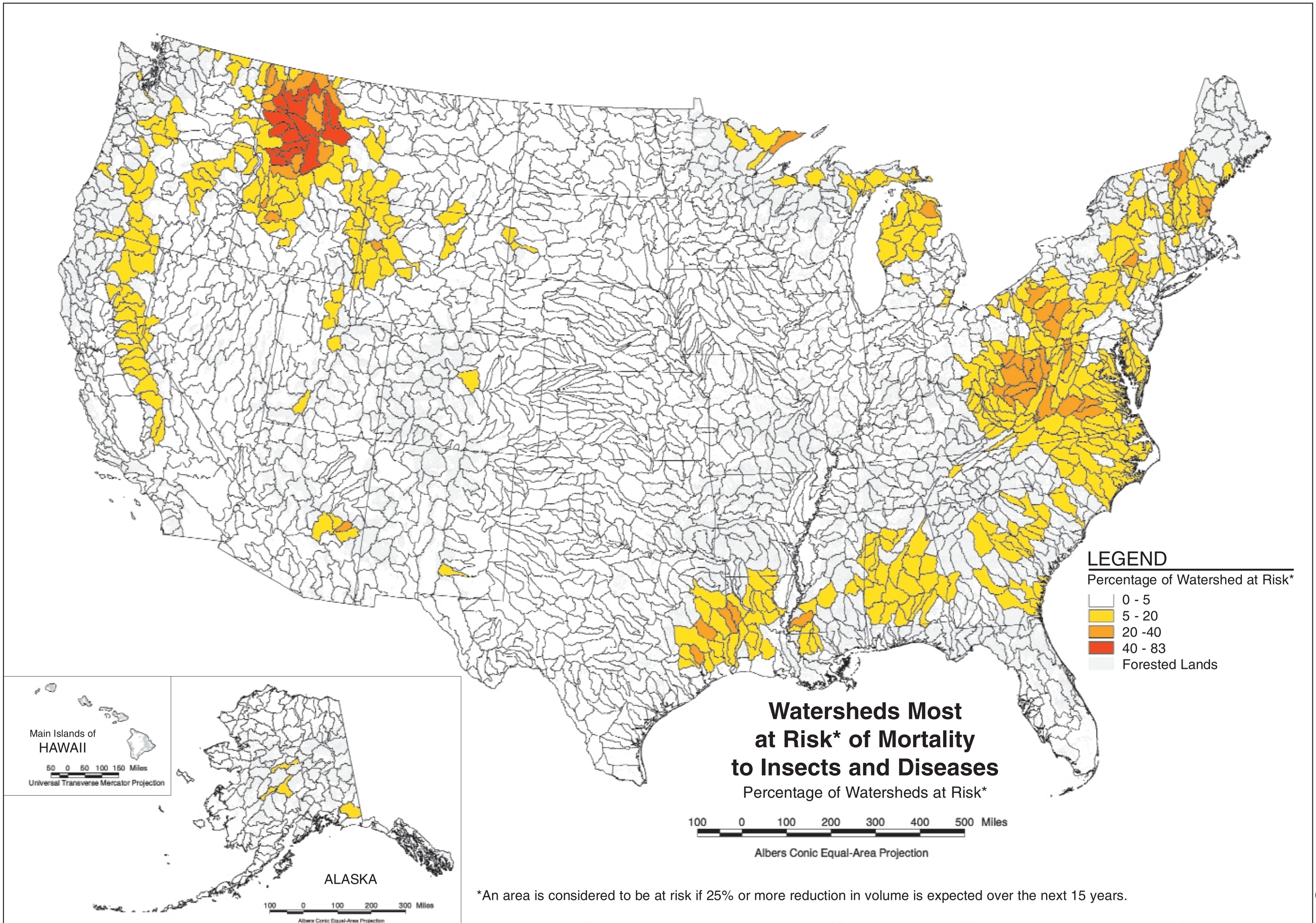
Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources, and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

Figure 33



Risk from Insects and Diseases
to Host Species of Special Concern*
LEGEND
Dogwood Anthracnose
Butternut Canker
Oak Wilt
Balsam Woolly Adelgid
White Pine Blister Rust
Port Orford Cedar Root Disease
Pitch Canker
Pinewood Nematode
Pine Tip Moths
Cottonwood Decline
Diplodia Blight
Cercospora Blight
Forested Lands
100 0 100 200 300 400 500 Miles
Albers Conic Equal-Area Projection
ALASKA
100 0 100 200 300 Miles
Albers Conic Equal-Area Projection
Main Islands of
HAWAII
50 0 50 100 150 Miles
Universal Transverse Mercator Projection
*Host species are considered to be of special concern when they are minor components of the forest (less than 25 percent) but are of high ecological, economic, or aesthetic importance to the surrounding community.
Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources, and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.
08/09/99

Figure 34



*An area is considered to be at risk if 25% or more reduction in volume is expected over the next 15 years.

Disclaimer Note: The risk map is a visual representation of future tree mortality. The underlying data were compiled from various sources, and are subject to periodic revisions. The displayed results are not intended for site-specific analysis.

02/24/99

Appendix D—Reviewers

The Insect & Disease Risk Mapping Team thanks the following colleagues for reviewing an earlier draft of this document. Their willingness to thoroughly review the draft and provide insightful comments and suggestions is greatly appreciated.

Dr. Ronald F. Billings
Texas Forest Service
P.O. Box 310
Lufkin, TX 75902

Dr. Mark Delfs
USDA, Forest Service
Strategic Planning and Resource Assessment
201 14th Street
Washington, D.C. 20250

Dr. Brian Giles
USDA, Forest Service
Rocky Mountain Research Station
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Flagstaff, AZ 86001

Dr. Ladd Livingston
Idaho Department of Lands
3780 Industrial Ave. So.
Coeur D'Alene, ID 83815

Dr. Ariel Lugo
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International Institute of Tropical Forestry
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Rio Piedras, PR 00928-5000

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USDA, Forest Service
Rocky Mountain Research Station
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Fort Collins, CO 80526

Dr. Evan Nebeker
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Mississippi State, MS 39762

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Vegetation Management and Protection Research
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Arlington, VA 22209

Dr. David Struble
Maine Forest Service
Statehouse Station 22
Augusta, ME 04333

Dr. Michael R. Wagner
School of Forestry
P.O. Box 15018
Northern Arizona University
Flagstaff, AZ 86011

Dr. William E. Wallner
USDA, Forest Service
Northeastern Center for Forest Health Research
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Hamden, CT 06514

Dr. John D. Walstad
Department of Forest Resources
280 Peavy Hall
Oregon State University
Corvalis, OR 97331-5703

Appendix E—Cover Letter to Reviewers

Dear

Thanks very much for agreeing to review the enclosed paper titled "Mapping Risk from Insects and Diseases." You are one of 13 reviewers that were selected because of their extensive background and knowledge of forest health issues. Some reviewers are experts on forest insects and diseases, and some have backgrounds in other areas.

Please keep the following questions in mind as you read through the document:

- Does the general approach to identifying risk seem reasonable? If not, how can it be improved?
- Are the risk functions for individual organisms appropriate? Did we overlook any factors (variables} that determine susceptibility?
- Do you know of any existing data that would improve the risk projections?

Keep in mind that the paper is not intended to be a research document, but rather a general paper that explains what the Forest Service is doing to identify forested areas that are at high risk to forest health concerns. Of course, any comments and suggestions you offer will be greatly appreciated.

I would like to receive your review before April 1 if possible, but since you're doing me a favor, I'll take it whenever I can get it.

Please reply to:

Joe Lewis
USDA Forest Service
201 14th St.
Washington, D.C. 20250

FS e-mail: jlewis/wo
Internet: jlewis/wo@fs.fed.us
Phone: 202-205-1597
FAX: 202-205-1139

Again, I appreciate your willingness to take the time to critique this paper.

Sincerely,

Joseph W. Lewis

Appendix F—General Comments and Issues Raised by Reviewers

All reviewers made very helpful suggestions for improving the document. Several reviewers complimented the team for producing a document that is easily understood and logically presented. Some reviewers identified similar issues and concerns. Following is a summary of general comments followed by issues raised by more than one reviewer:

General Comments

"The paper, as it stands, reads very well. It is easy to understand with logical flow of thoughts, ideas and concepts." (Livingston)

"It is a very well written document and I particularly like the clarity with which assumptions and decisions are presented—a transparent document, as it should be." (Lugo)

"Reading the document clears up a number of questions that I have and I now have a clearer picture of the intent." (Nebeker)

"Having the document helps greatly in understanding the data and how to use it." (Wagner)

"I believe that you and your team have done a fine job of approaching this important issue of forest risk to insect pests." (Wallner)

"As expected, the February 3 draft you sent me is very well prepared, and I had little difficulty following the logic and process used to develop the risk maps." (Walstad)

Issue—Elaborate on the concept of "normal level of mortality."

Four reviewers suggested that a more thorough explanation of what we meant by "beyond the normal level of mortality" and how we used the concept in our definition of risk.

"In the section, "Methodology," item #1, Define risk" the last sentence talks about mortality "(beyond the normal level)." My question is, how was the "normal" level established? There is no mention of what this is or how it was determined. This seems to need clarification to me." (Livingston)

"It was wise to select the definition of risk that you identify in this section. A key point in this definition is that the 25 percent mortality is above natural mortality. I am not sure how closely you adhere to this definition, i.e., how closely you assure that indeed your estimates are above natural rates. But, for the record, natural mortality is usually about 2 percent per year, resulting in 30 percent over a 15 year period. Therefore, your threshold is about 55 percent over a 15 year period, right? Also, abnormal mortality can be sudden and catastrophic or gradual and of low intensity. I don't know how you deal with this except that you probably rely on expert opinion. It seems to me that a field check is needed to validate assumptions and map results as part of developing a second generation set of maps. Later in the document you quote a 1.7 percent annual mortality as abnormal, yet that is within the range of normal tree mortality. Was that 1.7 percent above the normal rate? A forest can absorb 2 percent per year mortality and live happy." (Lugo)

"What is the normal level? This was not defined in the paper. Is normal 15 percent mortality and/or growth loss hence there needs to be 40 percent before it is classified as being at risk?" (Nebeker)

"The concept of risk used in this project is so seriously flawed that we judge it not only inadequate but incorrect. To begin with, the meaning of "25 percent or more tree mortality (beyond the normal level) or growth loss can be expected over the next 15 years" is not clear regardless of how precise it appears to be. Various, critical terms such as "normal level" and "growth loss" are not defined and may not have been consistently applied." (Shaw/Geils/Lundquist)

Response to comments

We concur that the issue needs clarification. The text has been revised to address this concern.

Issue—What type of publication is intended?

Three reviewers inquired about the intended type of publication for this document.

"I might have been able to give some more specific suggestions if the journal or publication outlet was known." (Nebeker)

"The cover letter (Lewis Feb. 7, 2000) notes the paper under review is "not intended to be a research document, but rather a general paper that explains what the Forest Service is doing to identify forested areas that are at high risk to forest health concerns." The implication is that because the effort is not research, a science-based approach is unnecessary. This contrasts with current Forest Service emphasis on the importance of science-based management (as exemplified in the draft forest planning regulations). Without detailed documentation, the project loses creditability because it cannot be verified and loses future value because it cannot be repeated. Neither the cover letter nor the paper identify the intended audience and outlet; therefore we do not know what specific publication criteria are appropriate. Nonetheless, the paper would be unsuitable either as a technical or management report published by Forest Health Protection or as a scientific article in a professional journal. Basing a "strategic evaluation of forest health risk on all forested lands in the United States" (stated objected of the paper, emphasis added) on anything less than a science-based process responsive to peer review would seem to jeopardize the entire effort." (Shaw/Geils/Lundquist)

"It would be helpful to know where this will be sent/published/used. As written it would not fly as a journal article because the literature is not adequately reviewed and some details of evaluation are not included. As an internal report it is probably OK with the points noted below." (Wagner)

Response to comments

As stated in the cover letter to reviewers (see appendix E), the intent of this paper is to explain how the risk maps were developed. Thus, it was deemed sufficient to produce this document as an informal publication. However, that does not mean it should not be held to high standards and scrutiny. The document has been expanded in several ways as a result of reviewers' comments.

Issue—Evaluation details should be included for all organisms evaluated.

Two reviewers suggested that more details should be provided on how risk was determined for all 26 insects and diseases, not just the 7 that accounted for the bulk of the acres at risk.

"There is some inconsistency that should be corrected. For Southern pine beetle, a basal area threshold of 90 sq. ft. is specified, but for Mountain pine beetle you say "certain thresholds of BA were exceeded." It is important to specify what those BA's were." (Wagner)

"Another place I had difficulty involves the calculation of risk associated with the insects and diseases that were not among the seven organisms that are featured in the paper. What were the principle variables used to determine their relative risk? Perhaps the equation functions could be summarized in tabular form in conjunction with the species list in Appendix B." (Walstad)

Response to comments

We concur and have now described the method for determining risk for all 27 organisms (pinyon decline was inadvertently omitted from the draft document, so there are now 27 organisms). We have also included a map for each organism.

Issue—Definition of Risk

Two reviewers questioned the definition of risk used in this paper.

"The concept of risk used in this project is so seriously flawed that we judge it not only inadequate but incorrect. To begin with, the meaning of "25 percent or more tree mortality (beyond the normal level) or growth loss can be expected over the next 15 years" is not clear regardless of how precise it appears to be. Various, critical terms such as "normal level" and "growth loss" are not defined and may not have been consistently applied. According to an individual who provided information used to map heart rot in Alaska, the qualifier "beyond the normal level" was not included in the given criteria. If it had been, no risk from decay in Alaska should have been reported. In these unmanaged, old-growth forests, the decay process is rapid; the volume turnover from sound to decayed wood is large; and the net result is little change in biomass. Although a high rate of decay may
be undesirable (or not), it is a totally natural process that is "normal" for these forests.

What is included as mortality or growth loss requires additional explanation. Does growth loss refer to 25 percent reduction in diameter increment (basal area, volume) on surviving trees? Or does it refer to 25 percent reduction in live, sound growing stock (includes increment loss and mortality)? How expectation, spatial distribution, size distribution, and ingrowth are considered is also not explained. Is a 50 percent likelihood of incurring 50 percent mortality the same as a 100 percent likelihood of 25 percent mortality? Is there a difference between the loss of one out of four trees spread over a 1 sq km area and loss of all trees on one-quarter of the area? If the age or size class distributions were altered, but the overall mortality remains less than 25 percent is there no effect?

No statistical qualifications are provided on the estimates of risk or of data used to derive it. How regional or site-specific information, collected by various procedures, at multiple scales, and differing resolutions was combined into an estimate is not adequately described in the text and risk functions presented. As discussed later, the extent and types of expert judgments used in the exercise cannot be determined from the information provided. Even if the 25 percent metric were well defined, consistently applied, and statistically quantified, the rationale for selecting this amount of mortality or growth loss is not presented. No literature is cited in support of the metric, which is not surprising as we know of no such literature. There is no justification that this or any other particular level of mortality (or growth loss) would be the single appropriate measure of forest health risk in any and all forest ecosystems, regardless of composition, age, or development. What rationale other than convenience exists for this "one size fits all" definition of risk escapes us." (Shaw/Geils/Lundquist)

"Probably the most important concern is that you haven't given adequate justification for picking the "25 percent or more tree mortality" threshold for "at risk." Risk ought to be a continuous function, or at least a series of categories. I would be much happier with three levels of risk, i.e., high, med, and low, with different percentages attached to each. For example: high = 25 percent or more; med = 10-24 percent; low = less than 10 percent. You are taking a continuous function variable and creating a threshold (either/or) from that. If you feel strongly that you want a high risk vs. no risk dichotomy, you definitely need to justify that better in the paper." (Wagner)

Response to comments

The section on defining risk has been expanded to elaborate on the options the team considered when attempting to arrive at a workable approach to identifying areas at risk.

Issue—Usefulness of coarse filter maps

Two reviewers expressed views about the usefulness of coarse filter maps.

"The general approach to identifying risk (hazard) on a regional scale appears reasonable for the southern pests I am most familiar with. The final risk maps, in most cases, provide a general overview, but are of little use to land managers. Admittedly, these maps have their greatest use on the national level to show regional problem areas and as a basis for prioritizing Federal forest health programs. Even here, however, caution should be used. For example, the oak wilt problem in live oak stands in central Texas is much more severe than that in mixed hardwood stands in the Lake States, due to the abundance of susceptible hosts (live oak) and other factors. Yet, the oak wilt risk map fails to distinguish these differences." (Billings)

"I realize the intent of this first iteration of risk rating is to develop a series of coarse filter maps as a starting point. However, as it currently stands, I don't see that this level of definition is very useful to the second issue of your priorities, i.e., fostering dialogue and soliciting feedback with potential users, since it is far too broad. I agree that it cannot be site specific, but it needs to be more focused. Perhaps an organism or organisms from the different U.S. regions could be selected and, using historical data to validate your risk functions of them, express them, for example, on a county-by-county basis. Ultimately, this would be a useful level for the dialogue to be germane to the problem." (Wallner)

Response to comments

The risk mapping effort described in this paper is meant to be a starting point for a strategic examination of the relative susceptibility of forests throughout the United States to insect-and disease-caused damage. It is an attempt to provide some spatial resolution, albeit large-scale, to identify the extent and general location of the most susceptible areas. The team spent most of its time refining the mortality risk projections, and has presented them in two formats—pixel map (figure 31) and watershed map (figure 34). There was disagreement among team members as to which format appropriately reflected the underlying data. Some felt the pixel map, because of the "dotted" effect, would easily be misinterpreted as being more site-specific than it actually is. Some felt the watershed map was misleading because the underlying stand characteristic data used in the risk functions was derived mostly from FIA databases that were not meant to be used on areas as small as 4th level HUCs (watersheds). Most agreed that we should not use any smaller land units for this strategic endeavor. However, we agree that more site-specific analyses would be helpful for making management decisions about individual organisms. The "growth loss" map is a first-cut that needs considerable refinement, and the "organisms of special concern" map is admittedly crude and intended only to indicate the general areas where those organisms are found.

Issue—Size of maps

Two reviewers pointed out the shortcomings of using small maps in the document.

"Hopefully the place where this is published will allow large figures. Trying to represent the U.S. on a half page or even a page with this detail becomes a challenge." (Nebeker)

"By-and-large the maps are quite graphic in the problem areas they delineate. However, I recommend that the final publication portray them on full 8.5x11-inch size paper, rather than half sheets. It's just too hard to see enough detail on the smaller format." (Walstad)

Response to comments

Larger maps are included in the final document.