Forest Health Monitoring 2004 National Technical Report

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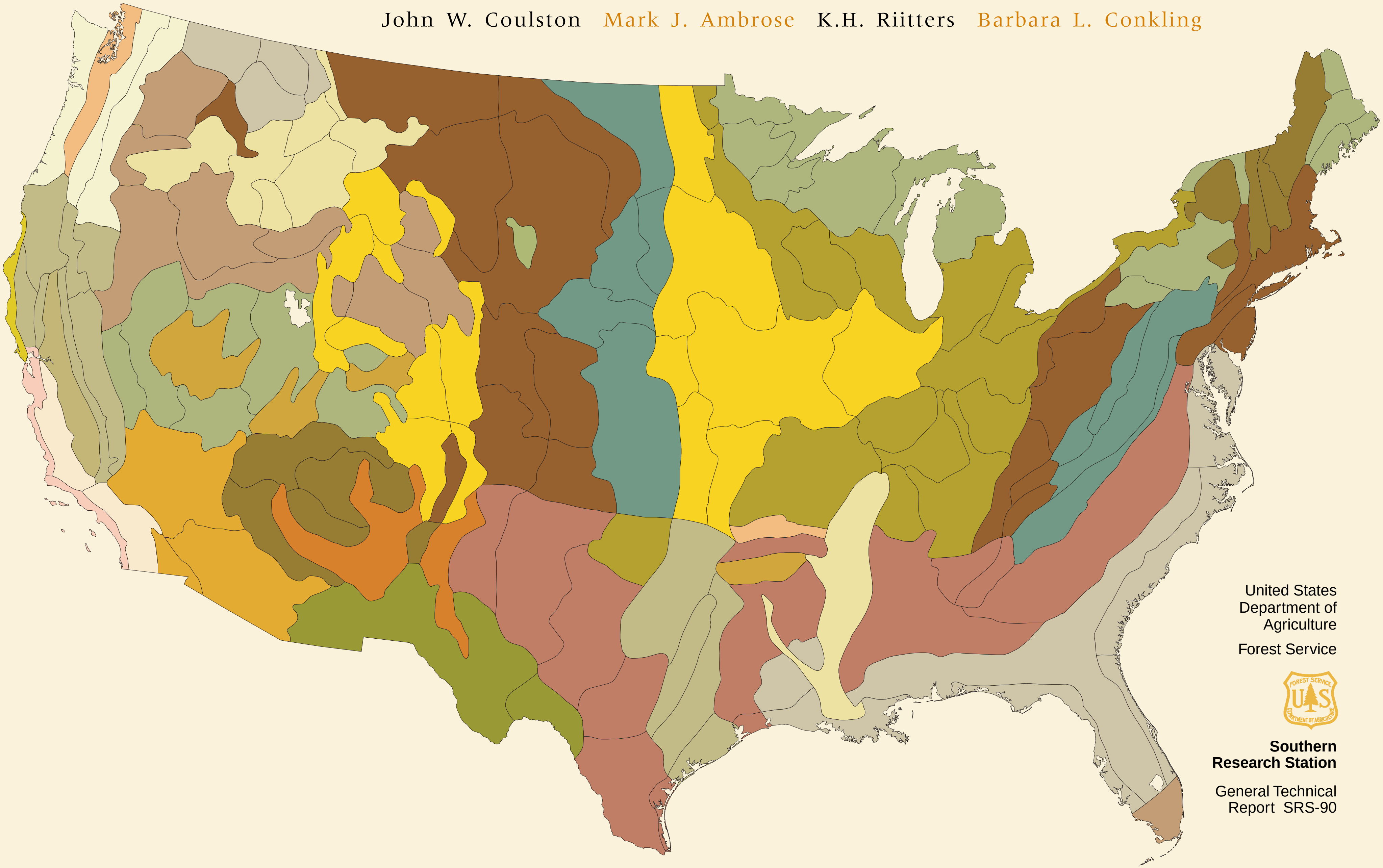

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Front cover map: Bailey's ecoregion provinces and ecoregion sections for the coterminous United States (Bailey 1995).

Back cover map: Forestland (green) backdrop derived from Advanced Very High Resolution Radiometer satellite imagery (Zhu and Evans 1994).

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Abstract

The Forest Health Monitoring (FHM) Program's annual national technical report presents results of forest health analyses from a national perspective using data from a variety of sources. Results presented in the report pertain to the Santiago Declaration's Criterion 1—Conservation of Biological Diversity and Criterion 3—Maintenance of Forest Ecosystem Health and Vitality. We include status and trend information where possible, consistent with previous FHM national technical reports. Additional analytical techniques and results, new to the national report, are presented as examples of ways forest health data can be used. This report has eight sections. The first contains introductory material. The next four contain results from analyses of status and change for selected forest health indicators, e.g., several measures of forest fragmentation, mortality- and defoliation-causing insects and diseases, crown condition, and tree mortality, similar to analyses in previous FHM national reports. The next two sections describe analytical techniques and provide information about assessments presented in the national report for the first time, and the final section is a summary.

Keywords: Assessment, criteria and indicators, crown, dieback, drought, fire, forest health, mortality.

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Executive Summary

Introduction

The annual technical report is designed to present forest health analysis results from a national perspective, and to present techniques useful for analyzing large forest health datasets. The indicators described in the Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Anon. 1995a) continue to be used by the Forest Health Monitoring (FHM) Program as a national reporting framework.

This report has eight sections. The first contains introductory material. The next four sections contain results from analyses of status and change for selected forest health indicators, e.g., several measures of forest fragmentation, mortality- and defoliation-causing insects and diseases, crown condition, and tree mortality, similar to analyses in previous FHM national reports. The next two sections include analytical techniques and information about assessments presented in the national report for the first time, and the final section is a summary.

USDA Forest Service (Forest Service) data sources are: FHM ground plot data (1990 through 1999), Forest Inventory and Analysis (FIA) phase 3 annual survey data (2000 through 2002), Forest Health Protection (FHP) data (1996 through 2002), and the Remote Sensing Applications Center (Remote Sensing Applications Center 2004). Other data sources are the National Oceanic and Atmospheric Administration (NOAA)—Palmer Drought Severity Index (1895 through 2003) (National Climate Data Center 1994), and additional drought data (Cook and others 1999).

Hotspots of Forest Fragmentation in Ecological Provinces of the United States

Previous FHM national reports have described various aspects of forest fragmentation in the coterminous United States. With a view towards setting regional priorities for conservation and restoration, we examined the geographic concentrations of different types of forest spatial patterns in 21 ecological provinces. We mapped unfragmented forest and three types of forest fragmentation (edge, perforation, and patch) and then used a statistical procedure to identify significant geographic clusters of each type of fragmentation. All types of fragmentation were widespread, and all ecological provinces contained significant clusters of each type. The most significant clusters, i.e., the hotspots, of a given type of fragmentation were usually concentrated in a few provinces, but those provinces depended on the type of fragmentation. In other words, any regional plan for managing forest fragmentation should depend on the type of forest fragmentation that dominates in the region.

Landscape-Level Assessment of Insects and Diseases and Ties to Results from Evaluation Monitoring

The nationally compiled FHP aerial survey data from 1996 through 2002 were used to assess mortality- and defoliation-causing insect and disease activity at the landscape level. Exposure was defined as the area in hectares with mortality- or defoliation-causing agents present. The spatio-temporal trend analysis was based on relative exposure (observed vs. expected) on a county basis and was used to identify hot spots of activity during the time period. Results from published evaluation monitoring projects are also discussed in the full report.

Several ecoregion sections in the Northeast FHM region contained areas with relative exposure scores of more than five times the expected exposure to mortality-causing insects and disease, defoliation-causing insects and diseases, or both: 212C—Fundy Coastal and Interior in eastern Maine; 221C—Upper Atlantic Coastal Plain in New Jersey; and much of the forested area in Section M221A—Northern Ridge and Valley in Pennsylvania and West Virginia.

In the South FHM region, most aerial surveys were conducted specifically to detect southern pine beetle. Areas with more than five times the expected exposure to mortality-causing insects and diseases were found in Sections 231A—Southern Appalachian Piedmont, M221D—Blue Ridge Mountains, 221H—Northern Cumberland Plateau, 221I—Southern

Cumberland Mountains, and 221J—Central Ridge and Valley. Some defoliation activity was also recorded, and the forest tent caterpillar was active in Sections 232C—Atlantic Coastal Flatlands and 232B—Coastal Plains and Flatwoods, Lower.

Forests in the Northcentral FHM region had a few hotspots of mortality-causing insect and disease activity. Emerald ash borer caused mortality in part of Sections 222I—Erie and Ontario Lake Plain and 222J—South Central Great Lakes in Michigan. Also, Section M334A—Black Hills in South Dakota continued to have above expected rates of mortality-causing insect and disease activity. There were several areas in the Laurentian Mixed Forest Province (212) in northern Michigan that had between two and three times the expected relative exposure to defoliation-causing insects and diseases.

The Interior West FHM region had large areas of higher than expected exposure to mortality-causing insects and pathogens, with most of the activity of defoliation-causing agents in the southern part of that region. Sections 331J—Northern Rio Grande Basin in northern New Mexico; M313A—White Mountain—San Francisco Peaks—Mogollon Rim in Arizona and New Mexico; and M331G—South-Central Highlands in southern Colorado and northern New Mexico all had relative exposure scores to defoliation-causing insects and diseases greater than five times that expected. Sections with high relative exposure to mortality-causing insects and diseases included M333D—Bitterroot Mountains, and several forested areas in M331H—North-Central Highlands and Rocky Mountain, and M331I—Northern Parks and Ranges in Colorado.

In the West Coast FHM region most of the mortality- and defoliation-causing insect and disease activity occurred east of the Cascade Mountains and in the Sierra Nevada Mountains. There were areas in Section M333A—Okanogan Highlands in northern Washington with more than five times the expected exposure. The northern part of Section M261E—Sierra Nevada in California also had more than five times the expected exposure to mortality-causing insects and diseases. Exposure to defoliation-causing insects and diseases was highest in Sections

M242C—Eastern Cascades and M332G—Blue Mountains in Oregon and the southeast tip of Washington.

Crown Condition

Crown dieback and foliar transparency were used to calculate a crown index, using a variation of the method proposed by Zarnoch and others (see footnote 6). This index in theory represents the amount by which the foliage of the tree is reduced relative to an ideal, fully foliated tree having the same crown diameter. In the full report, data are presented using an index threshold for unhealthy crowns.

In all ecoregions of the United States, < 15 percent of the basal area was associated with unhealthy crowns, and in most ecoregions 10 percent or less of the basal area was associated with unhealthy crowns. Ecoregion sections having > 10 percent average basal area associated with unhealthy crowns were mostly located in the Interior West; in the Eastern United States, there was only one such ecoregion section.

A plot-level analysis of crown condition was also performed. The percentage of basal area associated with trees with unhealthy crowns was very low for most plots. However, individual plots and clusters of plots in the Northeast and elsewhere had a high percentage of basal area associated with trees with unhealthy crowns.

Tree Mortality

To compare mortality rates across forest types and climate zones, the ratio of annual mortality volume to gross volume growth (MRATIO) is used as a national mortality indicator together with an additional mortality value, the ratio of the average dead tree diameter to the average live tree diameter (DDLD ratio). A DDLD ratio was calculated for each plot where mortality occurred. The MRATIO values presented represent the annual mortality over the time periods from the earliest plot establishment in each ecoregion section through the most recent year of available data (2000 to 2002). The highest MRATIO value in the country (3.689) occurred in Section 331A—Palouse Prairie in Idaho and western Washington. MRATIO values were also very high (0.901 to 2.00) in ecoregion Section 313A—Grand Canyon in southern Utah and Colorado, and in Section M331E—Uinta Mountains in northeast Utah and northwest Colorado. In the Eastern United States, the highest MRATIO value (2.582) occurred in Minnesota's ecoregion Sections 251A—Red River Valley and 251B—North-Central Glaciated Plains. When an ecoregion section has a high MRATIO, it is useful to also look at the DDLD ratio for information about the size of the trees that died. These data are presented in the full report.

Temporal Perspectives on Drought Occurrence

Because drought data are available representing hundreds of years, it is possible to examine long time series, i.e., hundreds of years, as well as assess current status. A long time series analysis can be important because it contributes information to assessments that attempt to identify whether or not disturbances are "out of the range of historic variation." An example of this kind of analysis and the application are presented in this report. Two other drought analyses presented are (1) deviation from historic drought occurrence (drought deviation), representing the difference between drought occurrence in the current decade (1994 through 2003) and historic averages (1895 through 2003); and (2) drought occurrence in 2003. These analyses used Palmer Drought Severity Index data.

Only a few ecoregion sections in the Eastern United States had a drought deviation of > 12 months (12 months of drought over a 10-year period in addition to that expected based on the historical average): M221D—Blue Ridge Mountains, and 232G—Florida Coastal Lowlands (Eastern), primarily along the eastern coast of Florida. Many areas in the Northeast, Southeast, and Northcentral United States experienced either close to or less than the expected amount of drought. The past decade has been drier than expected for much of the Western United States and several ecoregion sections had a drought deviation of 12 months or more. Section 322B—Sonoran Desert in southern Arizona experienced an additional 42 months of drought and Section 313C—Tonto Transition in Arizona experienced an additional 37 months of drought over what was expected.

The year 2003 was an especially dry year in the Western United States, where 18 ecoregion sections experienced 12 months of drought. These sections included 313C—Tonto Transition in Arizona; M331H—North-Central Highlands and Rocky Mountain in Colorado and extending a small amount into southern Wyoming; and M332G—Blue Mountains in Oregon and the tip of southeast Washington. A majority of the forested ecoregion sections in the West experienced more than 6 months of drought in 2003. This was in sharp contrast to the Eastern United States where 54 ecoregion sections did not experience any drought.

Nationally Consistent Spatial Data on Daily Fire Occurrence

We describe and suggest analytical methods to summarize fire occurrence information based on data from the MODIS Active Fire Detections for the United States database (Remote Sensing Applications Center 2004). The Forest Service, NASA Goddard Space Flight Center, and the University of Maryland collaborate to produce daily active fire maps using moderate resolution imaging spectroradiometer (MODIS) imagery. The resolution of the fire maps is 1 km where the center of each pixel identified as having an active fire is recorded as a point. These data only represent whether a fire was active, not the areal extent of the fire. The MODIS sensor can actually detect fires as small as 1 ha or 10,000 m^2 if the fires are burning at high temperatures. For these reasons, the MODIS fire data should only be used for large-scale, e.g., national or regional, assessments. We have included examples of methods to use the data in assessing status (describing a fire season) and trends (in fire occurrence).

There are many ways to describe a fire season using these data and two methods are described in the report. The first entails summarizing the data for each ecoregion section and spatially displaying the proportion of forested pixels that had an active fire. Several ecoregion sections had a relatively high percentage of forest pixels showing active fires in 2003. Section M262B—Southern California Mountains and Valleys had approximately 15 percent, and Section M333C—Northern Rockies in Montana had 11.7 percent. The scattered forest in Section 251F—Flint Hills in eastern Kansas and northern Oklahoma had active fires identified on 9.8 percent of its forest pixels by the MODIS imagery.

The second method of assessing status entails counting the number of forested pixels that had an active fire for each day and examining the time series. The peak of the 2003 fire season, as identified by maximum number of forested map pixels labeled with active fires, occurred in late October on Julian date 300. There also was a relatively large number of forested pixels with active fires in late August (Julian date 233).

The fire information derived from the MODIS sensor can also be used to assess trends in fire occurrence. Although several other techniques are available, this report examines three approaches to describe trends: (1) examine the cumulative fire occurrence over multiple years, (2) examine the difference between the percent of forest pixels with fire occurrence for each ecoregion section for two different years, and (3) compare the cumulative distribution functions (CDF) of fire occurrence for multiple years. The first approach is discussed in this summary as an example.

Examining the cumulative occurrence of fire over multiple years can be used to identify particular ecoregion sections that continuously experience relatively high rates of fire occurrence. For 2002 and 2003 most of the Northeastern United States and the Great Lakes States had less than expected fire occurrence. There were several ecoregion sections in the South with more than expected fire occurrence; e.g., Section 232F—Coastal Plains and Flatwoods, Western Gulf in Louisiana and extending into eastern Texas had a relative fire occurrence of approximately 3.5 (3.5 times the expected amount of fire occurrence), and Section 251F—Flint Hills in northern Oklahoma extending into Kansas had six times the expected amount of fire occurrence. There were more ecoregion sections in the Western

United States than the Eastern United States with higher than expected rates of fire occurrence. In particular, Sections M262B—Southern California Mountains and Valleys in California and M333C—Northern Rockies in Montana had a relative fire occurrence of approximately 11 and 7, respectively. Other forested areas had relative fire occurrence values approximately three times the expected value.

The following should be noted: the fire occurrence data derived from the MODIS sensor can be used for large-scale assessments; however, the information may not be directly comparable to official wildland fire statistics compiled by the National Interagency Fire Center. The MODIS data identify whether a pixel had an active fire for every day. The areal extent of the active fire is not known; therefore, acreages cannot be reported. Detected fires occur on all land use/landcover types. Here we used forest cover data to identify which pixels with active fire occurred in forested areas. The fire occurrence data can be used to estimate proportions. In these analyses, we estimate the percentage for forested pixels with active fire. This percentage should not be used as a surrogate for percent forest.

Introduction

The Forest Service FHM Program produces an annual technical report as one of its products. The indicators described in the Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Anon. 1995a) continue to be used by FHM as a national reporting framework. This report has eight sections. The first contains introductory material. The next four sections contain results from analyses of status and change for selected forest health indicators, e.g., several measures of forest fragmentation, mortality- and defoliation-causing insects and diseases, crown condition, and tree mortality, similar to analyses in previous FHM national reports. The next two sections include analysis techniques and information about assessments presented in the national report for the first time, and the final section is a summary.

A main objective of FHM is to determine on an annual basis the status of and changes in forest health indicators. The annual technical report is designed to present forest health data analysis results from a national perspective. In-depth interpretation and analysis of specific geographic or ecological regions are beyond the scope of the annual national report. However, we recognize there are issues and indicators that are of interest nationally, even though interpretation may vary among geographic and ecological regions. Therefore, data results are presented in this report such that items of interest can be identified for further investigation at a regional level. Examples in this report are the analysis results for fragmentation, mortality- and defoliation-causing insects and diseases, crown condition, tree mortality, relative exposure to drought, and drought occurrence.

A second main objective of the national report is to present analytical techniques useful for analyzing large forest health datasets. Examples from this report include analysis of drought data and newly available fire data. The presentation of these analyses focuses on the techniques as well as the data results.

The Forest Health Monitoring Program

To conduct FHM activities, the Forest Service cooperates with State forestry and agricultural agencies, as well as other Federal Agencies and universities. The FHM Program has five major activities (Tkacz 2003):

- Detection monitoring—nationally standardized aerial and ground surveys to evaluate status and change in condition of forest ecosystems
- Evaluation monitoring—projects to determine extent, severity, and causes of undesirable changes in forest health identified through detection monitoring
- Intensive site monitoring—to enhance understanding of cause and effect relationships by linking detection monitoring to ecosystem process studies and assess specific issues, such as calcium depletion and carbon sequestration, at multiple spatial scales
- Research on monitoring techniques—projects to develop or improve indicators, monitoring systems, and analytical techniques, such as urban and riparian forest health monitoring, early detection of invasive species, multivariate analyses of forest health indicators, and spatial scan statistics
- Analysis and reporting—synthesis of information from various data sources within and external to the Forest Service to produce issue-driven reports on status and change in forest health at national, regional, and State levels

The FHM regions cooperate with their respective States in producing "State Highlights" factsheets (available on the FHM Web site www.fhm.fs.fed.us) and other State reports such as Keyes and others (2003), Laustsen and others (2003), and Neitlich and others (2003).

About the Report

The assessment framework for this report is the Santiago Declaration and accompanying criteria and indicators (Anon. 1995a, 1995b). This is consistent with the use of the criteria and indicators as a forest sustainability framework in other Forest Service reports (Smith and others

2001, U.S. Department of Agriculture Forest Service 2001, U.S. Department of Agriculture Forest Service 2004). The seven criteria are:

Criterion 1—conservation of biological diversity

Criterion 2—maintenance of productive capacity of forest ecosystems

Criterion 3—maintenance of forest ecosystem health and vitality

Criterion 4—conservation and maintenance of soil and water resources

Criterion 5—maintenance of forest contribution to global carbon cycles

Criterion 6—maintenance and enhancement of long-term multiple socioeconomic benefits to meet the needs of societies

Criterion 7—legal, institutional, and economic framework for forest conservation and sustainable management

Results presented in this report pertain to Criterion 1—Conservation of Biological Diversity and Criterion 3—Maintenance of Forest Ecosystem Health and Vitality. We include status and trend information where possible, consistent with previous FHM national technical reports. Additional analytical techniques and results, new to the national report, are presented as examples of ways forest health data can be used. Appendix A, Supplemental Methods, provides details about the analyses that are useful to have readily available. Appendix B provides a supplemental data table, and appendix C provides brief quality assurance information.

In approaching the analysis of monitoring data, we considered the appropriateness of the data to make cause and effect inferences. A discussion about this issue is provided in the sidebar. Cause and effect inferences generally are not made in the FHM annual national technical reports, which are based on monitoring data.

Monitoring Data and Making Cause and Effect Inferences (Conkling and others 2005)

The question of whether or not large-scale monitoring data are suitable for identifying cause and effect relationships has been asked by researchers many times. In a discussion paper, Schreuder and Thomas (1991) addressed this question using Forest Service FIA data as an example. They stated that although establishing correlation is easy, establishing cause and effect is difficult. To highlight this, Schreuder and Thomas (1991) presented three criteria from Mosteller and Tukey (1977) with the note that two of the three criteria need to be met to infer cause and effect relationships:

1. Consistency—implies the presence and magnitude of the effect (y) are always associated with a minimal level of the suspected causal agent (x)

2. Responsiveness—established by experimentally exposing the population under study to the suspected causal agent and by reproducing the symptoms

3. Mechanism—established by demonstrating a cause and effect linkage in a step-by-step approach

Monitoring data or observational data such as FIA phase 2 (FIA annual inventory plots) and phase 3 (or FHM detection monitoring data) most clearly address the consistency criterion (Olsen and Schreuder 1997). Feinstein (1988) used examples from epidemiology in his discussion of a scientific approach to use observation data; e.g., monitoring data, to help determine cause and effect relationships. Olsen and Schreuder (1997) said that two kinds of field plots, in addition to monitoring plots, are important when testing and establishing cause and effect relationships. The number of one kind of plot should be fewer than the number of monitoring plots and be measured more frequently, with the option of destructive sampling. The other kind of supplemental plots should be at long-term ecological research sites from which data will be used to study responsiveness and mechanisms. These kinds of additional plots correspond well to FHM evaluation monitoring studies, FHM intensive site monitoring sites, and Long-Term Ecological Research sites. Using data from all these various sources presents a more complete approach to identifying cause and effect relationships than using monitoring or observational data alone; however, such an approach is best suited to an in-depth, interpretive report rather than an annual report such as this.

We also considered the appropriate spatial scale for our analyses. The spatial scale used for analysis should be appropriate for both the scale of the data and the ecological component of interest. We use Bailey's ecoregion sections (Bailey 1995), which are based on climate, vegetation, and soil factors, as the primary assessment unit whenever possible, although we recognize that one spatial scale may not be the best for all indicators. Bailey's system is a national hierarchical system of ecological units that classifies the United States into ecoregion domains, divisions, provinces, sections, subsections, land-type associations, and land types (McNab and Avers 1994). Ecoregion sections typically contain thousands of square miles and usually have similar geologic regions and lithology, regional climate, soils, potential natural vegetation, and/or potential natural communities (Cleland and others 1997) (fig. 1). Bailey's ecoregion sections provide a common framework for an ecologically based assessment and are a good starting point for analyzing the monitoring data.

Forest Service data sources are: FHM ground plot data (1990 through 1999), FIA phase 3 annual survey data (2000 through 2002), FHP data (1996 through 2002), and the Remote Sensing Applications Center (Remote Sensing Applications Center 2004). Other data sources are the NOAA— Palmer Drought Severity Index (1895 through 2003) (National Climate Data Center 1994), and additional drought data (Cook and others 1999).

Specific field data collection methods for FHM ground plots are described in the 1999 FHM field methods guide.[1] Data collection methods for FIA field plots are presented in volumes 1 and 2 of the FIA national core field guide.[2] [3] The most current field guides are available on the national FIA Web site, http://fia.fs.fed.us/library.htm#Manuals.

In FHM national reports, we use maps to illustrate discussions in the text and spatially display the relative rankings of indicator values

[1] U.S. Department of Agriculture Forest Service. 1999. Forest health monitoring 1999 field methods guide. 480 p. On file with: The Forest Health Monitoring Program National Office, 3041 Cornwallis Road, Research Triangle Park, NC 27709.

[2] U.S. Department of Agriculture Forest Service. 2002. Forest inventory and analysis national core field guide: field data collection procedures for phase 2 plots. Version 1.7. Vol. 1. Internal report. On file with: USDA Forest Service, Forest Inventory and Analysis, Rosslyn Plaza, 1620 North Kent Street, Arlington, VA 22209.

[3] U.S. Department of Agriculture Forest Service. 2002. Forest inventory and analysis national core field guide: field data collection procedures for phase 3 plots. Version 1.7. Vol. 2. Internal report. On file with: USDA Forest Service, Forest Inventory and Analysis, Rosslyn Plaza, 1620 North Kent Street, Arlington, VA 22209.

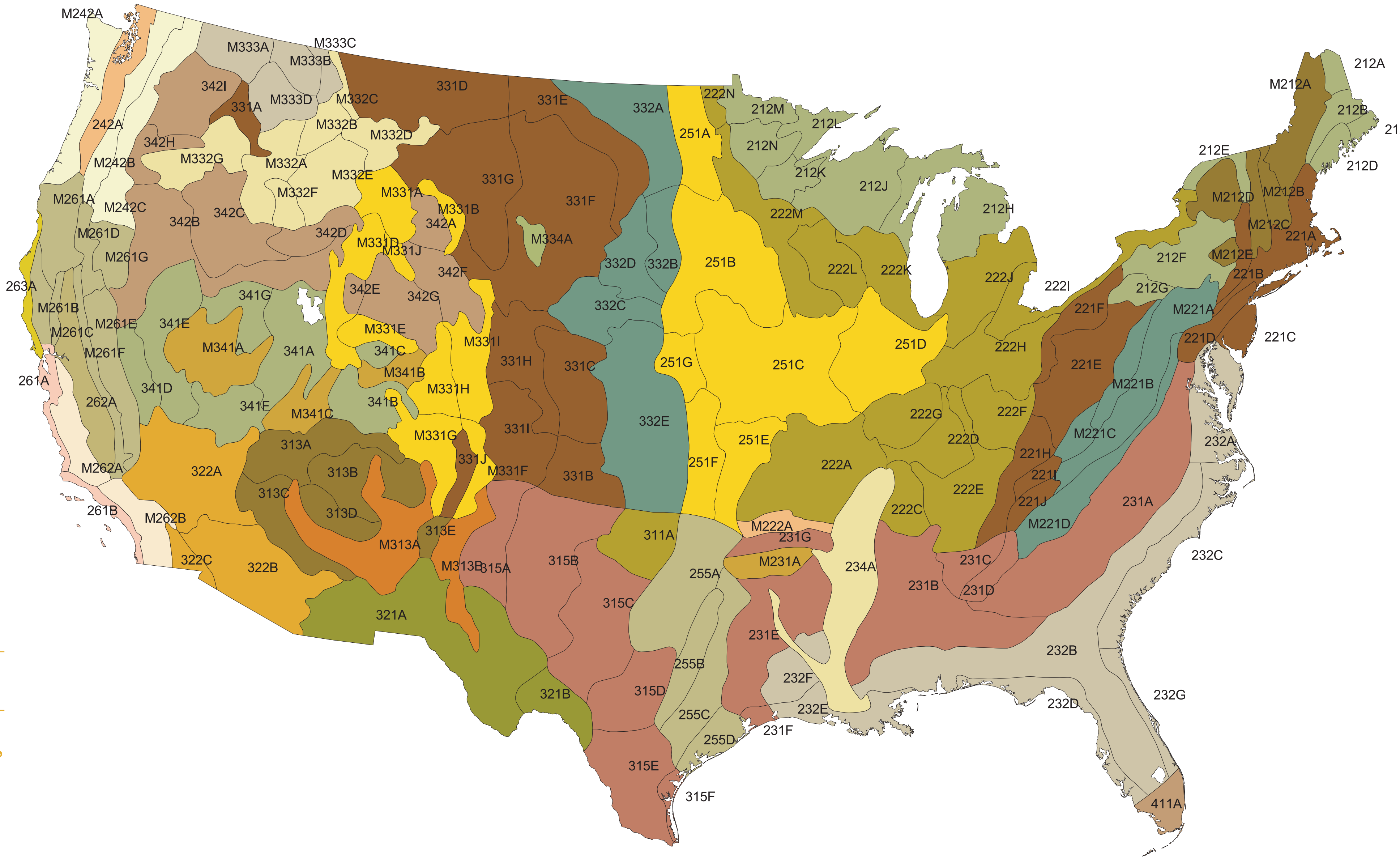


Figure 1—Bailey's ecoregion provinces and ecoregion sections for the coterminous United States. Similar colors in groups are the ecoregion sections within the ecoregion provinces.

Eastern ecoregion provinces

- Adirondack—New England Mixed Forest—Coniferous Forest—Alpine Meadow (M212)
- Central Appalachian Broadleaf Forest—Coniferous Forest—Meadow (M221)
- Eastern Broadleaf Forest (Continental) (222)
- Eastern Broadleaf Forest (Oceanic) (221)
- Everglades (411)
- Laurentian Mixed Forest (212)
- Lower Mississippi Riverine Forest (234)
- Ouachita Mixed Forest—Meadow (M231)
- Outer Coastal Plain Mixed Forest (232)
- Ozark Broadleaf Forest—Meadow (M222)
- Prairie Parkland (Subtropical) (255)
- Prairie Parkland (Temperate) (251)
- Southeastern Mixed Forest (231)

Western ecoregion provinces

- American Semi-Desert and Desert (322)
- Arizona—New Mexico Mountains Semi-Desert—Open Woodland—Coniferous Forest—Alpine Meadow (M313)
- Black Hills Coniferous Forest (M334)
- California Coastal Chaparral Forest and Shrub (261)
- California Coastal Range Open Woodland—Shrub—Coniferous Forest—Meadow (M262)
- California Coastal Steppe, Mixed Forest, and Redwood Forest (263)
- California Dry Steppe (262)
- Cascade Mixed Forest—Coniferous Forest—Alpine Meadow (M242)
- Chihuahuan Semi-Desert (321)
- Colorado Plateau Semi-Desert (313)
- Great Plains Steppe (332)
- Great Plains Steppe and Shrub (311)
- Great Plains—Palouse Dry Steppe (331)
- Intermountain Semi-Desert (342)
- Intermountain Semi-Desert and Desert (341)
- Middle Rocky Mountain Steppe—Coniferous Forest—Alpine Meadow (M332)
- Nevada—Utah Mountains—Semi-Desert—Coniferous Forest—Alpine Meadow (M341)
- Northern Rocky Mountain Forest—Steppe—Open Woodland—Coniferous Forest—Alpine Meadow (M333)
- Pacific Lowland Mixed Forest (242)
- Sierran Steppe—Mixed Forest—Coniferous Forest—Alpine Meadow (M261)
- Southern Rocky Mountains Steppe—Open Woodland—Coniferous Forest—Alpine Meadow (M331)
- Southwest Plateau and Plains Dry Steppe and Shrub (315)

(Conkling and others 2005). The spatial displays provide the opportunity to help identify possible regional patterns in the indicator values. Generally, the rankings are classified on the range of observed values rather than solely on thresholds of "good" and "bad." When interpretations such as healthy and unhealthy are applied to the data, this information is provided in the figure caption. An example of general ranking is figure 2. The average ecoregion section values range from 1 to 25 and the total range is arbitrarily divided into five categories (1 to 5, 6 to 10, 11 to 15, 16 to 20, 21 to 25). Each ecoregion section is color coded according to the category in which it belongs. This allows the reader to evaluate each ecoregion section and compare it to other ecoregion sections throughout the United States. This type of display does not inherently indicate which categories are of concern. Discussion about the maps is found in the text and is integral to the data presentation.

On some of the maps, only the forested parts of ecoregion sections are shaded with the data result ranking colors. So, the actual distribution of forestland appears as a backdrop on these maps. The forestland backdrop comes from landcover maps derived from 1-km-resolution Advanced Very High Resolution Radiometer satellite imagery (fig. 3). Also, some maps include State or regional boundaries to help orient readers geographically.

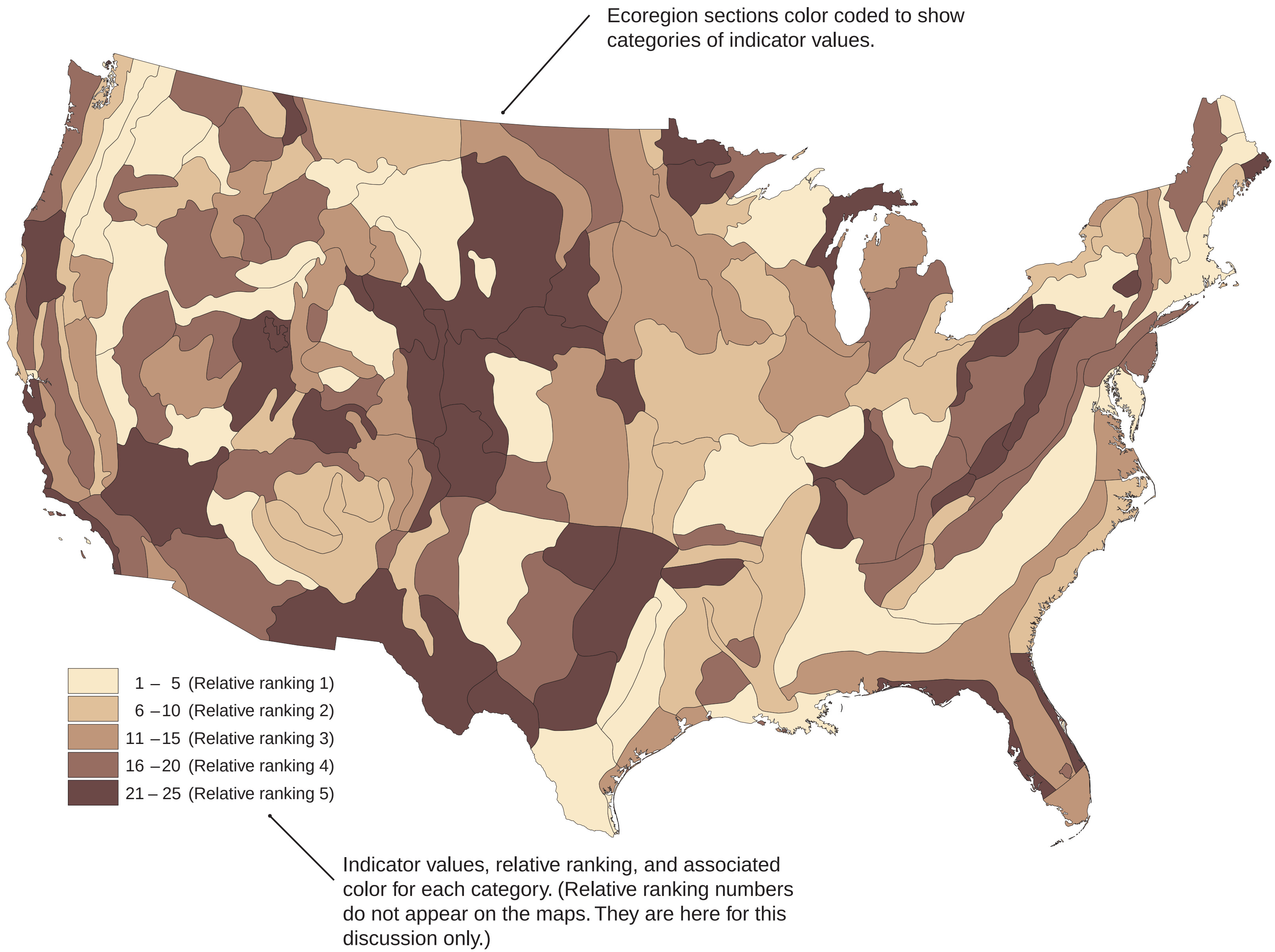


Figure 2—How to read a map in this report.

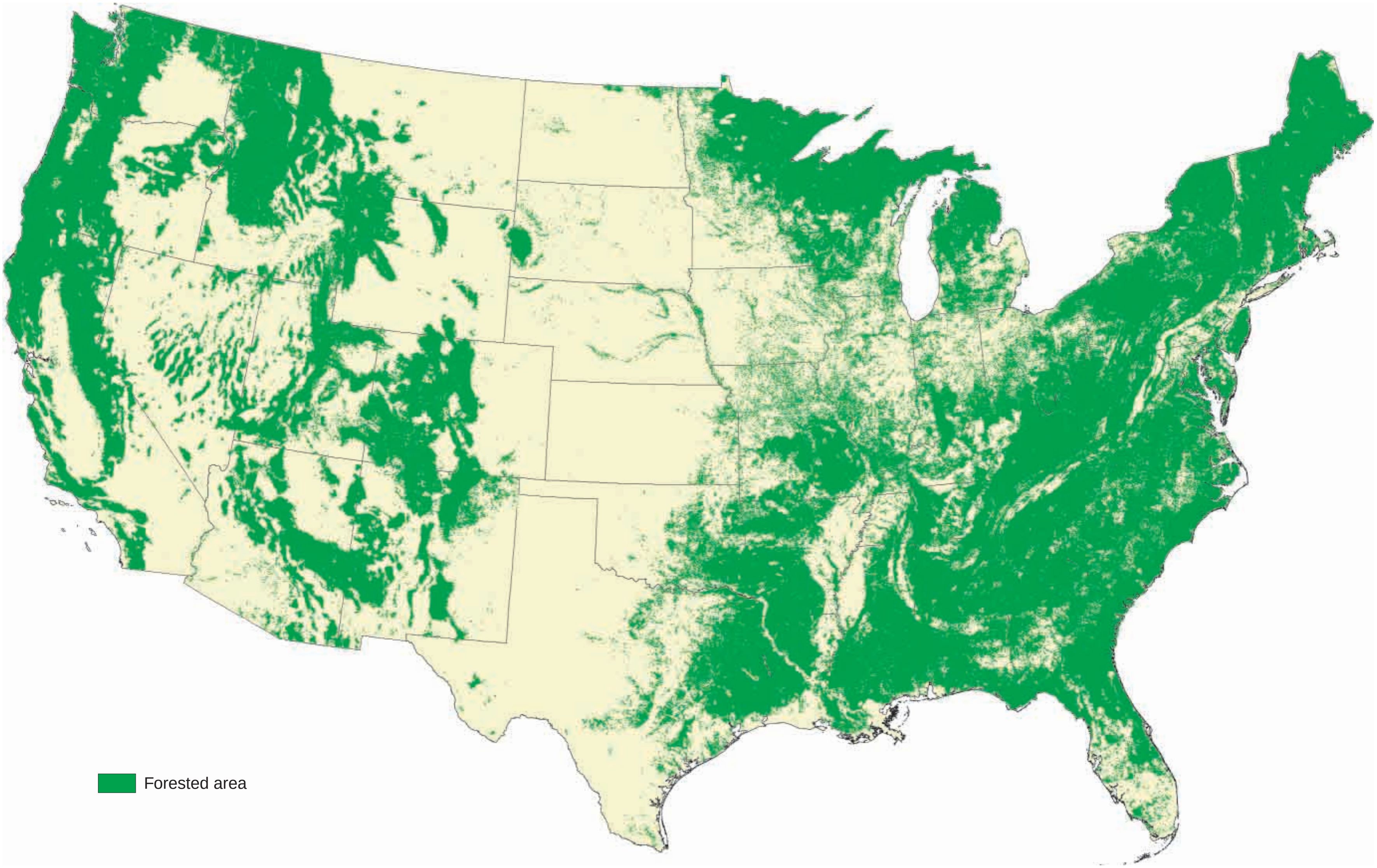


Figure 3—Forestland backdrop derived from Advanced Very High Resolution Radiometer satellite imagery (Zhu and Evans 1994).

Introduction

The cumulative impact of local land uses is often regional change in forest fragmentation and ecological processes that depend on intact forest. Local land management decisions address specific needs such as providing habitat for specific endangered species or protecting water supplies for particular communities. Regional analyses are needed to evaluate whether the cumulative result of local management actions is overall forest sustainability. Different regions experience different types of fragmentation owing to the natural distribution of forest and historic land uses. Therefore, a regional plan to manage fragmentation could consider the individual needs and capabilities of the region. With a view towards formulating regional conservation and restoration goals, we examined the geographic distribution of different types of forest fragmentation in the coterminous United States.

Recent analyses of national landcover maps showed substantial geographic variation in forest fragmentation (Heilman and others 2002; Riitters and others 2002, 2004). Forestland tends to be the dominant landcover type where it occurs, yet fragmentation is so extensive that most forestland is fragmented and exposed to edge effects that extend only 100 m away from forest edge. The largest remnants of core (far from edge) forest are concentrated in only a few ecological provinces.

Those studies did not address the types of fragmentation that characterize ecological provinces. For example, the amount of core forest was used to indicate fragmentation, but it is not known whether low amounts of core forest were caused by the perforation of forest patches or the loss of forest on patch perimeters. That distinction is important ecologically because, for example, perforations introduce edge effects deeper into intact forests.

Knowledge of the types of fragmentation in a region could help to choose appropriate management regimes. For example, the establishment of narrow riparian forest corridors may improve streamwater quality, but will have little impact on core forest and may adversely affect terrestrial biodiversity. There is naturally less fragmentation and more core forest in heavily forested areas, but it is not feasible to reduce fragmentation by planting forest everywhere. The most efficient management regimes for increasing core forest might be identified by looking at places where there is a low rate of fragmentation per unit of forest area.

The objective of the analyses presented in this report is to improve the definition of regional goals and priorities for managing forest fragmentation. We used national landcover and road maps to identify different types of fragmentation in a consistent fashion nationwide, and a spatial scan statistic to identify geographic clusters of each type. Recognizing that all types of fragmentation are widespread, we examined the relative differences to identify the most significant geographic clusters, i.e., "hotspots," of different types. We then evaluated whether or not the hotspots were concentrated in particular ecological provinces.

Methods

We measured forest fragmentation on landcover and road maps. The base map was a generalized forest/nonforest map of the coterminous United States from the National Land-Cover Database (NLCD). The NLCD project used Landsat Thematic Mapper data to map 21 classes of landcover at a spatial resolution of 0.09 ha/pixel (Vogelmann and others 1998, 2001). We aggregated the 4 NLCD forest classes (coniferous, deciduous, mixed, and wetland forest) into 1 forest class, and 15 of the remaining NLCD classes into 1 nonforest class. The water (including ice and snow) and bare rock (including bedrock, talus, and desert, but excluding quarries and mines) NLCD classes were treated as missing values and were not permitted to fragment the forest.

To account more accurately for road-mediated fragmentation, we superimposed a detailed road and street map (Geographic Data Technology 2002) upon the forest/nonforest map, and converted all forest pixels that contained at least one road segment to nonforest pixels. No distinctions were drawn between type of road, traffic volume, or other factors. We focused on 21 ecological provinces (Bailey 1995) with significant amounts of forest (fig. 4), and conducted separate analyses for eastern and western provinces as divided by the Great Plains.

Type of fragmentation was classified by using a model adapted from Riitters and others (2000, 2002). The classes are based on the amount of forest and its connectivity within a defined neighborhood (fig. 5). Each forest pixel was classified according to the type of fragmentation in the surrounding 7.29-ha neighborhood. We used a 7.29-ha neighborhood because that size best differentiates the type of fragmentation on the NLCD map (Riitters and others 2002) and because it approximates a realistic size for local land management actions.

The model (fig. 5) identifies four types of fragmentation including “none,” i.e., unfragmented or “core” forest, “edge,” “perforated,” and “patch.” A “core” forest pixel is surrounded by a completely forested neighborhood, and is by definition at least 120 m from the nearest nonforest pixel. The most fragmented neighborhood is “patch” forest, that is, a forest pixel surrounded by a neighborhood containing < 60 percent forest. “Edge” and “perforated” forest are forest pixels surrounded by neighborhoods with 60 through 99 percent forest. In “perforated” neighborhoods, forest constitutes the background and nonforest types tend to appear as patches on that background. In “edge” neighborhoods, the forest is fragmented by relatively larger nonforest patches.

After labeling each forest pixel according to the type of fragmentation in its neighborhood, the total area (rounded to the nearest ha) of forest, and of each fragmentation type, were calculated within nonoverlapping 56.25 km^2 square (5625 ha) analysis units (fig. 6). All subsequent analyses were based on the aggregated statistics. The geographic location of each analysis unit was established by the location of its center point. After excluding partial analysis units, e.g., near international borders, the total number of analysis units was 48,797 in the East and 25,649 in the West (table 1).

Spatial scan statistics (Coulston and Riitters 2003; Kulldorff 1997, 1999) are designed to detect geographic clusters with significantly high rates of an event in a population, i.e., “hotspots,” and to rank those clusters according to the statistical likelihood that the observed rate is higher than the background population rate. We implemented the scan statistic by using version

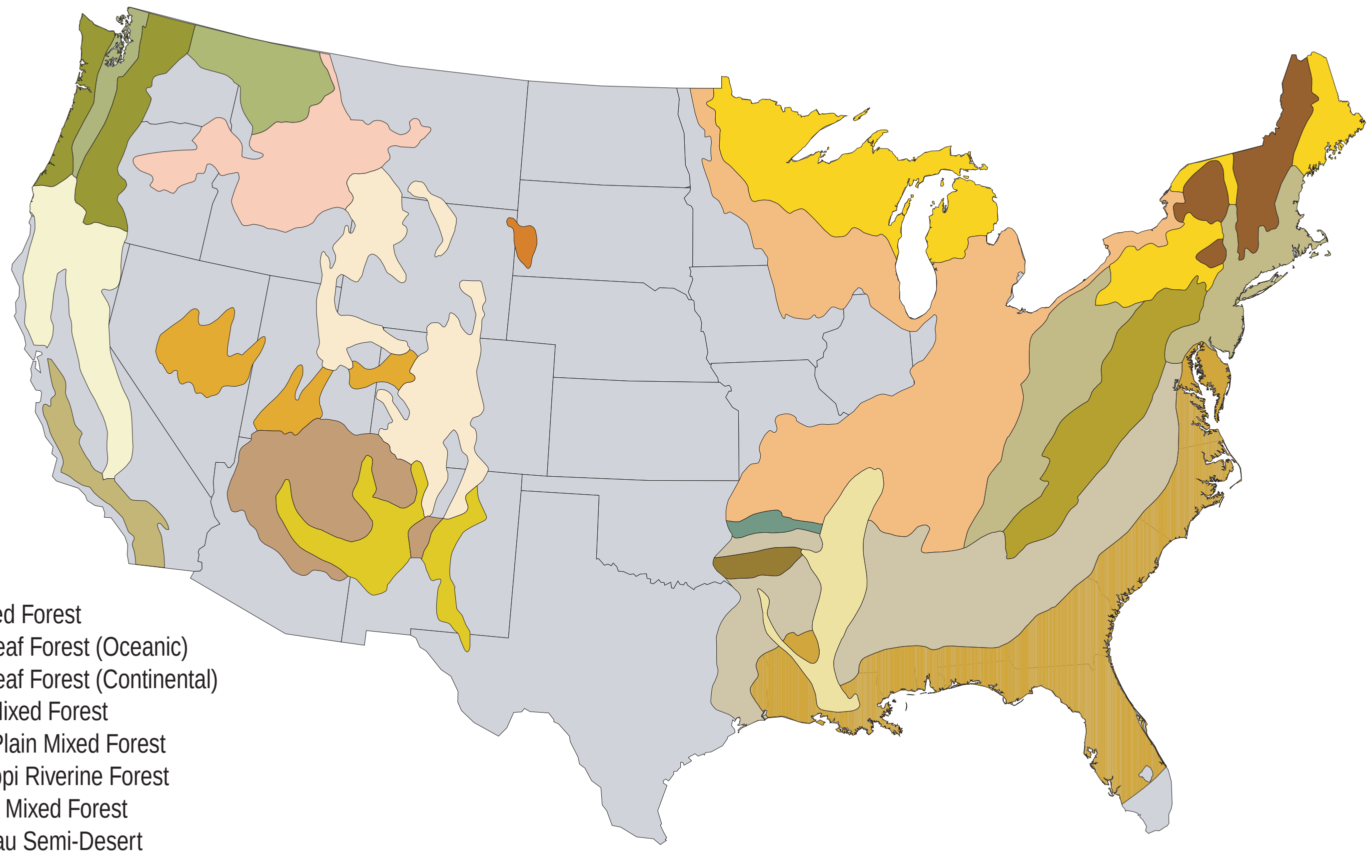


Figure 4—Twenty-one ecological provinces (Bailey 1995) with a substantial amount of forest. The spatial scan was applied separately to the 10 eastern and 11 western provinces.

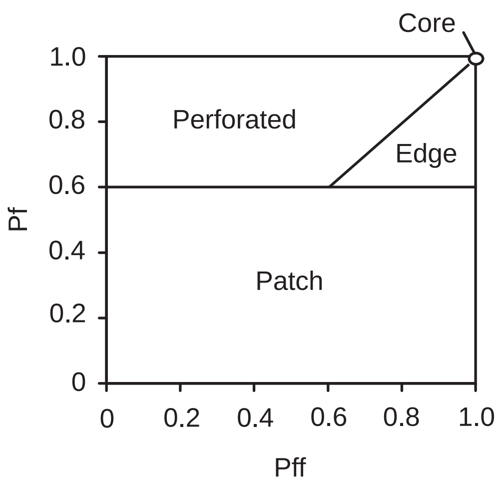


Figure 5—The classification model identifies four types of forest spatial patterns according to the amount of forest (Pf) and its connectivity (Pff) within a defined neighborhood.

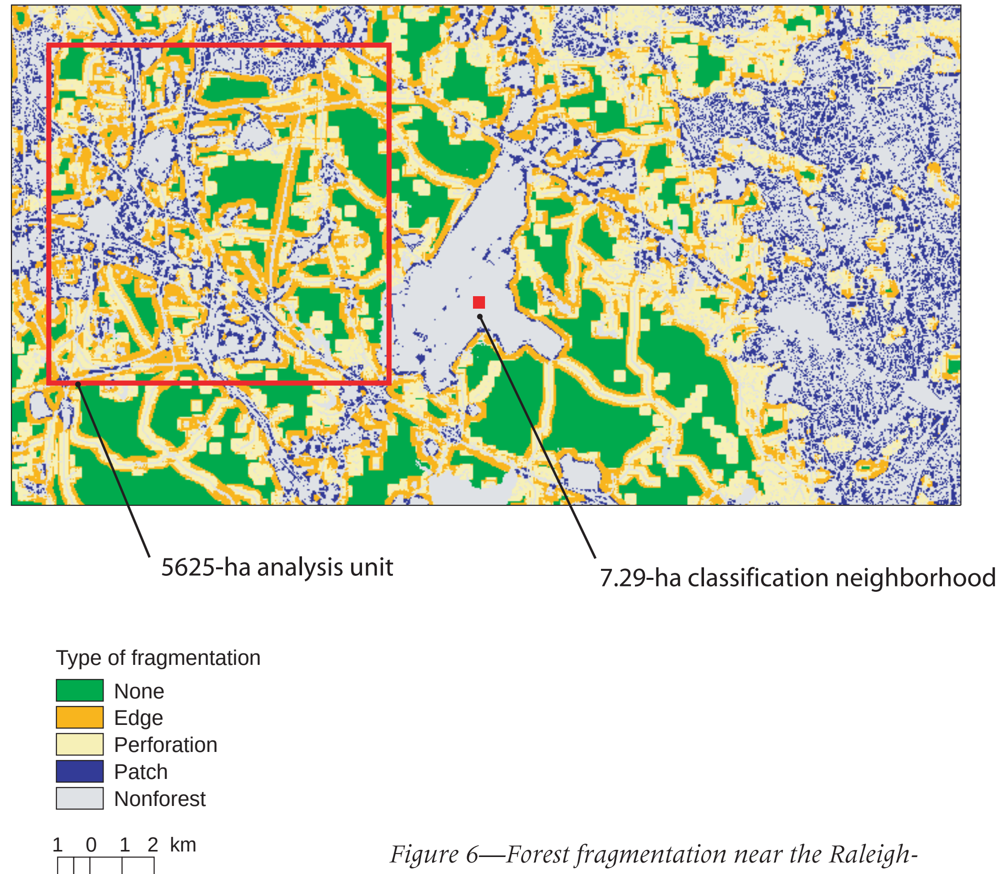


Figure 6—Forest fragmentation near the Raleigh-Durham (NC) airport. The small red square shows the size of the neighborhood that was used to classify the type of fragmentation surrounding each forest pixel. The large red box shows the size of the analysis unit that was used to summarize the pixel values prior to applying the scan statistic.

Table 1—Distribution of geographic clusters of fragmentation rates within and among ecological provinces—the number of analysis units by province and the percent of regional totals; the percent of each province area that was contained in a cluster of the given fragmentation type (the total for a province may not equal 100 percent because some analysis units were contained in more than one cluster type, and others were not contained in any cluster); and the percent of fragmentation type area that was contained in the given province

Ecological province	Analysis units		Percent of province area				Percent of fragmentation type area			
			Core	Edge	Perforated	Patch	Core	Edge	Perforated	Patch
	no.	*percent*								
Eastern provinces										
Laurentian Mixed Forest	6,771	13.9	26.7	17.1	36.6	11.7	19.7	9.0	24.9	6.0
Eastern Broadleaf Forest (Oceanic)	4,812	9.9	18.5	33.9	22.9	28.0	9.7	12.7	11.1	10.3
Eastern Broadleaf Forest (Continental)	12,438	25.5	5.4	28.8	9.9	51.3	7.3	28.0	12.4	48.7
Southeastern Mixed Forest	8,905	18.2	19.5	29.0	28.1	15.3	18.9	20.2	25.2	10.4
Outer Coastal Plain Mixed Forest	7,978	16.3	11.5	36.3	18.4	27.1	10.0	22.6	14.7	16.5
Lower Mississippi Riverine Forest	2,040	4.2	17.7	19.9	5.3	36.9	3.9	3.2	1.1	5.7
Adirondack—New England Mixed Forest—Coniferous Forest—Alpine Meadow	2,010	4.1	49.1	4.1	26.1	0.0	10.7	0.6	5.3	0.0
Central Appalachian Broadleaf Forest—Coniferous Forest—Meadow	3,136	6.4	45.2	12.3	15.3	9.1	15.4	3.0	4.8	2.2
Ozark Broadleaf Forest—Meadow	298	0.6	46.3	16.8	13.4	10.1	1.5	0.4	0.4	0.2
Ouachita Mixed Forest—Meadow	409	0.8	62.1	5.4	3.7	0.5	2.8	0.2	0.2	0.0
All eastern provinces	48,797	100.0	18.8	26.2	20.4	26.9	100.0	100.0	100.0	100.0
Western provinces										
Pacific Lowland Mixed Forest	677	2.6	31.3	46.4	9.7	25.4	4.3	4.4	1.2	2.1
Colorado Plateau Semi-Desert	3,485	13.6	2.1	9.4	15.5	47.4	1.4	4.6	10.2	19.7
Cascade Mixed Forest—Coniferous Forest—Alpine Meadow	2,468	9.6	45.1	32.8	22.2	6.8	22.3	11.4	10.3	2.0
Sierran Steppe—Mixed Forest—Coniferous Forest—Alpine Meadow	3,142	12.2	14.5	10.2	47.4	30.4	9.2	4.5	28.1	11.4
California Coastal Range Open Woodland—Shrub—Coniferous Forest—Meadow	1,153	4.5	0.0	0.5	1.2	64.7	0.0	0.1	0.3	8.9

continued

Table 1—Distribution of geographic clusters of fragmentation rates within and among ecological provinces—the number of analysis units by province and the percent of regional totals; the percent of each province area that was contained in a cluster of the given fragmentation type (the total for a province may not equal 100 percent because some analysis units were contained in more than one cluster type, and others were not contained in any cluster); and the percent of fragmentation type area that was contained in the given province (continued)

Ecological province	Analysis units		Percent of province area				Percent of fragmentation type area			
			Core	Edge	Perforated	Patch	Core	Edge	Perforated	Patch
	no.	*percent*								
Arizona—New Mexico Mountains Semi-Desert—Open Woodland—Coniferous Forest—Alpine Meadow	2,314	9.0	15.6	14.5	30.4	39.0	7.2	4.7	13.3	10.8
Southern Rocky Mountain Steppe—Open Woodland—Coniferous Forest Alpine Meadow	4,719	18.4	21.4	44.9	11.1	35.8	20.3	29.8	9.9	20.2
Middle Rocky Mountain Steppe—Coniferous Forest—Alpine Meadow	3,770	14.7	23.8	41.4	15.0	30.8	18.0	21.9	10.7	13.9
Northern Rocky Mountain Forest—Steppe—Open Woodland—Coniferous Forest—Alpine Meadow	1,758	6.9	43.0	36.7	11.1	6.5	15.2	9.1	3.7	1.4
Black Hills Coniferous Forest	170	0.7	23.5	57.1	12.9	32.9	0.8	1.4	0.4	0.7
Nevada—Utah Mountains Semi-Desert—Coniferous Forest—Alpine Meadow	1,993	7.8	3.3	29.0	31.6	37.9	1.3	8.1	11.9	9.0
All western provinces	25,649	100.0	19.4	27.7	20.7	32.6	100.0	100.0	100.0	100.0

3.1.2 of the SatScan software (Kulldorff 1999, Kulldorff and Information Management Services Inc. 2002). The SatScan algorithm places a circular window on the center point of each analysis unit, and tests circular windows of increasing size. The analysis units contained within each circle constitute a potential geographic cluster, and the test statistic is based on the likelihood of obtaining the observed excess of fragmentation in a larger window. We used the likelihood function for a specific window under the Bernoulli model (Kulldorff and Nagarwalla 1995). The "events" were taken to be the number of hectares of forest of a given type of fragmentation, and the "controls" were the number of hectares of forest that were not of that type of fragmentation. The analysis was performed separately for each type of fragmentation, and for each region (east and west).

We specified SatScan parameters so as to improve the interpretability of results among ecological provinces. To get small and reasonably homogeneous clusters, we specified a maximum scan circle radius of 0.25 decimal degrees (approximately 20 km depending on latitude). We also specified that the clusters not overlap one another so that each analysis unit appeared in at most one cluster for a given scan. These choices produced at least 500 significant ($p < 0.001$) and small (< 30 analysis units each) clusters for each scan. SatScan retained the 500 most significant clusters for further analysis. This procedure yielded 1,000 clusters of each type of fragmentation—500 in the east region and 500 in the west region.

Results

The 500 most significant geographic clusters identified for each of the 8 scans (4 for the East and 4 for the West) are shown in figure 7. Against the background of color-coded ecological provinces (compare to figure 4), the 100 most significant clusters are shown in the darkest color, the 100 next most significant have a medium color, and the 300 least significant clusters have the lightest color. The clusters of all types of fragmentation were widespread and every ecological province contained at least one significant cluster of each type of fragmentation. The substantial variation within provinces is indicated by the incomplete obscuring of the

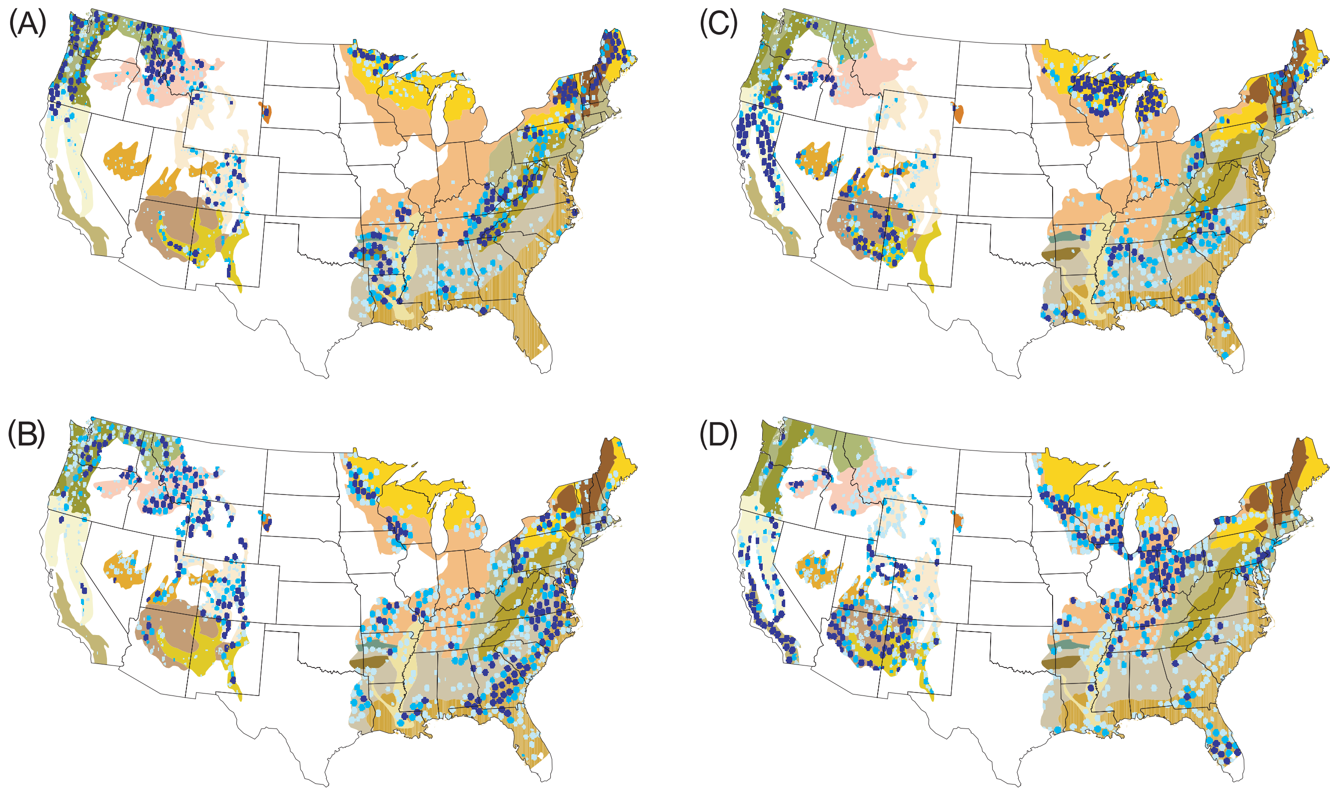


Figure 7—The location of geographic clusters identified by the spatial scan statistic. The 100 most significant clusters are shown as the darkest blue color, the 100 next most significant clusters are shown as medium blue, and the 300 least significant clusters are shown as the lightest blue. The yellow-brown background colors refer to ecological provinces as shown in figure 4. The maps portray core fragmentation (A), edge fragmentation (B), perforated fragmentation (C), and patch fragmentation (D).

background (province) color by clusters. The regional hotspots are easier to perceive by looking at the 100 most significant clusters (darkest color) from each scan. Those clusters typically occur in fewer provinces, in comparison to all 500 clusters, which are more widespread among provinces.

There is an interaction between ecological province and type of fragmentation such that the specific hotspot provinces change with type of fragmentation. For example, the most significant clusters for perforated fragmentation (fig. 7C) are mostly in the northern parts of Michigan, Wisconsin, and California, whereas the most significant clusters for patch fragmentation (fig. 7D) are in different provinces in the southern parts of those States.

The results were compared in two ways, within and among ecological provinces (table 1). One comparison (table 1) is of the percentage of total area within each province that was included in one of the 500 clusters. The second comparison (table 1) is of the percentage of area in all 500 clusters that was in a given ecological province. Differences in the latter are due partly to total size differences among provinces (table 1) because larger provinces will contain more of any type of cluster even when clusters are uniformly distributed. Comparisons of values shown in table 1 can help to focus attention on provinces with the most area of high fragmentation rate (table 1), or provinces with a larger proportion of area subject to a high fragmentation rate (table 1).

An example of interpreting table 1 is the case of the core class. The distribution of total core cluster area among provinces in the East varied from 1.5 percent for the Ozark Broadleaf Forest—Meadow Province to 19.7 percent for the Laurentian Mixed Forest Province (table 1). The lower percentage was due to the relatively small size of the Ozark Broadleaf Forest—Meadow Province (table 1). However, about twice as much of the Ozark Broadleaf Forest—Meadow Province is in a core cluster (46.3 vs. 26.7 percent) (table 1). Targeting the Laurentian Mixed Forest Province might, therefore, preserve more total area of core forest, whereas emulating the management of the Ozark Broadleaf Forest—Meadow Province might increase the production efficiency of core forest.

Eastern provinces containing a large proportion of core forest cluster area (table 1) include the Ouachita Mixed Forest—Meadow (62.1 percent), the Ozark Broadleaf Forest—Meadow (46.3 percent), the Adirondack—New England Mixed Forest—Coniferous Forest—Alpine Meadow (49.1 percent), and the Central Appalachian Broadleaf Forest—Coniferous Forest—Meadow (45.2 percent). In the West, the Cascade Mixed Forest—Coniferous Province (45.1 percent) and the Northern Rocky Mountains Forest—Steppe—Open Woodland—Coniferous Forest—Alpine Meadow Province (43.0 percent) had more than one-third of total province area in a core cluster.

In the Midwest, hotspots of perforated fragmentation (fig. 7C) were located in the Laurentian Mixed Forest Province, whereas hotspots of edge (fig. 7B) and patch (fig. 7D) fragmentation were in the Eastern Broadleaf Forest (Continental) Province. Florida contained hotspots of edge, perforated, and patch fragmentation. Elsewhere in the South, hotspots of perforated fragmentation were in the Southeastern Mixed Forest Province and hotspots of edge fragmentation were in the Outer Coastal Plain Mixed Forest Province. In the Northeast, hotspots of fragmentation were usually associated with large urban areas and major transportation corridors.

In the West, hotspots of edge fragmentation were more common in the northern ecological provinces, whereas hotspots of perforated and patch forest were concentrated in the southern ecological provinces. In southern California, the California Coastal Range Open Woodland—Shrub—Coniferous Forest—Meadow Province was dominated by clusters of patch fragmentation, while in northern California, the Sierran Steppe—Mixed Forest Coniferous Forest—Alpine Meadow Province was dominated by clusters of perforated fragmentation. In contrast, provinces in the southern parts of the intermountain region contained many clusters of both perforated and patch fragmentation while the provinces in the northern parts of the region contained clusters of edge and patch fragmentation.

Although the clusters of a given type of fragmentation were not allowed to overlap, there was no restriction on the overlap of clusters of different types of fragmentation. Thus, it was possible to examine the coincidence of different types of fragmentation by finding the intersections of the sets of analysis units that they contained. To identify vulnerable core forest, we mapped the core cluster units that were also contained in a cluster of one of the other three types of fragmentation (fig. 8). For East and West combined, 1,498 analysis units in clusters of core fragmentation were also in clusters of edge fragmentation (fig. 8A); 1,428 were also in clusters of perforated fragmentation (fig. 8B); and 269 were also in clusters of patch fragmentation (not shown).

Discussion

The fragmentation classification was made in 7.29-ha neighborhoods, which is a relevant size for local management actions. In contrast, regional planning typically is based on aggregated statistics, perhaps using ecological or administrative regions for data aggregation. However, because fragmentation varies substantially within ecological and administrative regions, the aggregated measures have little practical meaning when managing specific land parcels (Riitters and others 2004). Therefore, once a regional or national goal has been decided, further analysis will be necessary to localize the goal so that appropriate actions can be taken in specific places. These analyses demonstrated the utility of the spatial scan statistic as a localization tool to identify fragmentation hotspots that could be candidates for different types of forest management. We used ecological provinces to summarize the hotspot information, but other designated divisions including administrative divisions could have been used instead.

All types of fragmentation are generally widespread, but our results show that a management strategy targeted to conserve or restore only one type of fragmentation will not have uniform benefits across all ecological provinces. Therefore, a single strategy to manage fragmentation probably should not be applied everywhere, at least not with an expectation that the results will be the same everywhere it is used. Managing fragmentation has to take into account the needs and capabilities of different provinces. For example, a focus on preserving

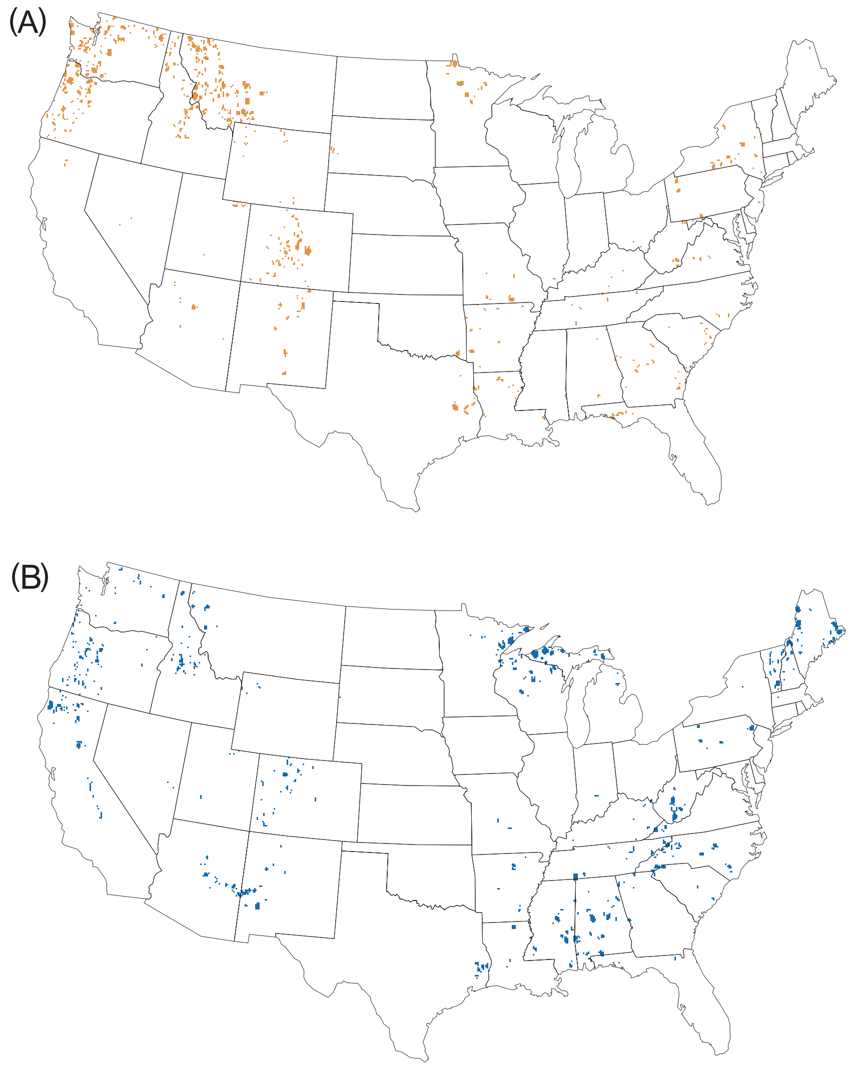


Figure 8—The location of core forest in close proximity to fragmented forest. The maps show the analysis units in core fragmentation clusters that were also in clusters of edge fragmentation (A) and perforated fragmentation (B).

intact or core forest would lead to management in provinces that would not be high priority if the focus were instead on restoring fragmented or perforated forest.

The geographic overlap between core fragmentation clusters (representing no fragmentation) and clusters of edge or perforated fragmentation (fig. 8) identify analysis units that are vulnerable to future loss of core forest. They are vulnerable because nonforestland uses tend to expand over time, and significant fragmentation is already evident nearby. In the West, there was more overlap with edge fragmentation, whereas in the East there was more overlap with perforated fragmentation. The western overlap with edge fragmentation is partly due to natural edge near upper and lower tree lines. In the East, the overlap with perforated fragmentation is almost certainly due to small anthropogenic patches embedded in larger regions of intact forest. The proximate cause or causes of fragmentation can be evaluated by using a modification of the fragmentation classification model (Wade and others 2003).

The high within-province variation means that ecological provinces are rarely ideal as a basis for summarizing fragmentation statistics or for implementing a regional management plan. The clusters found by the scan statistic might be better for both purposes because fragmentation is more homogeneous within clusters. Examples of management regimes to achieve particular objectives in a particular ecological province might be found in the clusters that we identified; or, alternatively, the scan statistic can find other sets of clusters with significantly lower (instead of higher) fragmentation rates to serve as management models.

Landscape-Level Assessment of Insects and Diseases with Ties to Results from Evaluation Monitoring

Introduction

Native insects and diseases are a natural part of ecosystems and are essential to ecological balance in natural forests (Castello and others 1995). Their populations are influenced by natural and anthropogenic factors such as climate, management activities, natural tree defenses, and natural enemies. Insects and diseases influence forest succession, productivity, and stability through complex ecosystem interactions (Berryman 1986). They influence patterns and processes of forested landscapes mostly through tree mortality, reduced tree vigor, or both.

National information on insects and diseases is maintained by Forest Service, FHP. FHP produces a yearly report on the forest insect and disease conditions to convey the current situation. There were several highlights from 2002 (U.S. Department of Agriculture Forest Service 2003b). Southern pine beetle activity increased from 2001 levels. Over 546 000 km^2 were affected by southern pine beetle in 2002. There was also an increase in mountain pine beetle activity. Approximately 6332 km^2 were affected in 2002. Gypsy moth activity in 2002 decreased from 2001 levels. Two native diseases, fusiform rust and dwarf mistletoes, were active on approximately 56 000 km^2 and 117 000 km^2 of forest in 2002, respectively. Sudden oak death, a disease of unknown origin, has been confirmed in 12 counties in California and 1 county in Oregon. Butternut canker has been found throughout most of the natural range of butternut. While the annual forest insect and disease conditions report describes the activity of individual insects and diseases, we examined activity from a different perspective.

Brief Methods

We used the nationally compiled FHP aerial survey data from 1996 to 2002 to assess insect and disease activity at the landscape level. Most of the forested area in the coterminous United States was surveyed for insect or disease activity in 2002 (fig. 9). Each agent recorded during the surveys was classified by FHP as mortality- or defoliation-causing in the database. Spatio-temporal trends (1996 to 2002)[4] in exposure to mortality- and defoliation-causing agents were assessed within each FHM region. Exposure was defined as the area in hectares with mortality- or defoliation-causing agents present. The spatio-temporal trend analysis was based on relative exposure (observed vs. expected) on a county basis and was used to identify hotspots of activity during the time period.

[4] Data were from 1996 through 2002 for all FHM regions except the South, where data were from 1998 through 2002.

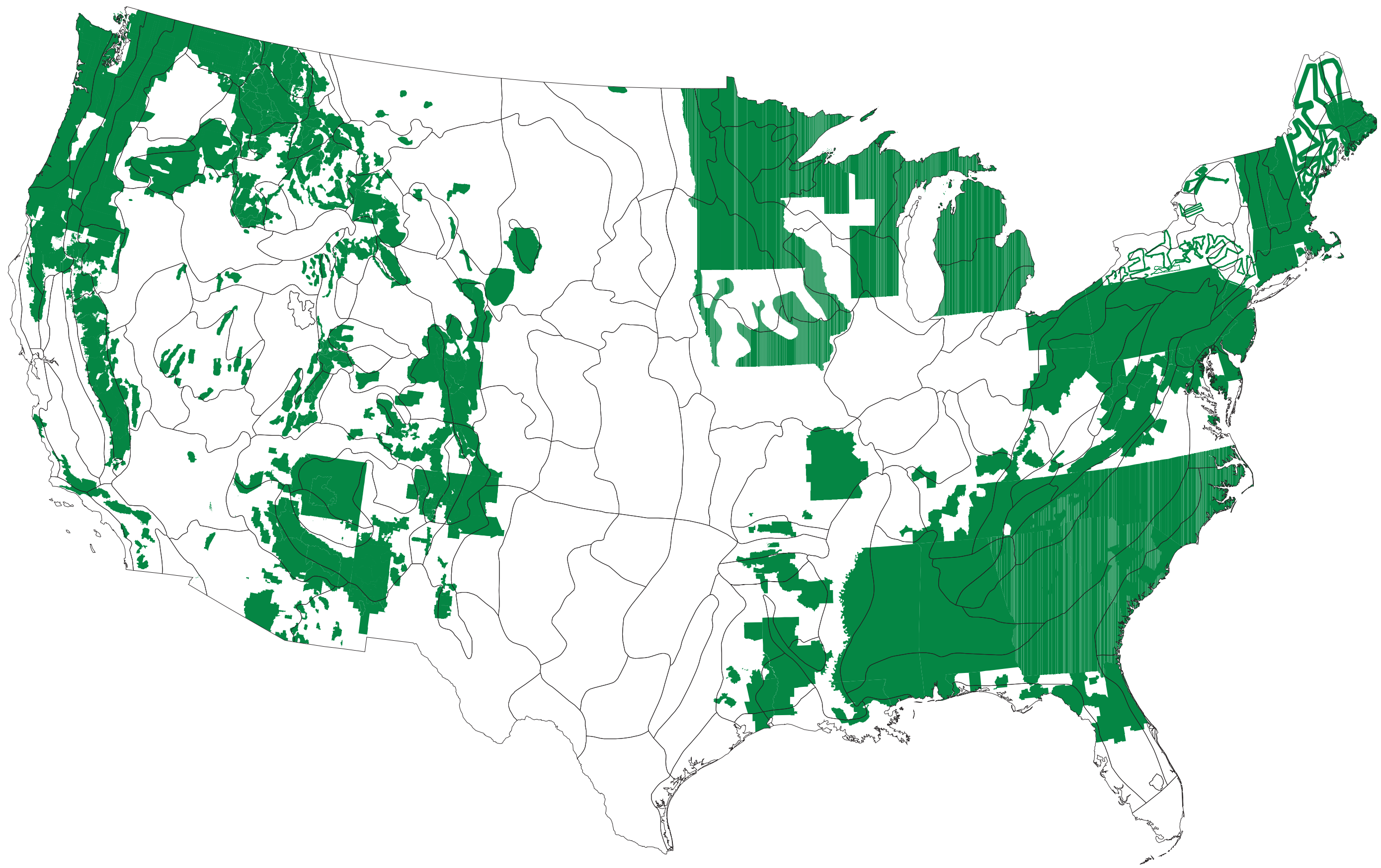


Figure 9—Areas where aerial surveys were conducted in 2002.

Expected amounts of exposure were based on a Poisson model (Kulldorf 1997). The measure is referred to as relative exposure and is the ratio of observed to expected exposure. Relative exposure was calculated for mortality- and defoliation-causing agents, and used to identify forested areas within FHM regions that were hotspots as compared to the rest of the region. The actual value calculated ranged from zero to infinity, where < 1 represented low relative exposure and less-than-expected defoliation or mortality within the region. A value > 1 represented more-than-expected exposure to mortality- or defoliation-causing agents within the FHM region of interest. The measure is linear, so a relative exposure value of 2 indicates an area has experienced twice the exposure expected for the region.

Results

In the Northeast FHM region, there were several hotspots of mortality- and defoliation-causing insect and disease activity (figs. 10A and 10B). Section 212C—Fundy Coastal and Interior in eastern Maine experienced widespread activity of the balsam woolly adelgid, which contributed to relative exposure scores greater than five times expected. Similarly, Section 221C—Upper Atlantic Coastal Plain in New Jersey had several areas with more than five times the expected exposure to mortality- and defoliation-causing insects and diseases. Much of the forested area in Section M221A—Northern Ridge and Valley, which cuts through Pennsylvania, West Virginia, Virginia, and into Tennessee, was exposed to more than five times the expected exposure to defoliation-causing insects and diseases. The defoliation was mostly caused by gypsy moth activity.

In the South FHM region, most aerial surveys were conducted specifically to detect southern pine beetle. There were several areas where southern pine beetle activity has been recorded every year since 1998 (see footnote 4). Areas

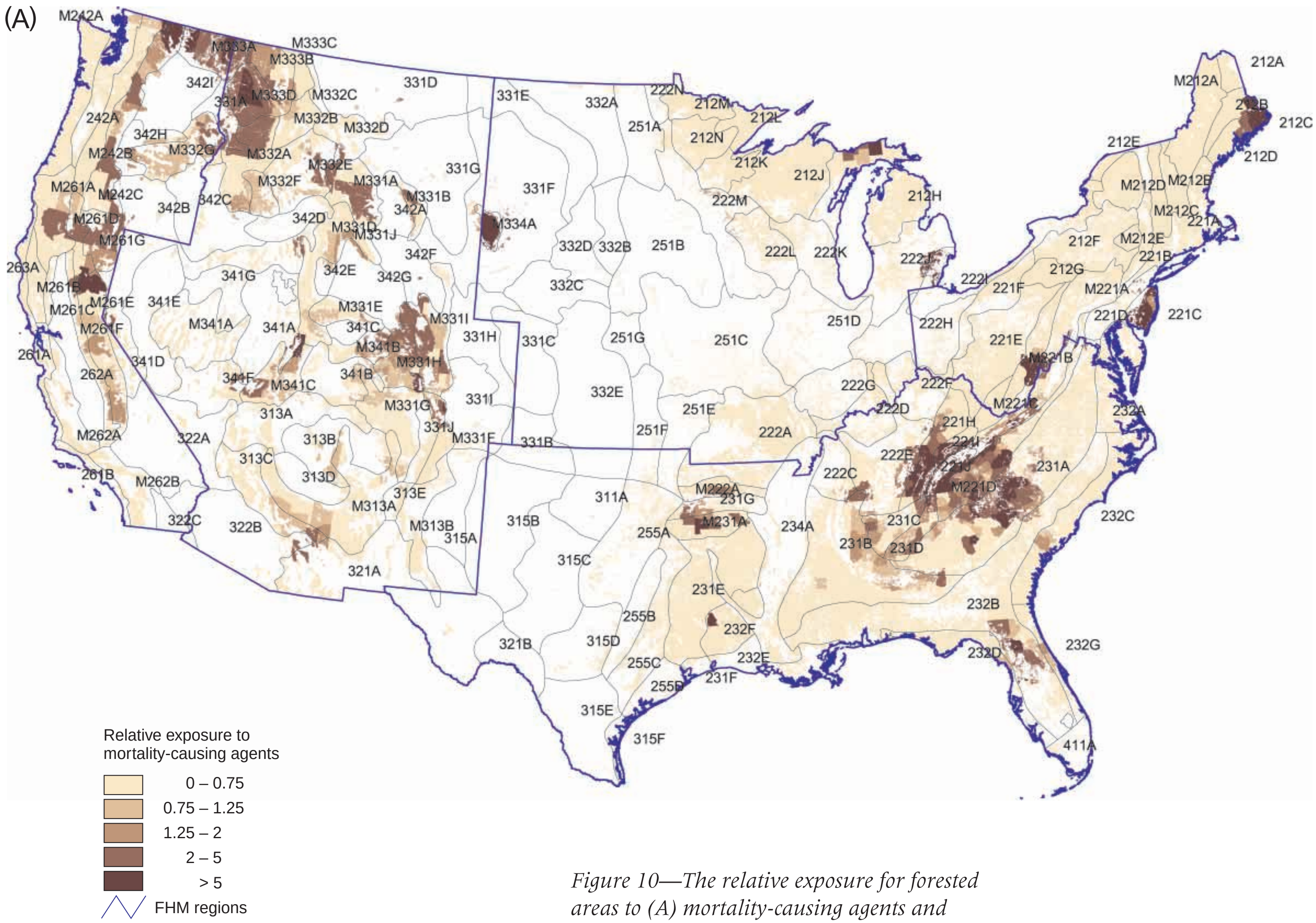
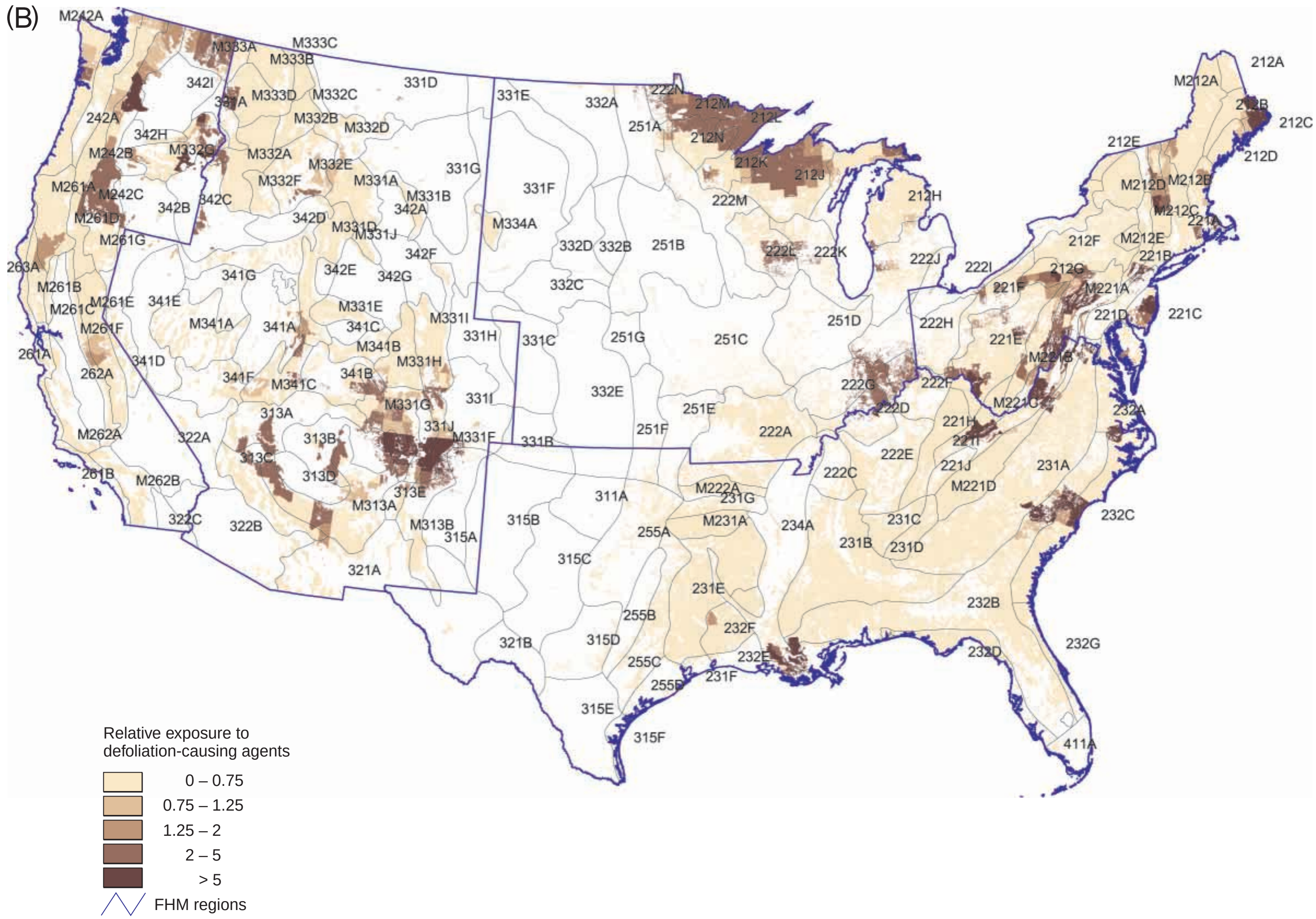


Figure 10—The relative exposure for forested areas to (A) mortality-causing agents and (B) defoliation-causing agents for each FHM region—1996 to 2002 (continued to next page).

(B)


Relative exposure to
defoliation-causing agents
0 – 0.75
0.75 – 1.25
1.25 – 2
2 – 5
> 5
FHM regions

with more than five times the expected exposure to mortality-causing insects and diseases were found in Sections 231A—Southern Appalachian Piedmont, M221D—Blue Ridge Mountains, 221H—Northern Cumberland Plateau, 221I—Southern Cumberland Mountains, and 221J—Central Ridge and Valley (fig. 10A). While most aerial surveys were aimed at detecting southern pine beetle, some defoliation activity was recorded (fig. 10B). Specifically, the forest tent caterpillar was active in Sections 232C—Atlantic Coastal Flatlands and 232B—Coastal Plains and Flatwoods, Lower.

Forests in the Northcentral FHM region had a few hotspots of mortality-causing insect and disease activity (fig. 10A). Emerald ash borer caused mortality in part of Sections 222I—Erie and Ontario Lake Plain and 222J—South Central Great Lakes in Michigan. Also, Section M334A—Black Hills in South Dakota continued to have above-expected rates of mortality-causing insect and disease activity. There were several areas in the Laurentian Mixed Forest Province (212) in northern Michigan that had relative exposure to defoliation-causing insects and pathogens between two and three times the expected value (fig. 10B). There was a range of agents responsible for this activity.

The Interior West FHM region had large areas of higher than expected exposure to mortality-causing insects and pathogens; however, most of the activity of defoliation-causing agents was in the southern part of the region (figs. 10A and 10B). Sections 331J—Northern Rio Grande Basin in northern New Mexico, M313A—White Mountain—San Francisco Peaks—Mogollon Rim in Arizona and New Mexico, and M331G—South-Central Highlands in southern Colorado and northern New Mexico all had relative exposure scores to defoliation-causing insects and pathogens greater than five times expected. Section M333D—Bitterroot Mountains continued to have a high relative exposure to mortality-causing agents. However, Sections M331H—North-Central Highlands and Rocky Mountain, and M331I—Northern Parks and Ranges in Colorado had several forested areas with more than four times the expected relative exposure to mortality-causing insects and pathogens.

In the West Coast FHM region most of the mortality- and defoliation-causing insect and disease activity occurred east of the Cascade Mountains and in the Sierra Nevada Mountains (figs. 10A and 10B). Much of the forested area in Section M242C—Eastern Cascades in Washington and Oregon was exposed to more than twice the expected exposure to mortality-causing insects and diseases for the region. There were also areas in Section M333A—Okanogan Highlands in northern Washington and Idaho with more than five times the expected exposure. The northern part of Section M261E—Sierra Nevada in California also had more than five times the expected exposure to mortality-causing insects and diseases. Exposure to defoliation-causing insects and diseases was highest in Sections M242C—Eastern Cascades and M332G—Blue Mountains in Oregon and the southeast tip of Washington. However, some forested areas in the northern part of Section M242A—Oregon and Washington Coast Ranges were exposed to more than twice the expected amount of defoliation-causing insects and diseases. This was mostly due to recent Swiss needle cast activity.

Ties to Evaluation Monitoring

The landscape-level approach used in this analysis identifies areas where mortality rates, defoliation rates, or both are high compared to the rest of the region. In some cases, these areas become candidates for further examination as part of evaluation monitoring (EM). EM projects are selected yearly based on the following criteria: linkage to FHM survey and FIA phase 2 and phase 3 plot data; significance in terms of the geographic scale; biological impact and/or political importance of the issue related to fire; and feasibility or probability that the project will be successfully completed within 1 to 3 years, with some immediate products in the first year and each year thereafter. Recently, McMillin and others (2003) and McMillin and Allen (2003) published the results of EM projects relating to insects and pathogens. The purpose of this section is to describe the findings from the EM phase and examine how well the landscape-level approach performed in the detection monitoring phase.

McMillin and Allen (2003) examined the effects of Douglas-fir beetle on forest conditions in western Wyoming. They found that the

1988 Yellowstone fire, which also burned part of the Shoshone National Forest, created an environment where the Douglas-fir beetle population could expand and invade neighboring stands in the Rocky Mountains of Wyoming. This caused Douglas-fir mortality in the early to mid-1990s. These infestations and subsequent Douglas-fir mortality significantly reduced the Douglas-fir overstory component, increased conifer regeneration, and led to an increase in forb, grass, and shrub abundance in the understory. McMillin and Allen (2003) suggest that the infestation only caused short-term effects to the understory and overstory.

McMillin and others (2003) examined the effects of the western balsam bark beetle on spruce-fir forests in northcentral Wyoming. Specifically, they examined part of the Bighorn National Forest (fig. 11). Based on the FHP aerial survey for their study area, there were approximately 6 km^2 affected by western balsam bark beetle in 1997. By 2000, approximately 70 km^2 and 31,270 subalpine fir trees had been affected. The effect of the subalpine fir mortality was a decrease of subalpine fir in the overstory. However, there were small increases in the understory. There was a significant positive linear relationship between the percentage of windthrown fir trees and the percentage of logs used by the western balsam bark beetle. McMillin and others (2003) suggested that blowdown events, in combination with the large fir component, have created ideal conditions for the beetle.

In the 2002 FHM national technical report (Coulston and others 2005a), we examined the relative exposure of forests to mortality-causing agents such as the western balsam bark beetle. Using the 1996 to 2000 aerial survey data, we found widespread activity of mortality-causing agents throughout the Interior West FHM region. However, the most activity was in Section M333D—Bitterroot Mountains in Idaho. Upon closer examination of the results from Coulston and others (2005a), the study area of McMillin and others (2003) was estimated to have approximately two and one-half times the expected activity of mortality-causing agents for the Interior West FHM region (fig. 11). Most of the activity was classified as subalpine fir mortality. In this case, the landscape approach (relative exposure analysis) correctly identified the study area as having elevated levels of disturbance.

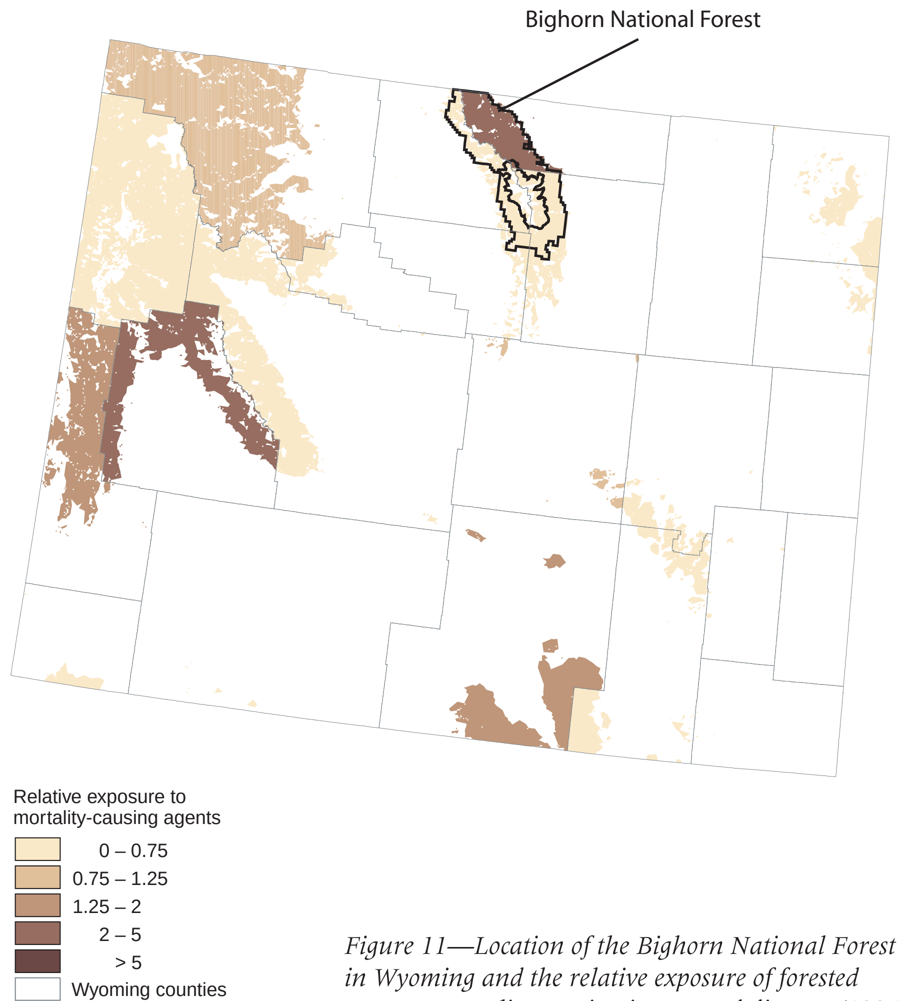


Figure 11—Location of the Bighorn National Forest in Wyoming and the relative exposure of forested areas to mortality-causing insects and diseases (1996 to 2000) from Coulston and others (2005a).

Crown Condition

Introduction

Crown condition assessments can include information about many aspects of tree crowns. Often included are some measurement of branch dieback and some measurement of how much foliage is present or missing. Crown condition has been studied in relation to carbohydrate content in different tree tissues (Liu and Tyree 1997, Renaud and Mauffette 1991), and in relation to photosynthesis, canopy nutrition, and soil and stand conditions (Ellsworth and Liu 1994, Wilmot and others 1995). Effects of forest stressors such as air pollution, diseases, or insect pests (Skelly and others 1987) and more transient stressors such as periodic drought (Lorenz and others 2001) may also be reflected in crown condition.

Because the crown foliage is important for tree survival, growth, and reproduction, several variables describing tree crowns are collected on phase 3 plots.[5] Two of these variables are crown dieback and foliar transparency. Crown dieback, estimated ocularly and recorded in 5-percent classes, is the percent mortality of the terminal portion of branches that are generally > 1 inch in diameter and in the upper, sun-exposed portion of the crown (Burkman and others 1995). Foliar transparency, also estimated ocularly and recorded in 5-percent classes, is the percent of sky visible through the live, normally foliated portion of the crown (Burkman and others 1995).

Methods

Assessment of tree crowns began by evaluating each tree. We combined foliar transparency and crown dieback to produce a composite foliage index for each tree. Using a variation of the method proposed by Zarnoch and others,[6] an index, hereafter referred to as the adjusted ZB-index, is given by the formula (Ambrose 2004):

$$Z_a = [1-(1-\frac{(T-15)}{100})(1-\frac{D}{100})] \qquad \text{if } T \geq 15$$

$$Z_a = \frac{D}{100} \qquad \text{if } T < 15$$

where

Z_a = adjusted ZB-index ($0 \leq Z_a \leq 1$)
T = percent foliar transparency ($0 \leq T \leq 100$)
D = percent crown dieback ($0 \leq D \leq 100$)

[5] U.S. Department of Agriculture Forest Service. 2004. Forest inventory and analysis national core field guide: field data collection procedures for phase 3 plots. Version 2.0. Vol. 2. Internal report. On file with: USDA Forest Service, Forest Inventory and Analysis, Rosslyn Plaza, 1620 North Kent Street, Arlington, VA 22209.

[6] Zarnoch, S.J.; Stolte, K.W.; Binns, R. Chapter 6 – crown condition. In: Lewis, T.E.; Conkling, B.L., eds. Forest health monitoring southeast loblolly/shortleaf pine demonstration project final report. Chapter 6.1–6.51. Unpublished manuscript. 535 p. On file with: The Forest Health Monitoring Program National Office, 3041 Cornwallis Road, Research Triangle Park, NC 27709.

The adjusted ZB-index, in theory, represents the amount by which the foliage of the tree is reduced relative to an ideal, fully foliated tree having the same crown diameter, live crown ratio, and crown density (other crown variables measured by FIA). For example, a tree with $Z_a = 0.25$ would have 75 percent of the foliage that the ideal fully foliated tree would have. Use of Z_a includes the assumption that any transparency up to 15 percent is healthy. Only the amount of transparency exceeding 15 percent is used as an indicator of poor crown condition. This is a reasonable assumption because zero transparency has only rarely been recorded for any tree, and most trees surveyed across all species have transparencies of 10 to 20 percent.

A threshold value for Z_a of 0.25 was selected to indicate trees that had poor or unhealthy crowns. In addition, softwood trees having dieback $\geq$ 10 percent were also considered to have unhealthy crowns, regardless of the overall adjusted ZB-index value (Coulston and others 2005a). Thus, a tree crown was considered to be unhealthy if either (1) the adjusted ZB-index was 0.25 or greater, or (2) the tree was a softwood and had dieback of 10 percent or greater. For an explanation of the rationale for these thresholds, see the 2003 FHM national technical report (Coulston and others 2005b).

Crown data were available for time intervals that varied by State. The following tabulation shows the years of FHM and FIA phase 3 plot crown data that were available for this analysis:

Years	States
1990–2002	CT, MA, NH, RI, VT
1990–2001	ME
1991–2002	DE, MD, NJ
1991–2001	AL, GA, VA
1992–2002	CA, CO
1994–2000	MI, MN, WI
1995–2002	WV
1995,1998–2001	PA
1996–2000	IN
1996–2002	ID
1997–2000	IL
1997–2002	OR, WA, WY
1998–2001	NC, SC
1999–2000	MO
1999–2002	NV, NY, UT
1999–2001	TN
2000–2001	AR, KY, LA
2001–2002	AZ
2001	FL, OH, TX

Data from 1990 to 1999 were collected using the FHM four-panel sampling design with overlap, in which one panel, i.e., one-fourth of the plots, was measured each year and one-third of the panel measured the previous year (overlap) was remeasured (Smith and Conkling 2005). Data from 2000 to 2002 were collected using the FIA five-panel sampling design with no annual overlap (Bechtold and Patterson 2005).

Results and Discussion

Figure 12 shows the average percentage of plot basal area associated with trees classified as having unhealthy crowns by ecoregion section. In all ecoregions of the United States, < 15 percent of the basal area was associated with unhealthy crowns, and in most ecoregions 10 percent or less of the basal area was associated with unhealthy crowns.

Ecoregion sections having > 10 percent average basal area associated with unhealthy crowns were mostly located in the Interior West. Ecoregion sections having the highest percent basal area associated with unhealthy crowns (> 10 percent) were M331A—Yellowstone Highlands and M331J—Wind River Mountain in northwest Wyoming, and 341F—Southeastern Great Basin in southeast Nevada and southwest Utah. In these regions, the sparseness of the tree crowns may partially be a natural water-conserving adaptation to arid conditions. The crown condition may also be related to droughts and insect outbreaks that have been affecting those regions (National Drought Mitigation Center 2004; U.S. Department of Agriculture Forest Service 2003a, 2003b). In the Eastern United States, the only ecoregion section having > 10 percent basal area associated with poor crowns was M231A—Ouachita Mountains in western Arkansas. Most of the Eastern United States had < 2.5 percent average basal area associated with poor crowns.

The percentage of basal area on each plot associated with trees with unhealthy crowns is shown in figure 13. Most plots had only a very low percentage of basal area associated with trees having unhealthy crowns. However,

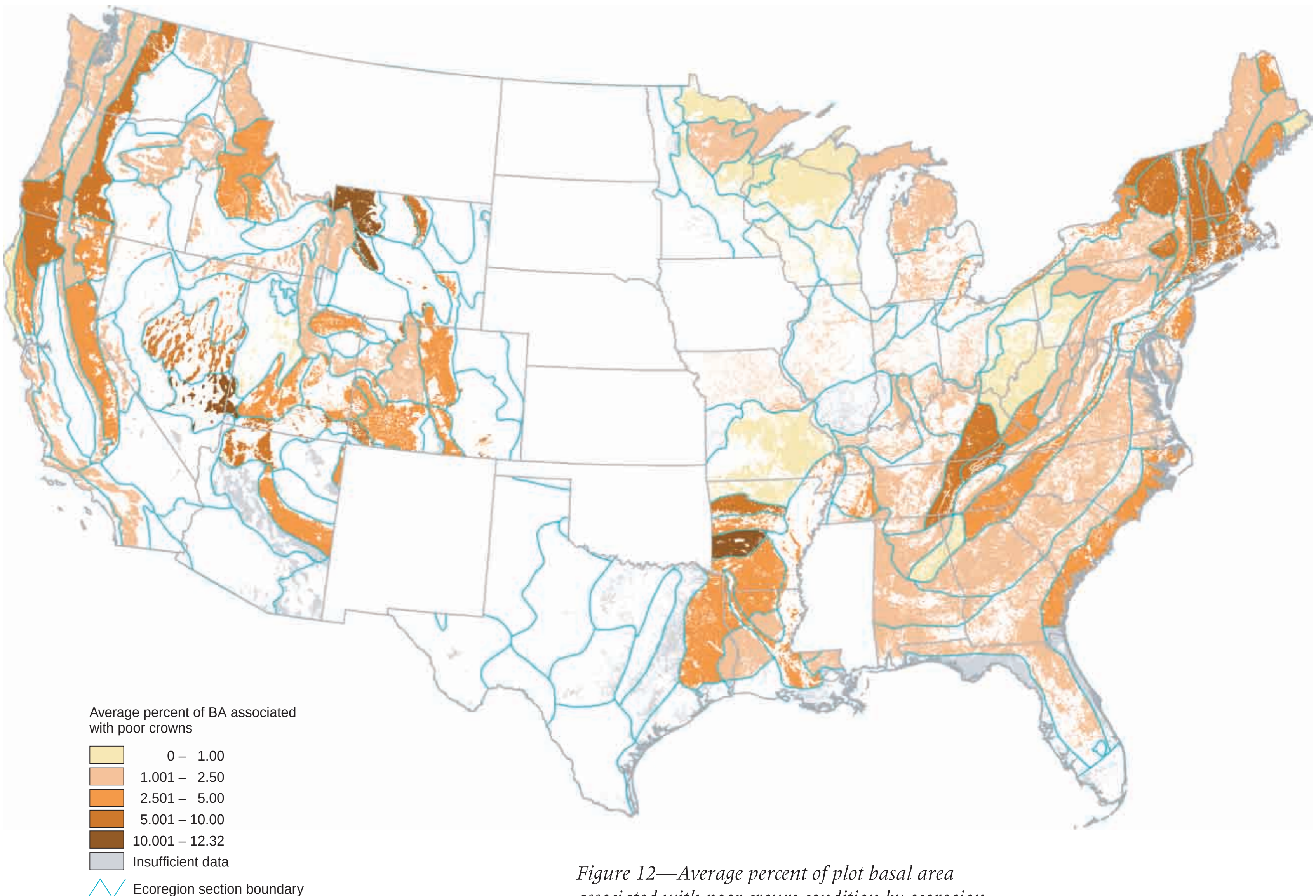


Figure 12—Average percent of plot basal area associated with poor crown condition by ecoregion section. Data came from plots sampled from 1999 through 2002. A tree was considered to have poor crown condition if its adjusted ZB-index was ≥ 0.25 or it was a softwood with 10 percent or greater dieback.

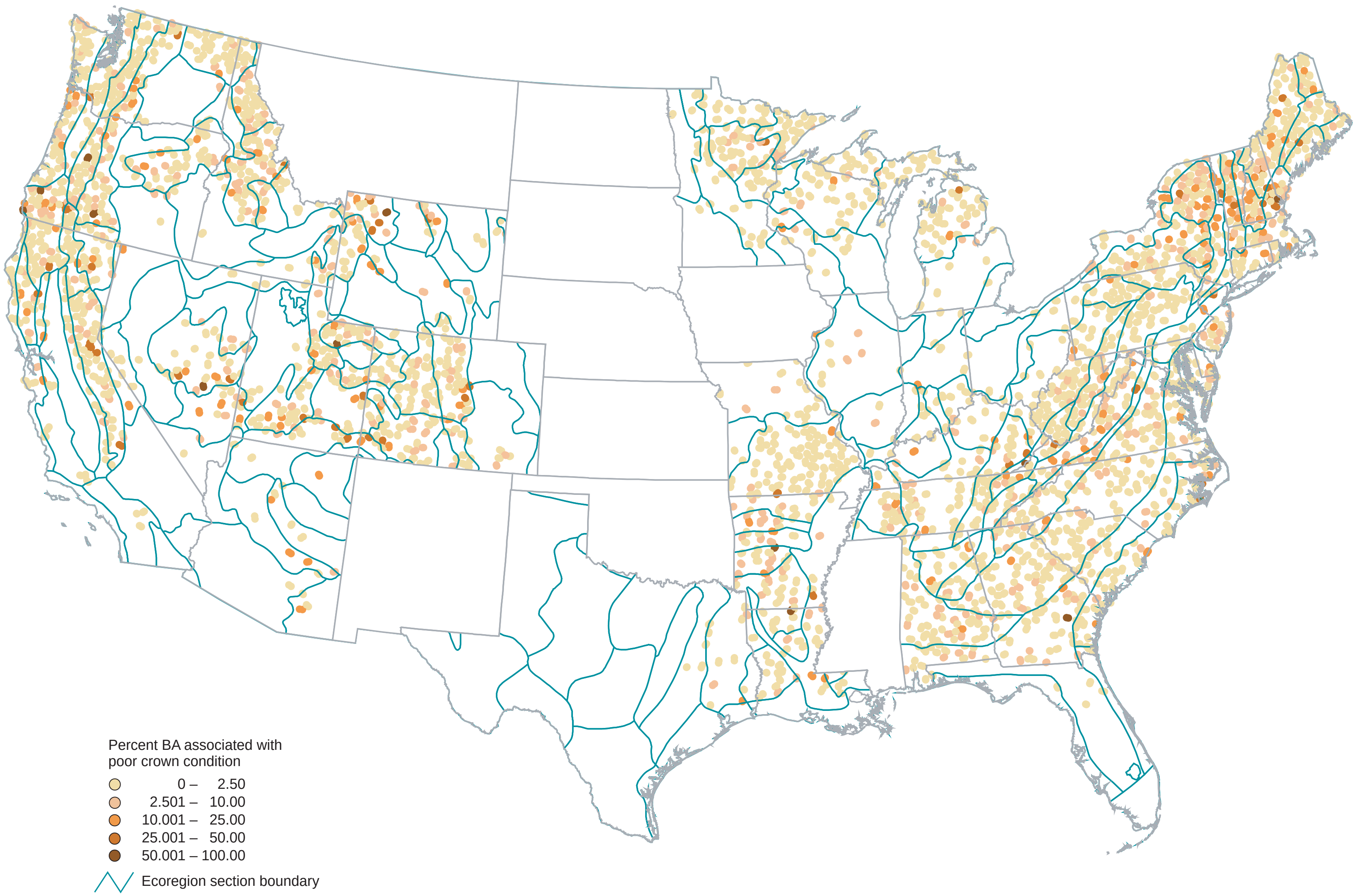


Figure 13—Percent of plot basal area associated with poor crown condition. Data came from plots sampled from 1999 through 2002. A tree was considered to have poor crown condition if its adjusted ZB-index was ≥ 0.25 or it was a softwood with 10 percent or greater dieback. Plot locations are approximate.

individual plots and clusters of plots (e.g., parts of the Northeast) across the country had a high percent basal area associated with trees with unhealthy crowns. The plot-to-plot variation was high in all ecoregion sections of the country (coefficients of variation ranged from 88.3 to 635.0). Generally, we did not find ecoregion sections where the majority of plots have a moderate-to-high percentage of basal area associated with poor crowns. Rather, in most ecoregion sections where, on average, a relatively high percent of basal area was associated with poor crowns, we found that the majority of plots had a low percent basal area associated with poor crowns. A small number of plots in those ecoregions had a very high percent basal area associated with poor crowns. This pattern suggests that the observed poor crown scores are probably more strongly associated with stand-level stressors than with more large-scale stressors.

Introduction and Methods

FHM estimates annual mortality, in terms of wood volume per acre, based on trees and saplings that have died since plot establishment. To compare mortality rates across forest types and climate zones, the ratio of annual mortality volume to annual gross growth volume (MRATIO) is used as a national mortality indicator (Stolte and others, in press; Coulston and others 2005d). An MRATIO value > 1 indicates that mortality exceeds growth and live standing volume is actually decreasing. MRATIOs were calculated for each ecoregion section from independently derived gross growth and mortality rates. The method for estimating the MRATIO is described in Stolte and others (in press), and Coulston and others (2005d).

The following tabulation shows the years of FHM and FIA phase 3 plot data that were used for this analysis. Data from 1990 to 1999 were collected using the FHM four-panel sampling design with overlap, in which one panel, i.e., one-fourth of the plots, was measured each year and one-third of the panel measured the previous year (overlap) was remeasured (Smith and Conkling 2005). Data from 2000 to 2002 were collected using the FIA five-panel sampling design with no annual overlap (Bechtold and Patterson 2005).

Years	States
1990–2002	CT, MA, NH, RI, VT
1990–2001	ME
1991–2002	DE, MD, NJ
1991–2001	AL, GA, VA
1992–2002	CO
1992–1999	CA
1994–2000	MI, MN, WI
1995–2002	WV
1995,1998–2001	PA
1996–2000	IN
1996–2002	ID
1997–2000	IL
1997–2002	OR, WA, WY
1998–2001	NC, SC
1999–2000	MO[7]
1999–2002	NV, NY, UT
1999–2001	TN[7]

MRATIOs were estimated using data from all States in which there were repeated measurements. MRATIO values are reported for all ecoregion sections that are, at least partially, in States where at least three panels had been remeasured and the data were available. The year of the most current data available varied by FIA region. Data from California from 2000 to 2002 were available, but were not used in this analysis because the phase 3 plots in California were not colocated with the FHM plots.

[7] Results not reported for ecoregion sections located entirely within these States, where remeasurement data were available from less than one-half of the panels.

MRATIO values can be large if an overmature forest is senescing and losing a cohort of older trees. If forests are not naturally senescing, a high MRATIO (> 0.6) may indicate high mortality due to some acute cause (insects or pathogens) or generally deteriorating forest health conditions (Coulston and others 2005c). An additional mortality indicator, the DDLD ratio—the ratio of the average dead tree diameter to the average live tree diameter—was calculated for each plot where mortality occurred. Low DDLD ratios (much < 1) usually indicate competition-induced mortality typical of young, vigorous stands, while high ratios (much > 1) indicate mortality associated with senescence or some external factors such as insects or disease (Smith and Conkling 2005). When an ecoregion section has a high MRATIO, it is useful also to look at the DDLD ratio for additional information about the size of the trees that died. High DDLD values in regions with very low MRATIOs can be difficult to interpret. This combination of mortality indicators may indicate small areas experiencing high mortality of large trees or locations where the death of a single large tree (such as a remnant pine in a young hardwood stand) produced a deceptively high DDLD.

Results and Discussion

Figure 14 shows MRATIOs by ecoregion section and plot-level DDLD ratios. The MRATIO values shown represent the annual mortality over varying time periods from the earliest plot establishment in each section through the year of the most recent available data for each section (see tabulation earlier in this section). The DDLD ratios are based on the accumulated mortality through the most recent measurement of each plot.

Throughout most of the country, MRATIO estimates have changed only slightly from the values reported in the "Forest Health Monitoring 2003 National Technical Report" (Coulston and others 2005b). This is to be expected because, absent catastrophic events, mortality rates change rather slowly.

The highest MRATIO value in the country (3.689) occurred in ecoregion Section 331A—Palouse Prairie in Idaho and western Washington. Most of the observed mortality there occurred on a plot that burned in the Burgdorf Junction Fire of 2000.[8] However, this section had relatively few plots (five). Therefore,

[8] Personal communication. 2004. Paul Rogers, Technical Writer/Editor, METI, Inc., 860 North 1200 East, Logan, UT 84321 (formerly of the USDA Forest Service Interior West FIA, Rocky Mountain Research Station).

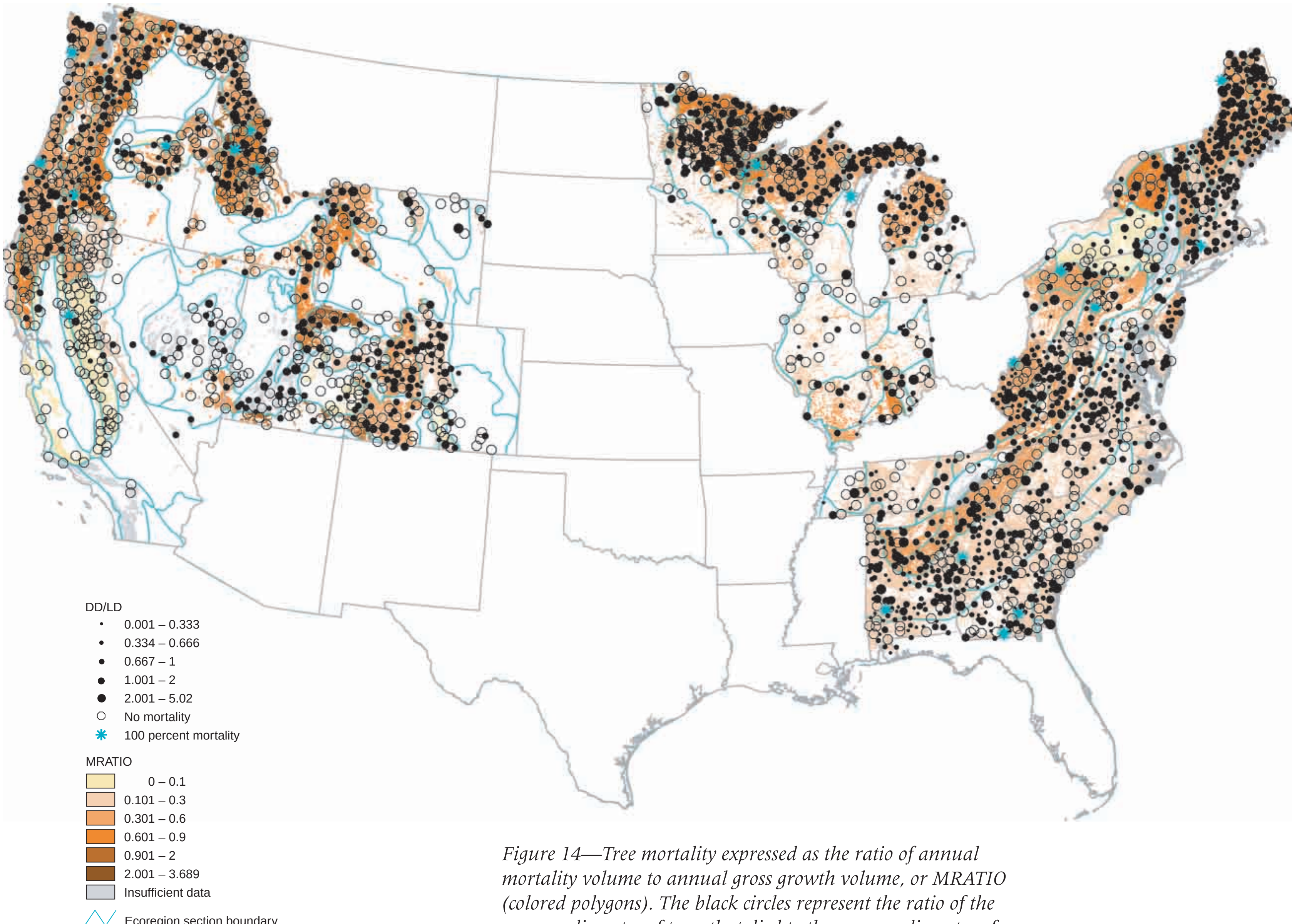


Figure 14—Tree mortality expressed as the ratio of annual mortality volume to annual gross growth volume, or MRATIO (colored polygons). The black circles represent the ratio of the average diameter of trees that died to the average diameter of surviving trees as of the most recent measurement of each plot, or DDLD. Plot locations are approximate.

a stochastic event such as a fire as mentioned above, affecting a single plot, may dramatically affect the mortality estimate for the ecoregion.

MRATIO values were also very high (0.901 to 2.00) in ecoregion Section 313A—Grand Canyon in southern Utah and Colorado, and in Section M331E—Uinta Mountains in northeast Utah and northwest Colorado. This mortality, as well as the moderately high mortality observed in much of the rest of the Interior West, may be related to drought conditions and insect outbreaks that have been affecting much of the region.

In the Eastern United States, the highest MRATIO value (2.582) occurred in Minnesota's ecoregion Sections 251A—Red River Valley and 251B—North-Central Glaciated Plains. These ecoregions are mostly grassland, and there were very few forested plots in the sample, so it is hard to tell if the high MRATIO value is significant.

MRATIO values were also high in Sections 212K—Western Superior (MRATIO = 0.677), 212L—Northern Superior Uplands (MRATIO = 0.700), and 212M—Northern Minnesota and Ontario (MRATIO = 0.646) in Minnesota and Wisconsin. In these areas, the mortality may be due to a number of causes. Extremely high mortality occurred in the Boundary Waters area due to a blowdown caused by straight-line winds in 1999 (Miles and others 2003). Several insects have been very active in Minnesota since 1996, including spruce budworm, forest tent caterpillar, large aspen tortrix, jack pine budworm, and larch casebearer. These insects have defoliated large areas of forest in northern Minnesota (fig. 10B), and this defoliation has sometimes led to mortality (Miles and others 2003). A portion of the observed mortality has occurred in relatively old (45- to 85-year-old) aspen and paper birch stands, so the mortality may be related to the senescence of older forests.

Another area having a high MRATIO (0.687) was ecoregion Section M212D—Adirondack Highlands. This is an area for which only three panels of data were available. Because this result is based on a limited amount of data spanning a relatively short time interval (1999 to 2002), there is relatively high uncertainty associated with the mortality and growth rate estimates (Coulston and others 2005b). Thus, the standard error on the MRATIO is high relative to the MRATIO itself (standard error = 0.521). As more data are collected, analyses using larger datasets should give a better indication of whether a forest health problem exists in this area.

Appendix table B.1 provides a summary of mortality statistics by ecoregion section. The reader should consult this table before drawing any conclusions from the map alone, especially where the period of estimation is short, the sample size is small, and where forest growth rates are low. The standard errors shown in appendix table B.1 are high in many cases. Wherever estimates are made over relatively short time periods, the standard error associated with both the growth rate estimate and the mortality rate estimate will be high, so the standard error of the MRATIO will be high. For information on calculation of the standard error, see Coulston and others (2005d).

Better estimates of MRATIO values will be possible in future years as more years of data are accumulated. Also, once FIA phase 2 plots are remeasured, data from that more intensive sample can be incorporated into this analysis.

Temporal Perspectives on Drought Occurrence

Background

Drought is a naturally occurring disturbance to forest communities. In the Eastern United States, droughts occur on an irregular basis while in other areas, e.g., western interior dry forests, droughts occur annually (Dale and others 2001). Because some drought data representing hundreds of years are available (e.g., Cook and others 1999, National Data Climate Center 1994), it is possible to examine long time series, i.e., hundreds of years, as well as assess current status.

Drought has also been linked to several natural phenomena, some of which are cyclic, e.g., the 18.6 lunar nodal tidal cycle (Cook and others 1997) and the 22-year Hale cycle (solar magnetic cycle) (Cook and others 1997). This linkage to cyclic natural phenomena has bearing on assessments that attempt to identify whether disturbances are "out of the range of historic variation." The results from Cook and others (1997) suggest that assessing drought occurrence with a relatively short time series of data could provide misleading results. For example, if one only looked at 18 years of drought occurrence data, it is likely that there would be one year where drought occurrence appeared heightened. However, upon examining a longer time series, the analyst would realize that apparent heightened drought occurrence was actually part of the long-term drought cycle.

Identifying Periodicity—Cook and others (1999) reconstructed historical drought occurrence from 1700 through 1978 for each of 154 points that systematically covered the coterminous United States. We used these data to calculate the proportion of the Eastern and Western United States under drought conditions for each year based on a 5-year moving average. Brocklebank and Dickey (1986) outlined a relatively simple procedure for identifying and testing for cyclic behavior. Using the data from Cook and others (1999), we performed a spectral analysis to identify whether there was some underlying frequency (ω) in the areal extent of drought occurrence for the East and West. Based on the frequencies identified in the spectral analysis, we then tested the null hypothesis that there was no component of ω in the time series using linear regression.

The Western United States generally has a greater portion of its land area under drought conditions in any given year as compared to the Eastern United States (fig. 15). However, both the Eastern and the Western United States seem to follow the same trends in the areal extent of drought (fig. 16). The spectral analysis revealed two potential frequencies related to the

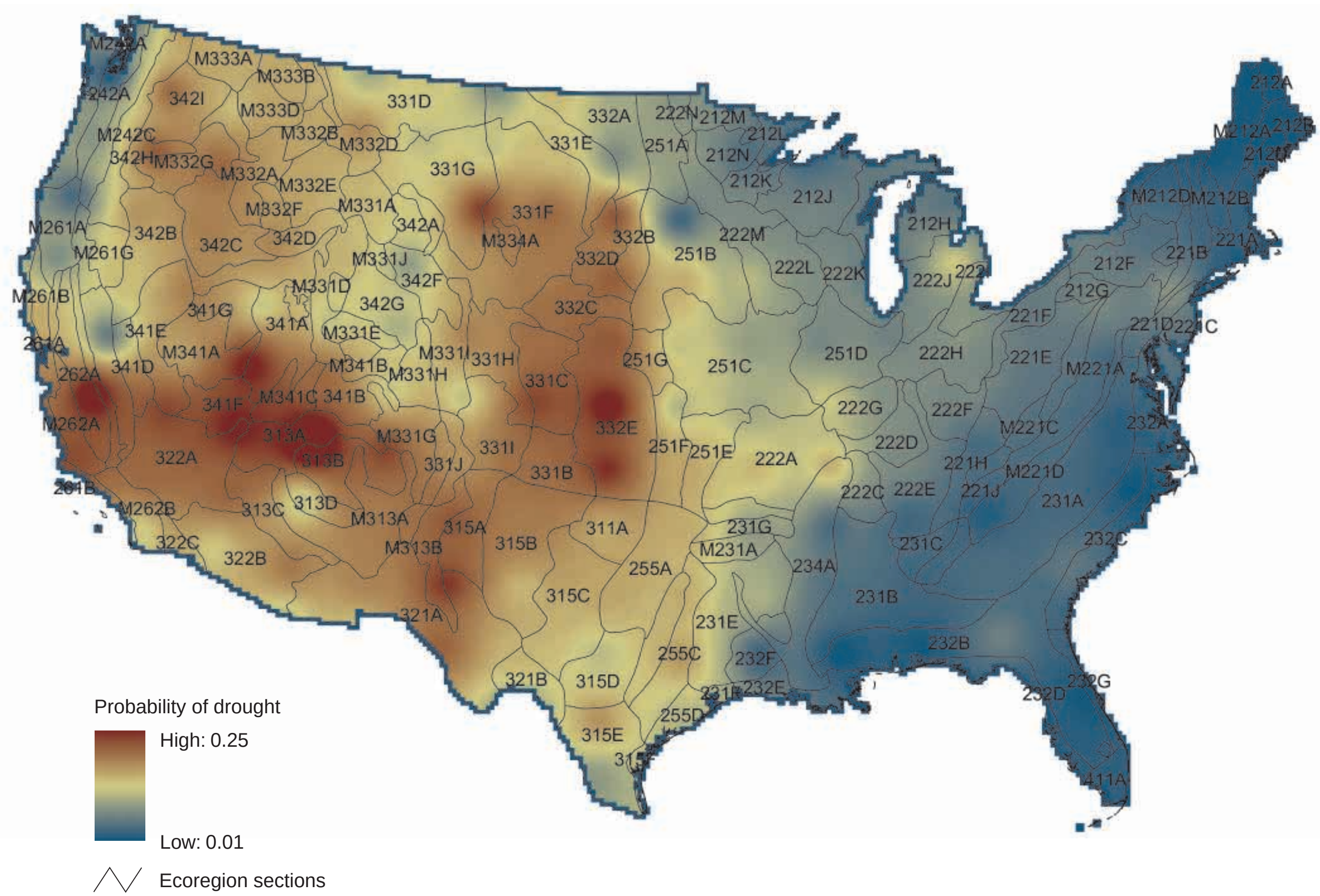


Figure 15—The probability of moderate, severe, or extreme drought occurrence in the United States (1700 through 1978) estimated by inverse distance interpolation using Cook and others (1999) data.

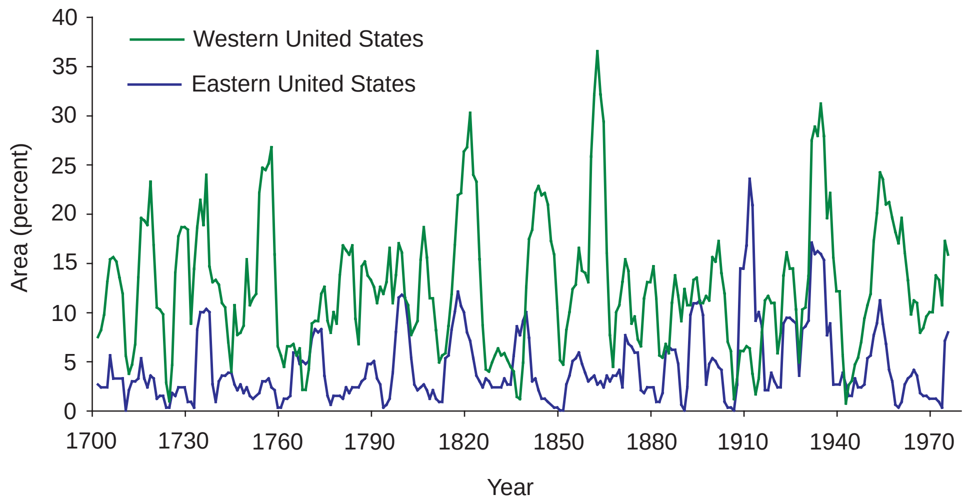


Figure 16—The proportion of the Eastern and Western United States under drought conditions from 1700 through 1978 based on a 5-year moving average.

fluctuation in the areal extent of drought. They were approximately 19 and 22 years. Because these potential frequencies were close to the lunar nodal tidal cycle (18.6 years) and the Hale cycle (22 years), we tested for the statistical significance of these cycles using PROC REG (SAS 1999). For both the Eastern and Western United States, the following model was used to test the statistical significance of an 18.6-year and 22-year frequency in the areal extent of drought occurrence:

$$D_t = \mu + a_1 \sin(\omega_1) + b_1 \cos(\omega_1) + a_2 \sin(\omega_2) + b_2 \cos(\omega_2) + e_t$$

where

D_t = the proportion of land area under drought conditions at time t
t = time step from 1 to 279
μ = mean of the time series
$\omega_1 = 2\pi\, t / 22$ (frequency of 2π radians per 22 years)
$\omega_2 = 2\pi\, t / 18.6$ (frequency of 2π radians per 18.6 years)
e_t = error term

The parameters for each frequency (ω_1 and ω_2) were significant ($p < 0.01$) based on an F-test, therefore, rejecting the null hypothesis (no component at frequency ω_1 and ω_2). The significance of ω_1 and ω_2 for the Western United States corresponded with Cook and others' (1997) results. The regression approach for identifying periodicity in a time series is relatively simple. Identifying periodicity can aid analysts when trying to identify whether or not events are out of the range of normal variation. Also, if there is a known temporal cycle, then analysts can control for the cycle in subsequent analyses.

Drought Occurrence (1994 through 2003)— Because ecosystems are generally adapted to the moisture regimes in which they exist, we also examined the deviation from expected drought occurrence to assess whether each ecoregion section was experiencing more or less than expected drought. We considered drought to occur when the Palmer Drought Severity Index ≤ -2. Deviation from historic drought occurrence (drought deviation) represents the difference between drought occurrence in the current decade and historic averages. Frequency of drought from 1895 through 2003 served as an historical account or reference point for each ecoregion section. For example, if 384 months of drought were recorded in an ecoregion section from 1895 through 2003, then approximately 35 months of drought would be expected on a 120-month (10-year) basis. The historical account was then compared to the current decade. If the expected number of months with drought conditions was 35, and 48 months of drought were recorded in the current decade, then the drought deviation was 48 – 35 = 13.

In the decade considered in this report (1994 through 2003), some ecoregion sections experienced more frequent droughts than expected based on historical averages, while others experienced less (fig. 17A). Only a few ecoregion sections in the Eastern United States had a drought deviation of > 12 months (12 months of drought over a 10-year period in addition to that expected based on the historical average). These sections were the M221D—Blue Ridge Mountains, and 232G—Florida Coastal Lowlands (Eastern), primarily along the eastern coast of Florida. Many areas in the Northeast, Southeast, and Northcentral United States either experienced close to the expected amount of drought or less than expected (fig. 17A). The decade considered here has been drier than expected for much of the Western United States. Several ecoregion sections had a drought deviation of 12 months or more (fig. 17A). However, forested areas in the Southwestern United States were the most droughty. Section 322B—Sonoran Desert in southern Arizona experienced an additional 42 months of drought and Section 313C—Tonto Transition in Arizona experienced an additional 37 months of drought over what was expected, however there is little forested area in these ecoregion sections.

Drought Occurrence in 2003—Drought occurrence can also have more immediate influences on ecosystems. For example, moderate drought stress can slow plant growth (Kareiva and others 1993). Drought can interact with other site characteristics, sometimes exacerbating other forest ecosystem stresses such as insects (Mattson and Haack 1987). Conversely, foliar injury to ozone sensitive plants generally does not occur during droughts because plants close their stomates in an effort to reduce water loss, and gas exchange does not occur when the stomates are closed.

The year 2003 was a dry year, particularly in the Western United States (fig. 17B). Eighteen ecoregion sections in the West experienced 12 months of drought. These sections included 313C—Tonto Transition in Arizona, M331H—North-Central Highlands and Rocky Mountain in Colorado and extending a small amount into southern Wyoming, and M332G—Blue Mountains in Oregon and the tip of southeast Washington. A majority of the forested ecoregion sections in the West experienced more than 6 months of drought in 2003. This was in sharp contrast to the Eastern United States where 54 ecoregion sections did not experience any drought.

Summary

Climatic events can influence many ecosystem attributes. Moisture, or lack of moisture, may influence species composition over the long term (Akin 1991) and other characteristics, such as insect outbreaks, over shorter time periods. Because drought is a naturally occurring event, many assessments attempt to describe whether drought occurrence is beyond the range of natural variation. These types of assessments can benefit from a multitemporal perspective on drought occurrence.

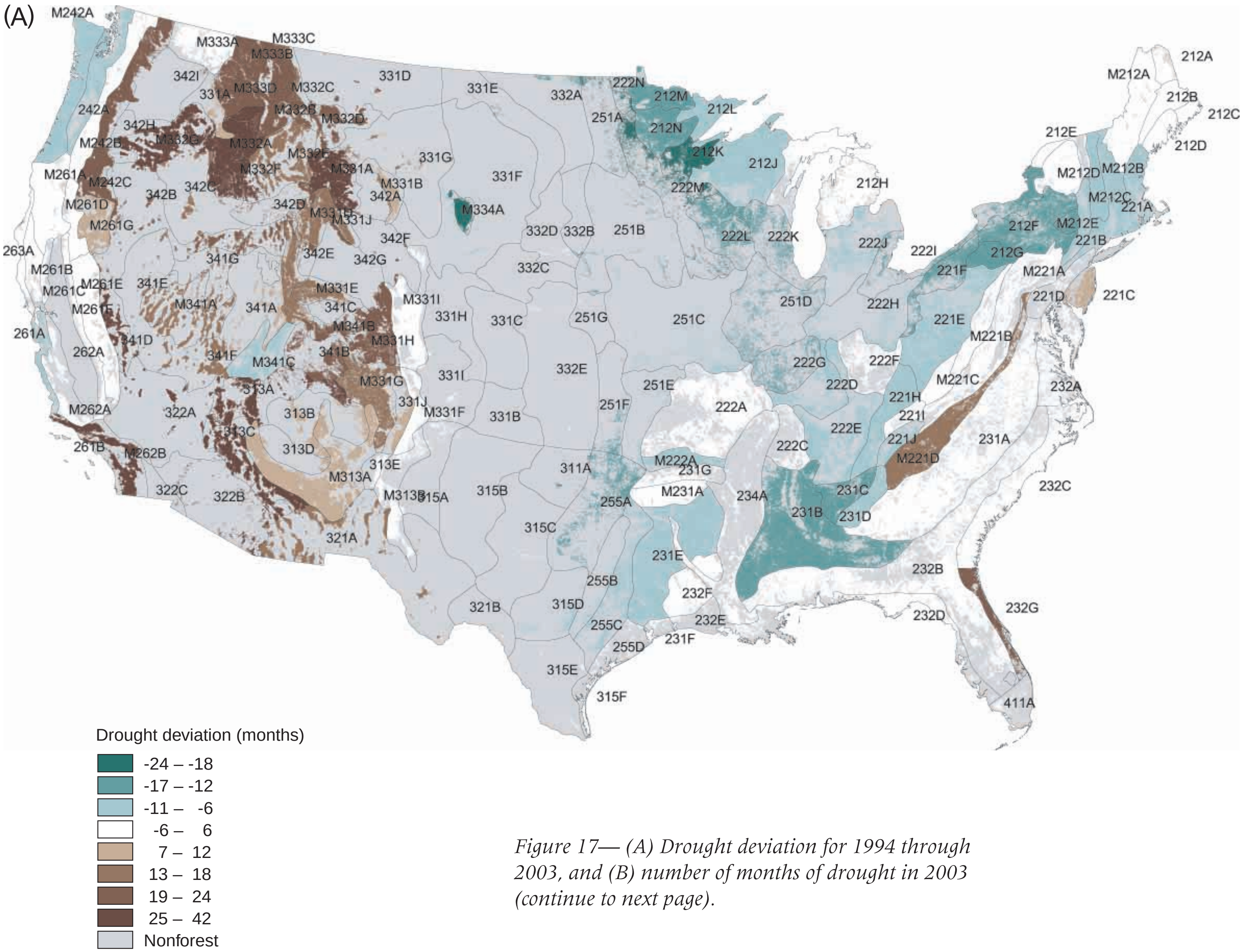
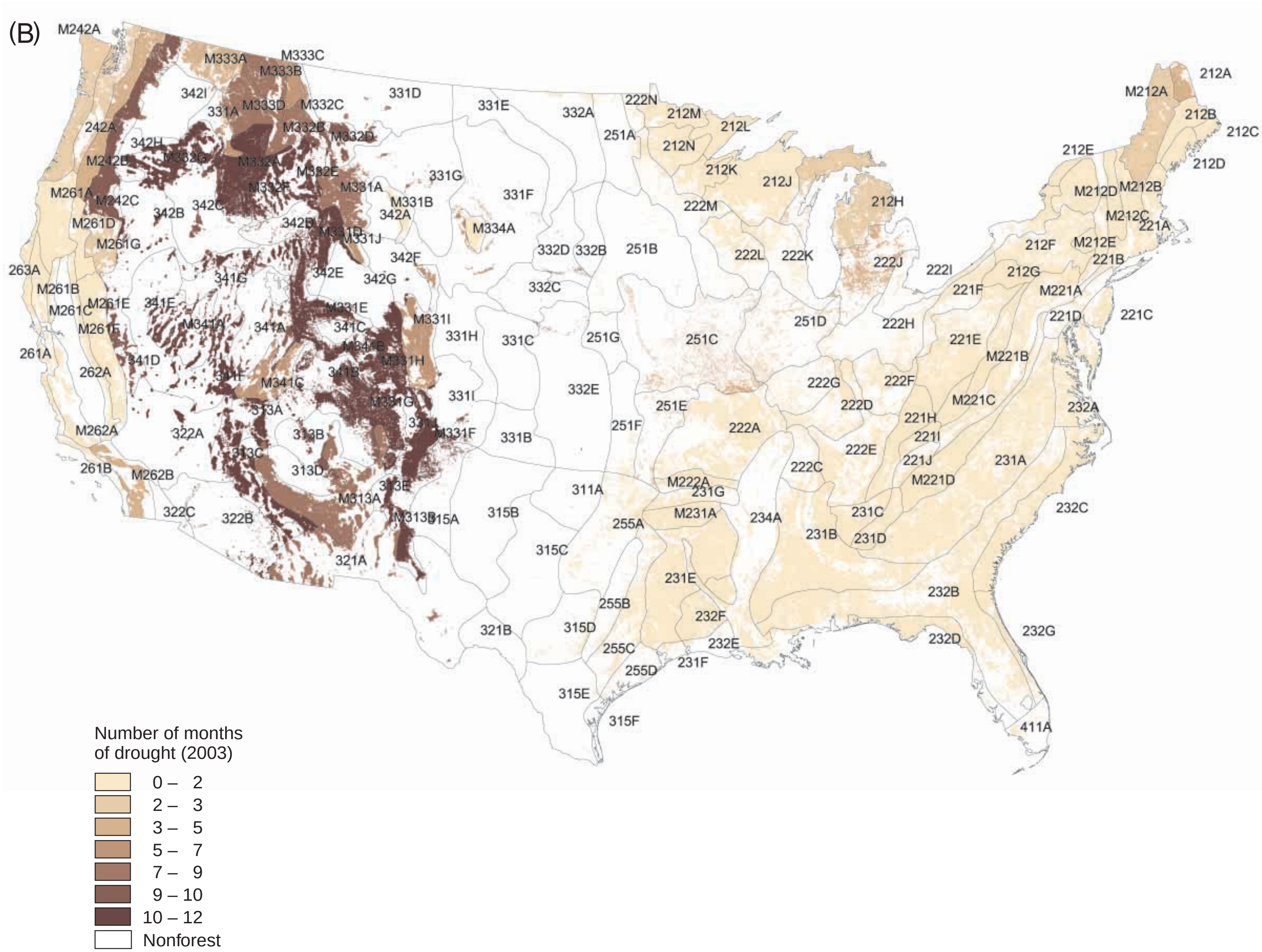


Figure 17— (A) Drought deviation for 1994 through 2003, and (B) number of months of drought in 2003 (continue to next page).


(B)
M242A
M333A
M333C
M333B
342I
331A
M333D
M332C
331D
331E
332A
222N
212M
212L
212A
M212A
212B
212C
242A
342H
M332B
M332D
251A
212N
212E
212D
M242B
M332G
M332A
M332E
212K
212J
331G
M261A
M242C
M332F
M331A
331F
M331B
342C
222M
212H
M212D
M212B
M261D
342B
342D
342A
M334A
M212C
221A
M331D
M331J
M261G
212F
M212E
332D
332B
251B
222L
222K
222J
222I
342F
221B
212G
263A
342E
342G
332C
221F
M221A
341G
M261B
M331E
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332E
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M221C
313A
251E
232A
221H
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322A
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251F
222A
221I
222E
313C
221J
231A
261B
M262B
313D
222C
313E
M222A
231G
M221D
311A
M313A
322C
322B
M313B
315A
315B
M231A
231C
232C
255A
234A
231B
231D
315C
321A
231E
255B
232B
232F
321B
315D
232G
232D
255C
232E
255D
231F
315E
315F
411A
Number of months of drought (2003)
0 – 2
2 – 3
3 – 5
5 – 7
7 – 9
9 – 10
10 – 12
Nonforest

Nationally Consistent Spatial Data on Daily Fire Occurrence

Background

Fire is a powerful, selective regulatory mechanism in forest ecosystems. It is a natural part of the environment, and fire-affected ecosystems depend on a particular frequency and intensity of fire. These ecosystems will remain in their natural state only if the fire regime to which they are adapted is present (Kimmins 1987). The frequency and intensity of burning depend on the buildup of fuels, weather conditions, and the occurrence of ignition sources. In previous FHM national technical reports we were unable spatially to display and summarize fire occurrence on a yearly basis because data were not available. Here we describe and suggest analytical methods to summarize fire occurrence information based on data from the MODIS Active Fire Detections for the United States database (Remote Sensing Applications Center 2004).

Fuel Loading

This section examines fire occurrence. However, fuel loading is an important aspect of wildfire risk and overall forest health. Information about down woody material is collected on phase 3 plots and the information can be used to assess forest fire risks, estimate fuel loadings, create national fuel maps, and monitor the effects of fuel reduction projects. The analytical techniques to assess down woody material using phase 3 data are being developed. For more information on this topic, see Woodall (2003), Fiedler and others (2003), and Chojnaky and Schuler (2004).

MODIS is a sensor on two satellites. Each gathers information in 36 spectral bands ranging from 0.4 to 14.4µm, and together they provide complete coverage of the mid to higher latitudes four times per day (National Aeronautics and

Space Administration 2004). The Forest Service, NASA Goddard Space Flight Center, and the University of Maryland collaborate to produce daily active fire maps using MODIS imagery. These fire maps are created based on the MODIS thermal bands. For a description of the algorithm see Kaufman and Justice (1998).

The resolution of the fire maps is 1 km where the center of each pixel identified as having an active fire is recorded as a point. The compiled data are stored as a geographic information system point file and can be downloaded from the Forest Service, Remote Sensing Applications Center (Remote Sensing Applications Center 2004). These data only represent whether a fire was active, not the areal extent of the fire. The MODIS sensor can actually detect fires as small as 1 ha or 10 000 m^2 if the fires are burning at high temperatures. For these reasons, the MODIS fire data should only be used for large-scale, e.g., regional or national assessments.

Assessing Status

There are many ways to describe a fire season using these data. Here we discuss two methods. The first entails summarizing the data for each ecoregion section and spatially displaying the proportion of forested pixels that had an active fire. The second method entails counting the number of forested pixels that had an active fire for each day and examining the time series.

The portion of forested pixels in each ecoregion section with active fire was estimated using the MODIS data. Forest cover information was provided by the Zhu and Evans (1994) forest cover type map. Several ecoregion sections had a relatively large percentage of forest pixels that had active fires in 2003 (fig. 18). Section M262B—Southern California Mountains and Valleys had approximately 15 percent of the forested pixels with active fires. Similarly, 11.7 percent of the forested pixels in Section M333C—Northern Rockies in Montana had active fires in 2003. The scattered forest in Section 251F—Flint Hills in eastern Kansas and northern Oklahoma had active fires identified on 9.8 percent of its forest pixels by the MODIS imagery.

The peak of the 2003 fire season occurred in late October. Approximately 2,150 forested pixels were identified as having active fires

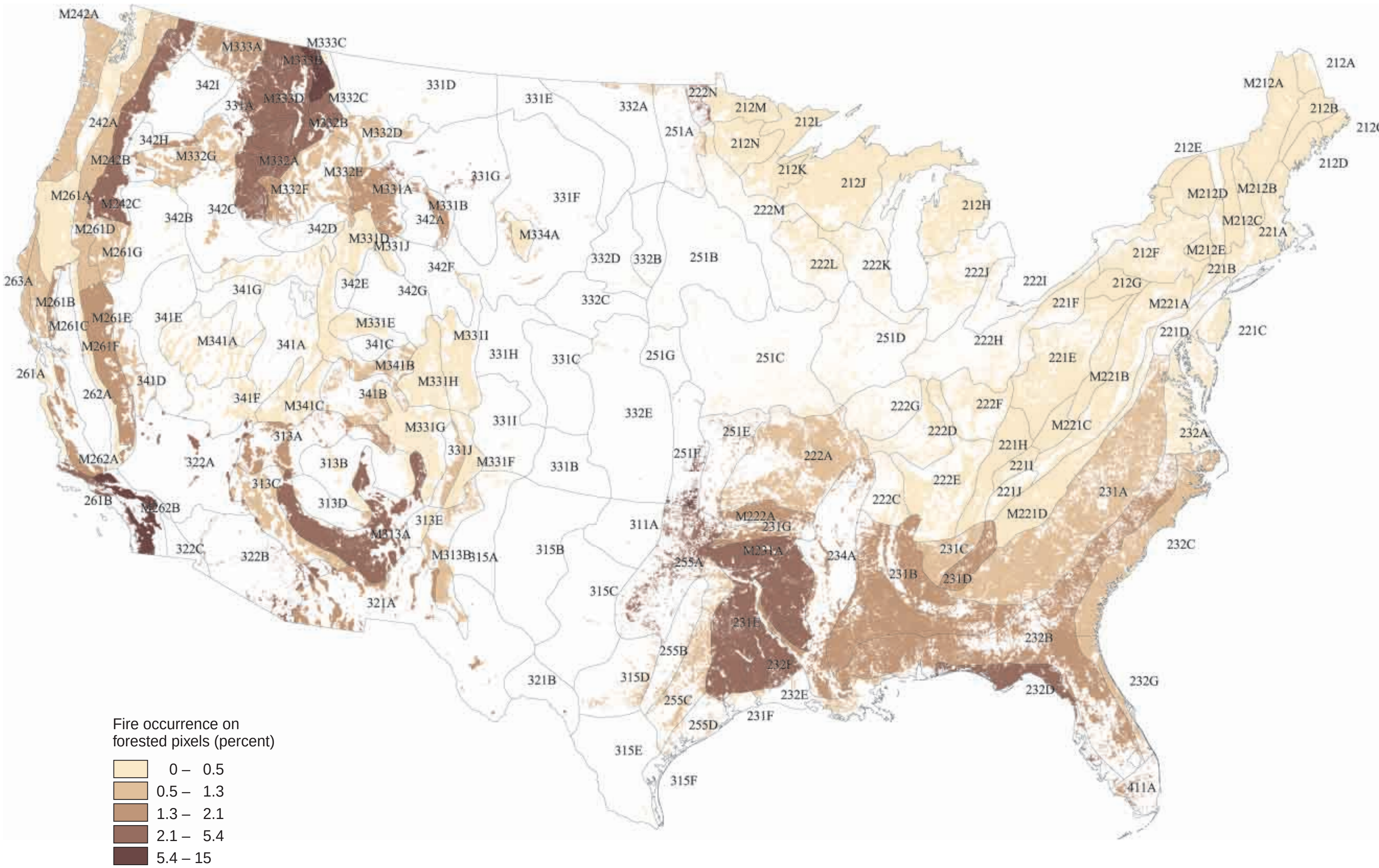

Figure 18—The percent of forested pixels with active fires by ecoregion section for 2003.

on Julian date 300 (fig. 19). These fires were located in several areas across the United States. However, a large portion of the detected fires were in Section M262B—Southern California Mountains and Valleys. The southern California fires of 2003 were located in several national forests including the Cleveland National Forest and the San Bernardino National Forest. There was also a relatively large number of forested pixels with active fires in late August (Julian date 233). According to the MODIS Active Fire Detections data, most of these fires were located in Sections M333D—Bitterroot Mountains, M332B—Bitterroot Valley, and M332A—Idaho Batholith.

Assessing Trends

The fire information derived from the MODIS sensor can also be used to assess trends in fire occurrence. Here we examine three approaches to describe trends, although there are several other techniques. One approach is to examine the cumulative fire occurrence over multiple years. Another approach is to examine the difference between the percent of forest pixels with fire occurrence for each ecoregion section for two different years. A third approach is to compare the cumulative distribution functions (CDF) of fire occurrence for multiple years. Here we explore all three options.

Examining the cumulative occurrence of fire over multiple years can be used to identify particular ecoregion sections that continuously experience relatively high rates of fire occurrence. We can calculate the relative fire occurrence (R_o) with the following formula:

$$R_o = N_e / rM_e$$

where

N_e = the number of forested pixels with fire occurrences in ecoregion section e for the time period
M_e = the total number of forested pixels in ecoregion section e for the time period
$r = N_t / M_t$ where N_t is the total number of forested pixels with fire occurrence and M_t is the total number of forested pixels for the time period. This value represents the expected rate of fire occurrence across ecoregion sections.

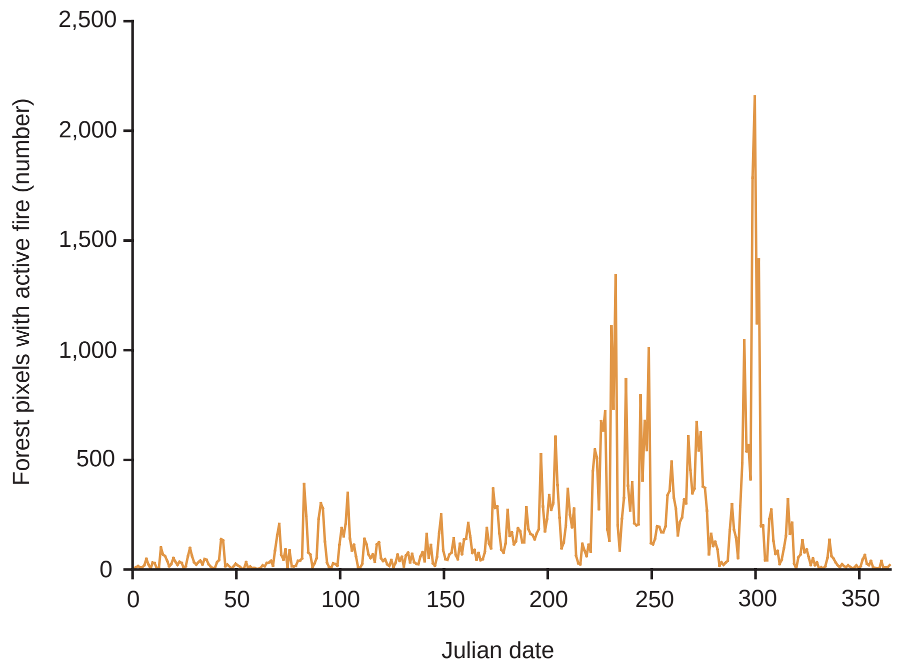

Figure 19—The number of forested pixels with active fires for each day during 2003.

An R_o value < 1 represents areas with less than expected rates of fire occurrence. Ecoregion sections with an R_o value > 1 have more than the expected rates of fire occurrence.

For 2002 and 2003 most of the Northeastern United States and the Great Lakes States had less than expected fire occurrence (fig. 20). There were several ecoregion sections in the South with more than expected fire occurrence. For example, Section 232F—Coastal Plains and Flatwoods, Western Gulf in Louisiana and extending into eastern Texas had an R_o of approximately 3.5 (three and one-half times the expected amount of fire occurrence), and Section 251F—Flint Hills in northern Oklahoma extending into Kansas had six times the expected amount of fire occurrence. There were more ecoregion sections in the Western United States than the Eastern United States with higher than expected rates of fire occurrence. Sections M262B—Southern California Mountains and Valleys in California and M333C—Northern Rockies in Montana had R_o values of approximately 11 and 7, respectively. Other forested areas, such as those

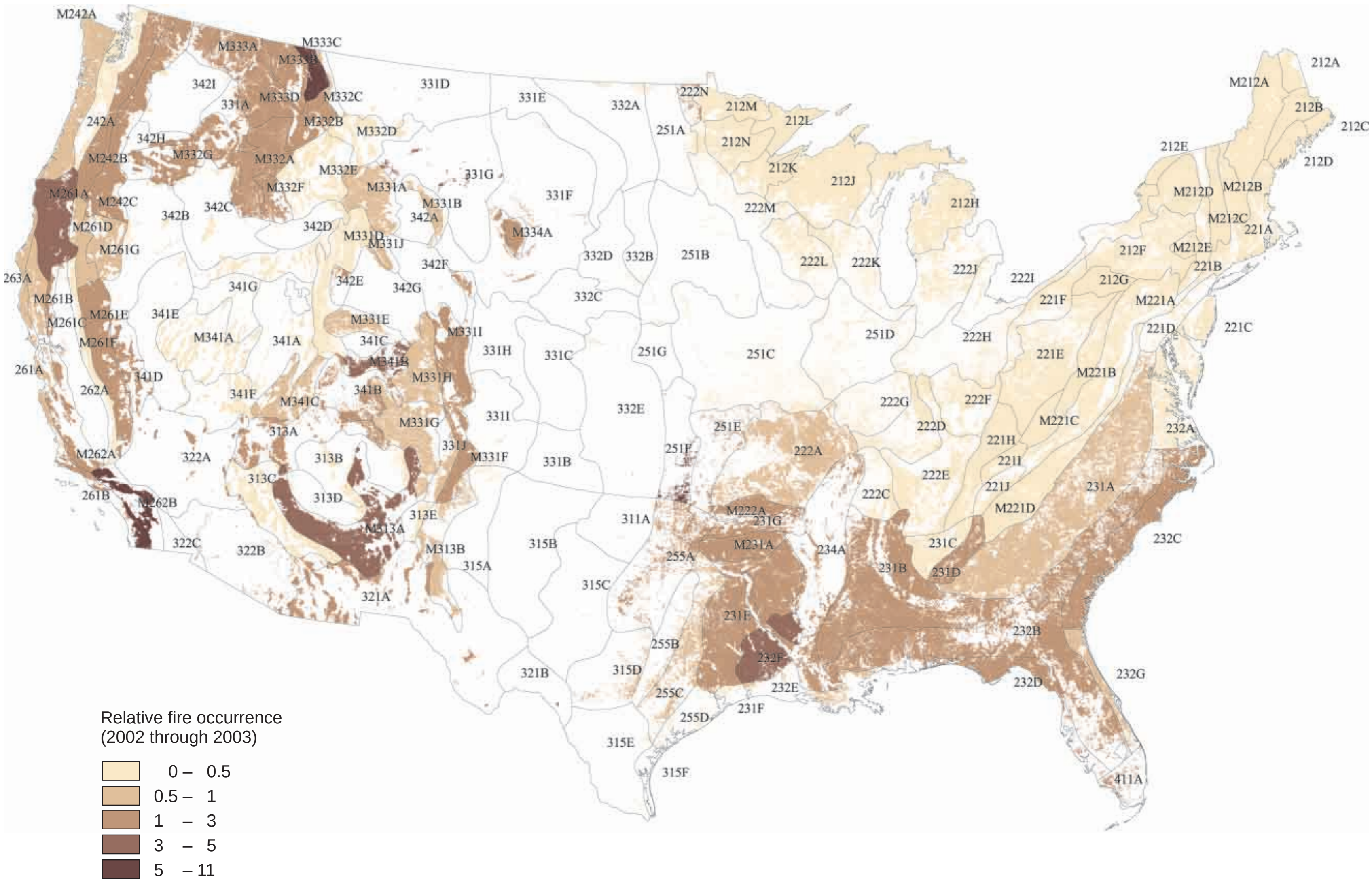

Figure 20—The relative occurrence (R_o) of fire for each ecoregion section (2002 through 2003).

in Sections M261A—Klamath Mountains in northern California and southern Oregon, M313A—White Mountain—San Francisco Peaks—Mogollon Rim in Arizona and New Mexico, and M341B—Tavaputs Plateau in western Colorado and eastern Utah had relative fire occurrence value approximately three times the expected value.

In some cases it may be of interest to examine whether fire occurrence has increased or decreased between years. Because the detection of a fire depends on several environmental conditions, e.g., cloud cover, and there is error associated with the detection of a fire, we use the following method. Calculate the percent of forested pixels with fire occurrence by ecoregion section for two dates, e.g., 2002 and 2003, and subtract the values for 2002 from the values for 2003. The result is a map of change. However, we want to guard against commission errors (identifying change where there is none). To identify which ecoregion sections had an increase or decrease, we examine the histogram of the change map, the mean change across ecoregion section, and the standard deviation. If the distribution is normal, then approximately two-thirds of the observations will be within 1 standard deviation of the mean, and 95 percent of the observations will be within 1.96 standard deviations of the mean. One option for identifying areas of concern is to select ecoregion sections that had a change value of ± 2 standard deviations from the mean. This choice is arbitrary but there are some practical concerns. The further the threshold value, e.g., mean ± 2 standard deviations, is away from the mean, the less likely one is to identify change where there is not change. However, at the same time, the likelihood of not identifying change where there is change (errors of omission) increases.

The mean change in percent forest pixels with fire occurrence across ecoregion section between 2002 and 2003 was 0.64 percent with a standard deviation of 1.9 percent (fig. 21). The thresholds for change were approximately -3.16 percent and 4.44 percent [0.64 ± (2) (1.9)]. Based on these thresholds five ecoregion sections had an increase in fire occurrence (change > 4.44 percent) between 2002 and 2003, and two ecoregion sections had a decrease (change < – 3.16 percent) (fig. 22). Sections M262B—Southern California Mountains and Valleys and

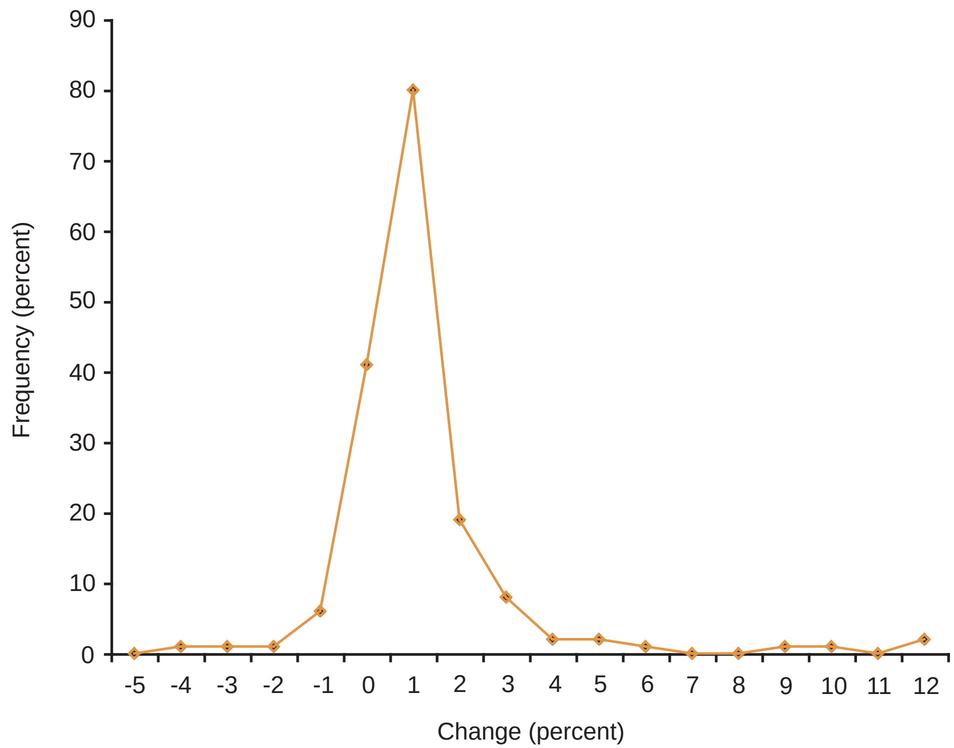

Figure 21—Change in percent forested pixels with active fire between 2002 and 2003.

M333C—Northern Rockies both had an increase over 11.6 percent. Section 251F—Flint Hills had an increase of 9.4 percent. Sections 322C—Colorado Desert in southern California and 321B—Stockton Plateau in south Texas also had increases; however, there is very little forest in these ecoregion sections based on Zhu and Evans' (1994) map. There was a 4.3 percent decrease in fire occurrence on forested pixels in Section M261A—Klamath Mountains and a 3.7 percent decrease in Section M341B—Tavaputs Plateau.

The duration and timing of the fire season can change between years. We examined the CDF of fire occurrence on forested pixels to test and describe the difference between the 2002 and 2003 fire seasons. To test if there was a statistical difference between 2002 CDF and the 2003 CDF we used the Kolomogorov-Smirnov test using PROC NPAR1WAY (SAS 1999). The null hypothesis for this test was that there was no difference between the CDF for 2002 and the CDF for 2003. The null hypothesis was rejected ($p < 0.0001$). Once the difference was established, we then qualitatively compared the 2002 and 2003 fire seasons. We considered the

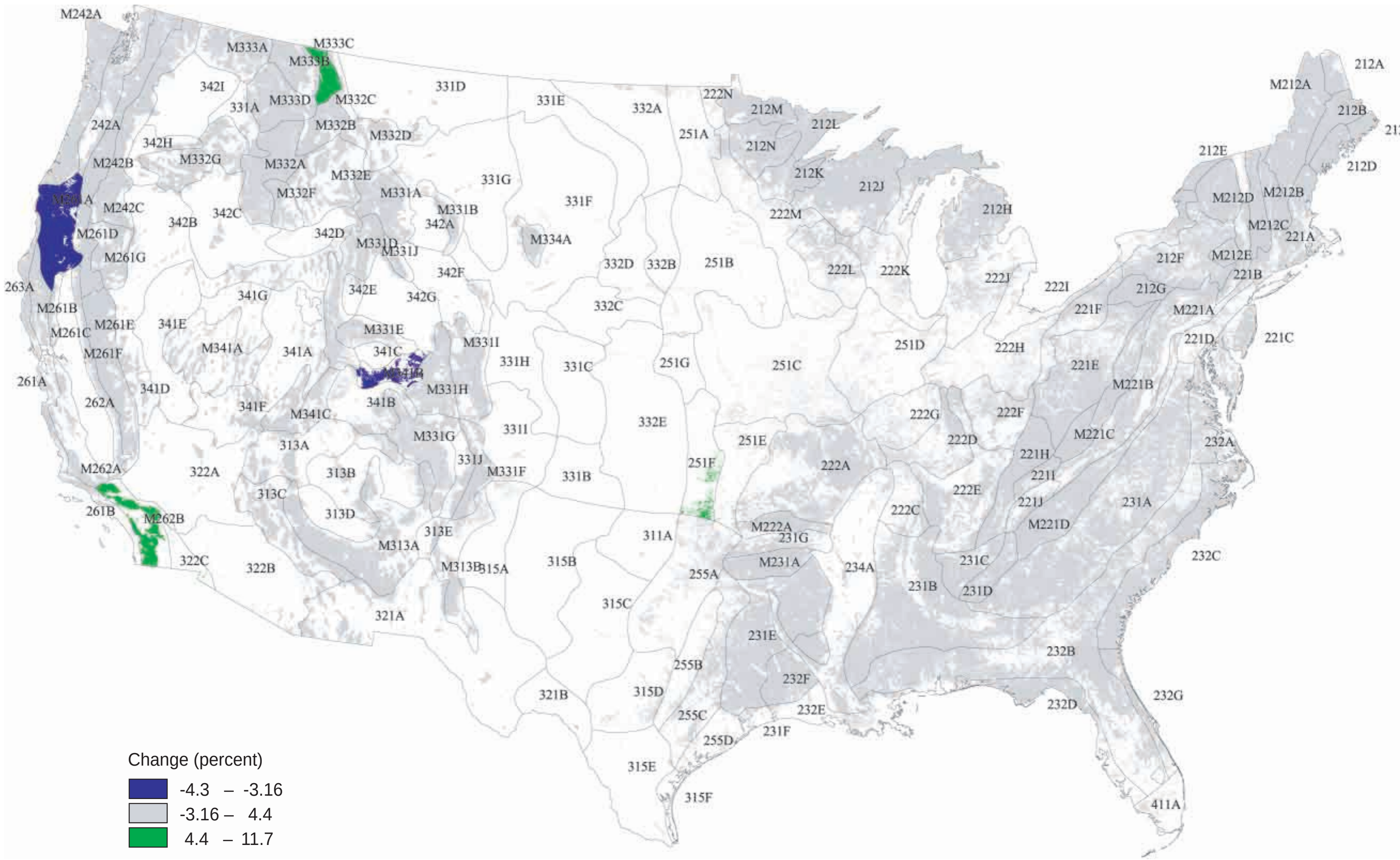

Figure 22—Ecoregion sections that had either an increase or decrease in fire occurrence between 2002 and 2003.

beginning of the 2002 fire season to occur at approximately Julian date 168 (fig. 23). We identified this by visually inspecting the CDF for a sharp increase in the slope. We identified the end of the 2002 fire season by visually identifying a sharp decrease in slope (the CDF approaching 1). This occurred at approximately Julian date 256. Based on this approach, the 2002 fire season ran from mid-June through mid-September. The 2002 fire season appeared to be shorter than the 2003 fire season. In 2003, the fire season began at approximately Julian date 173 (mid-to-late June) and ran through Julian date 304 (late October).

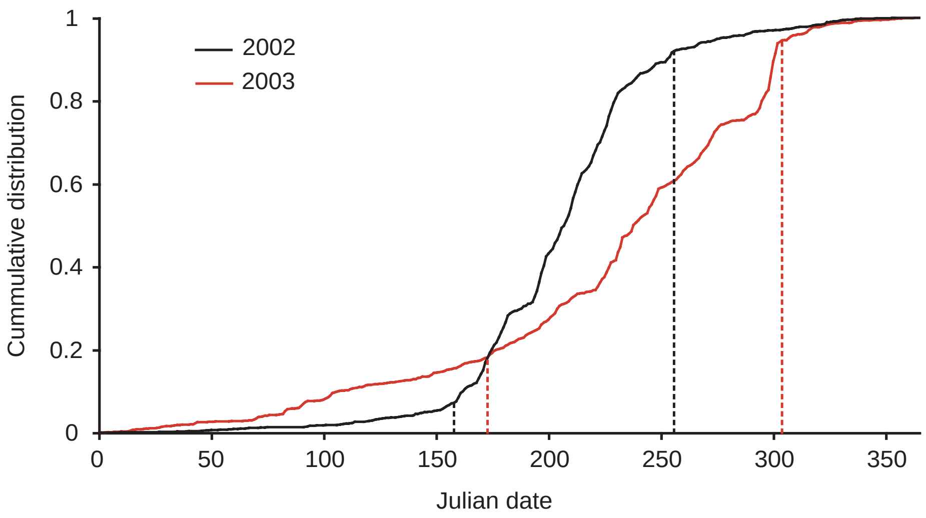

Figure 23—Cumulative distribution of fire occurrence for 2002 and 2003. The estimated beginning and end of each fire season is denoted by a dotted line.

Cautions

Fire occurrence data derived from the MODIS sensor can be used for large-scale assessments; however, the information may not be directly comparable to official wildland fire statistics compiled by the National Interagency Fire Center. The MODIS data identify whether a pixel had an active fire for every day. The areal extent of the active fire is not known; therefore, acreages cannot be reported. Detected fires occur on all land use and landcover types. Here we used forest cover data to identify which pixels with active fire occurred in forested areas. The fire occurrence data can be used to estimate proportions. In the analysis presented in this section, we estimate the percentage for forested pixels with active fire. This percentage should not be used as a surrogate for percent forest.

Summary

This FHM annual report focuses on indicators contributing information to "Criterion 1—Conservation of Biological Diversity" and "Criterion 3—Maintenance of Forest Ecosystem Health and Vitality" of the Criteria and Indicators for the Conservation and Sustainable Management of Temporal and Boreal Forests. Included were both ground plot (FHM and FIA phase 3) data and ancillary data such as fragmentation, climate, and fire data. National coverage helps provide an overview of conditions in the coterminous United States.

As stated in the Introduction, the main objectives of FHM are to determine on an annual basis the status of and changes in forest health indicators, and to present analysis techniques useful for analyzing large forest health data sets. In-depth interpretation and analysis of specific geographic or ecological regions are beyond the scope of the annual national report; however, data results are presented such that items of interest can be identified for further investigation at a regional level.

For example, in the fragmentation section, our conclusion was that all three types of fragmentation mapped (edge, perforation, and patch) were widespread, and that all ecological provinces contained significant clusters of each type. Although the most significant clusters of any particular type of fragmentation were usually concentrated in only a few provinces, the provinces varied based on the type of fragmentation. Regional application of the national data is an important use of the analysis results.

Continuing analysis of national monitoring data included several indicators. Landscape-level assessments of insects and diseases included relative exposure (observed vs. expected) to mortality- and defoliation-causing insects and diseases. Published results from FHM evaluation monitoring projects relating to insects and diseases were also incorporated into the discussion. Crown dieback and foliar transparency datasets, updated to include the available new data, were used to calculate a crown index, allowing readers to see the results of their region in the context of the coterminous United States. An additional year of data was also used where available for the tree mortality analyses, providing better estimates of mortality by ecoregion section. Drought occurrence for 2003 was presented using Palmer Drought Severity Index data. Drought deviation, over the 10-year period considered in this report compared to the historical average, provided another piece of information for use in interpreting analysis results.

This report contains several analysis techniques new to the FHM annual national report. Examples include useful considerations when examining long time series, such as the available drought data, and several analyses using newly available fire data. The presentation of these analyses focuses on the techniques as well as the data results. In future annual reports we will continue to focus on both.

Readers interested in specific forest health concerns in their region or State are encouraged to access reports listed in the Introduction. Additional information, including forest health highlights, is available online at the FHM (www.fhm.fs.fed.us) and Forest Service (www.fs.fed.us) Web sites.

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APPENDIX A
Supplemental Methods

Analysis of FHM and FIA ground plot data—Plot data were stratified using Bailey's ecoregion sections (Bailey 1995, McNab and Avers 1994, Miles and Goudy 1997) to conduct many of the analyses presented in this report. Generally, the minimum level of analysis was the mean plot value of each variable or metric by ecoregion section.[1] If an ecoregion section contained an insufficient number of plots for analysis, its plot data were combined with data from an adjacent section in the same ecoregion province. A minimum of five plots was required for analysis. In addition, for the analysis of mortality using generalized least squares models, data from adjacent ecoregion sections were sometimes combined to obtain sufficient data for PROC MIXED (SAS 1999) to converge on a solution.

The FHM Program strives to use the wealth of data collected by FIA. The FIA Program's phase 3 contains many of the forest health indicators that were previously measured as part of the FHM detection monitoring ground plot system. The FIA Program adopted the hexagonal grid used by FHM to establish a systematic grid of annual survey plots (phase 2), which are designed for measurement on a 5-year rotation—such that one-fifth of the plots are measured each year. The phase 3 plots are a subset of phase 2 plots (Bechtold and Patterson 2005).

There was not perfect continuity between the plot data collected from the FHM detection monitoring plots and the FIA phase 3 plots. Although in theory all FHM detection monitoring plots were to be maintained as FIA phase 3 plots, in some cases new phase 3 plots were established at locations different from the FHM plots. Data from the newly established plots cannot be used for analysis of mortality until they have been remeasured after 5 years. In particular, because the phase 3 plots in California were not colocated with the FHM plots, no data for 2000 or later from California were used in this analysis.

[1] Smith, W.D.; Gumpertz, M.L.; Catts, G.C. 1996. An analysis of the precision of change estimation of four alternative sampling designs for forest health monitoring. For. Health Monit. Tech. Rep. Ser. (10/96). 25 p. On file with: The Forest Health Monitoring Program National Office, 3041 Cornwallis Road, Research Triangle Park, NC 27709.

Also, data collected on phase 3 plots do not always document whether individual trees from FHM plots died or were logged. Because FIA treated all its phase 3 plots as new installations, even if the plots had been measured by FHM previously, there were no history codes to track mortality (if the tree was no longer standing), removals, or ingrowth. Determinations of whether a particular tree died or had been logged were made on the basis of other plot variables indicating logging on the site. Thus, there is some increased uncertainty associated with mortality estimates for periods ending in 2000 or later.

Because not all trees measured by FIA (2000 to 2002) corresponded with trees earlier recorded by FHM, the following assumptions were made with respect to those trees that did not match:

1. A tree appeared on the FHM plot tree list (1999 or earlier), but there was no record of it when the plot was measured by FIA (2000 to 2002)
   a) If a treatment code indicated that there had been any logging on or adjacent to the plot, the tree was assumed to have been cut
   b) Otherwise the tree was assumed to have died

2. A new tree occurred on the tree list for the phase 3 plot (2000 to 2002) that was not on the FHM plot
   a) If the tree d.b.h. was < 5 inches, the tree was assumed to be ingrowth on the microplot
   b) If the tree d.b.h. was ≥ 5 inches but relatively small, the tree was assumed to be ingrowth on the subplot. The method for determining if the tree was small enough to be considered ingrowth is as follows:
      i. Assuming that the tree was just below the 5-inch threshold for being recorded at the previous plot

measurement, the annual diameter growth increment between the last two plot visits was calculated

ii. In the Southeastern United States, if the calculated growth increment was 0.7 inches per year or less, the tree was considered to be ingrowth on the subplot

iii. Elsewhere, if the calculated growth increment was 0.5 inches per year or less, the tree was considered to be ingrowth on the subplot

c) Otherwise, the tree was considered to have been missed by FHM crews on previous visits to the plot and the tree was dropped from the analysis. However, in future analyses, the diameters of missed trees may be estimated for the years that they were missed.

On some plots, tree numbers in 2000, 2001, or 2002 did not match those used in earlier years. Where that occurred, an analysis of tree locations on the plot was performed to try to match trees. While we believe this procedure correctly accounts for most trees on those plots, some live trees may incorrectly have been assumed to have died. This introduces additional error into the mortality estimates.

APPENDIX B

Supplemental Data Table

Table B.1—Tree mortality summary statistics

Ecoregion section	Plots	Plots with mortality	Obs.[a]	Mortality	Growth	MRATIO	Standard error of MRATIO	DDLD ratio Mean	Minimum	Maximum	Standard error
				ft³ per acre per year							
212A	13	11	47	31.19	99.29	0.314	0.0856	1.318	0.523	2.491	0.7021
212B	29	26	115	29.52	81.59	0.362	0.0840	0.758	0.287	1.460	0.3155
212C	7	6	27	30.89	78.49	0.394	0.1465	0.919	0.623	1.802	0.4445
212D	19	18	79	33.46	68.49	0.489	0.1329	0.653	0.133	1.478	0.3527
212E	7	5	19	29.45	98.25	0.300	0.0986	1.215	0.367	2.646	0.8739
212F	31	18	65	7.41	94.28	0.079	0.0251	0.667	0.278	3.293	0.7247
212G	11	7	25	39.42	91.71	0.430	0.2754	1.330	0.148	2.987	1.1248
212H	79	61	208	35.09	59.71	0.588	0.1593	1.044	0.206	4.636	0.8557
212J	73	51	189	42.12	71.34	0.590	0.1713	0.897	0.219	2.225	0.5302
212K	23	15	60	29.00	42.81	0.677	0.2518	0.750	0.200	1.801	0.3600
212L	44	27	104	28.04	40.08	0.700	0.1856	1.148	0.192	2.493	0.3283
212M	30	17	71	29.56	45.75	0.646	0.1849	1.156	0.372	3.458	0.4363
212N	59	35	146	15.68	41.42	0.379	0.0983	1.042	0.208	3.284	0.4224
221A	46	43	182	20.63	72.71	0.284	0.0488	0.791	0.171	2.148	0.4584
221C, 221D	18	14	58	21.29	55.27	0.385	0.1715	0.857	0.291	2.612	0.6279
221E, 221F	44	34	157	38.21	75.69	0.505	0.2414	0.757	0.104	3.735	0.7343
221H, 221I	13	11	31	26.45	130.39	0.203	0.0738	0.842	0.315	1.770	0.4720
222C	9	4	18	22.84	180.83	0.126	0.0799	0.890	0.322	2.164	0.8654
222D	10	8	21	65.89	91.64	0.719	0.2379	0.928	0.273	2.249	0.6462
222E, 222F	31	17	71	27.63	115.39	0.239	0.0753	0.630	0.226	2.058	0.4894
222G	8	6	16	114.41	188.86	0.606	0.3872	1.043	0.217	1.781	0.6185
222H	10	8	20	79.39	114.72	0.692	0.3598	1.194	0.257	3.151	0.9787
222I, 222J	28	18	65	18.71	84.72	0.221	0.0605	0.764	0.176	1.548	0.4561

continued

Table B.1—Tree mortality summary statistics (continued)

Ecoregion section	Plots	Plots with mortality	Obs.[a]	Mortality	Growth	MRATIO	Standard error of MRATIO	DDLD ratio Mean	Minimum	Maximum	Standard error
				ft³ per acre per year							
222K	12	4	28	13.29	57.89	0.230	0.1130	1.341	0.703	2.206	0.6564
222L	15	9	33	29.27	47.68	0.614	0.3060	0.868	0.266	1.741	0.4177
222M, 222N	28	19	71	25.85	66.38	0.389	0.1108	0.898	0.348	2.240	0.3038
231A	168	130	488	28.22	126.46	0.223	0.0307	0.715	0.055	2.498	0.4766
231B	68	58	225	29.76	118.03	0.252	0.0524	0.679	0.115	2.254	0.5222
231C	19	17	59	47.37	84.76	0.559	0.1427	0.876	0.281	2.578	0.6234
231D	12	11	42	40.17	104.53	0.384	0.1651	0.748	0.234	1.370	0.3686
232A	39	29	123	34.60	138.76	0.249	0.0581	0.655	0.121	2.100	0.3610
232B	98	68	295	27.75	120.61	0.230	0.0433	0.634	0.085	3.127	0.4730
232C	45	28	111	24.71	105.04	0.235	0.0736	1.117	0.156	4.744	1.0051
242A	24	18	57	76.07	118.77	0.640	0.3464	0.735	0.206	1.469	0.3551
251A, 251B	5	3	13	81.26	31.47	2.582	0.9591	1.286	0.628	1.762	0.3398
251C, 251D	17	6	35	39.80	76.36	0.521	0.2826	0.635	0.290	0.939	0.2566
261A, M262A	8	0	18	0.00	26.86	0.000	—	—	—	—	—
263A	7	3	17	5.02	26.15	0.192	0.0988	1.427	0.598	2.924	1.2985
313A	20	4	48	14.74	9.32	1.582	1.5400	0.890	0.558	1.000	0.2208
331A	5	4	13	158.50	42.97	3.689	1.3856	0.861	0.494	1.088	0.3214
331F, 331G	7	2	18	0.93	6.83	0.136	0.0807	2.011	0.755	3.266	1.7755
331I	12	4	33	5.01	16.97	0.295	0.1202	0.843	0.372	1.000	0.3141
341B, 341C	25	6	59	1.80	22.62	0.080	0.0656	1.000	1.000	1.000	0.0000
341D	6	1	12	1.41	7.64	0.185	0.0901	1.000	1.000	1.000	0.0000
341F	14	4	28	1.28	3.88	0.330	0.2050	0.955	0.820	1.000	0.0900
342A, 342E, 342F, 342G	10	1	24	7.30	10.87	0.672	0.9324	1.610	1.610	1.610	0.0000
342B	18	8	43	8.35	23.07	0.362	0.1094	0.983	0.483	1.978	0.4359
342C	5	4	12	20.48	37.00	0.554	0.1374	0.952	0.760	1.148	0.1639
342H, 342I	8	3	18	1.20	45.91	0.026	0.0273	0.849	0.498	1.049	0.3051
M212A	70	66	281	38.02	71.09	0.535	0.0736	0.953	0.176	2.798	0.5933
M212B	21	18	92	18.32	83.29	0.220	0.0560	0.638	0.236	1.064	0.2377
M212C	18	18	68	36.45	80.62	0.452	0.1361	0.992	0.191	2.704	0.6437
M212D	15	8	30	37.31	54.31	0.687	0.5206	1.127	0.389	2.890	0.7719

continued

Table B.1—Tree mortality summary statistics (continued)

Ecoregion section	Plots	Plots with mortality	Obs.[a]	Mortality	Growth	MRATIO	Standard error of MRATIO	DDLD ratio Mean	Minimum	Maximum	Standard error
				ft³ per acre per year							
M221A	63	49	192	37.59	72.00	0.522	0.0655	0.796	0.160	2.546	0.5539
M221B	25	19	91	25.57	95.45	0.268	0.0861	0.880	0.196	2.324	0.6025
M221C	17	15	66	24.04	66.12	0.364	0.1149	0.667	0.207	1.392	0.4478
M221D	43	28	119	42.16	104.22	0.405	0.1145	1.063	0.184	4.737	0.9653
M242A	46	24	107	40.97	130.60	0.314	0.0959	0.760	0.131	3.371	0.7695
M242B	46	32	110	60.27	158.28	0.381	0.1069	0.623	0.053	1.788	0.4130
M242C	57	31	136	31.66	35.97	0.880	0.5004	0.791	0.245	2.283	0.4116
M261A	47	23	113	19.83	56.75	0.349	0.1879	0.951	0.369	5.020	0.9620
M261B	15	3	33	13.29	17.20	0.773	0.6094	1.903	0.290	4.570	2.3261
M261C, M261F	23	5	52	0.86	10.92	0.079	0.0479	0.619	0.096	1.365	0.5048
M261D	15	5	34	19.09	50.64	0.377	0.1639	0.782	0.153	2.000	0.7631
M261E	45	7	108	1.94	22.12	0.088	0.0405	0.599	0.186	1.012	0.3053
M261G	20	1	46	1.71	12.66	0.135	0.0820	0.361	0.361	0.361	0.0000
M331A, M331J	17	8	45	15.27	27.00	0.566	0.2184	1.256	0.654	3.339	0.9453
M331B	5	2	11	12.48	48.62	0.257	0.0997	1.315	0.441	2.189	1.2363
M331D	38	19	91	27.29	39.98	0.683	0.2710	0.856	0.202	1.440	0.4145
M331E	10	6	20	64.62	50.06	1.291	0.4958	1.079	0.558	1.803	0.4039
M331F	11	4	36	2.48	25.24	0.098	0.0246	0.973	0.749	1.142	0.1633
M331G	32	21	97	9.46	29.04	0.326	0.0952	1.021	0.225	3.129	0.6444
M331H	33	26	99	20.03	44.89	0.446	0.0966	0.909	0.303	1.917	0.4553
M331I	33	21	96	7.69	37.04	0.208	0.0625	0.789	0.122	1.671	0.4729
M332A	50	26	130	38.75	50.61	0.766	0.2690	0.953	0.193	1.640	0.3872
M332E	7	3	19	18.28	36.11	0.506	0.1891	1.124	0.676	1.909	0.6819
M332F	11	5	29	6.74	19.29	0.349	0.1716	1.737	0.503	5.001	1.8729
M332G	35	18	82	19.19	36.23	0.530	0.2803	0.765	0.099	2.044	0.5108
M333A	37	20	96	42.42	74.90	0.566	0.1842	0.820	0.162	1.802	0.4756
M333D	26	19	70	36.43	100.05	0.364	0.1033	0.881	0.212	2.688	0.6388
M341B	15	7	38	1.71	14.15	0.121	0.0561	0.874	0.209	1.379	0.4153

— = value not calculated.

[a] A visit to a single plot in a given year to measure live and dead tree volume constitutes one observation.

APPENDIX C

Quality Assurance Information

The Forest Service FIA Program has a comprehensive quality assurance/quality control (QA/QC) component to ensure the production of complete, accurate, and unbiased forest information of known quality.[1] Several kinds of QA/QC data are collected regularly by FIA staff. The target numbers and types of QA/QC data are documented in the FIA Quality Assurance Program plan (see footnote 1) along with an explanation of each type of QA/QC data collected.

The FIA Data Quality Assessment Report[2] contains four main sections and an appendix. The four main sections are: introduction; methods, including field data collection, data analysis techniques, and data-matching algorithms; results, including core variables and missing/extra trees; and discussion of results. The appendix contains tables of the regional QA results by variable. We expect this report to be available in the future on an FIA Web site.

We seek to include QA/QC information for FIA plot variables when possible because the information relates to the data used in some sections of the FHM national reports such as “Crown Condition” and “Tree Mortality.” References to the QA results are for the information and convenience of readers. QA/QC information about plot variables will be included in future FHM national reports as the information is available.

[1] U.S. Department of Agriculture Forest Service. Manuscript in preparation. Forest inventory and analysis plot component quality assurance implementation plan. Version 1.0. Internal report. On file with: USDA Forest Service, Forest Inventory and Analysis, 201 14th St., Washington, DC 20250.

[2] Pollard, J.E.; Westfall, J.A; Patterson, P.A. [and others]. Manuscript in preparation. First national forest inventory and analysis data quality assessment report. [August 2004 draft].

Coulston, John W.; Ambrose, Mark J.; Riitters, K. H.; Conkling, Barbara L. 2005. Forest health monitoring: 2004 national technical report. Gen. Tech. Rep. SRS-90. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 81 p.

The Forest Health Monitoring (FHM) Program's annual national technical report presents results of forest health analyses from a national perspective using data from a variety of sources. Results presented in the report pertain to the Santiago Declaration's Criterion 1—Conservation of Biological Diversity and Criterion 3—Maintenance of Forest Ecosystem Health and Vitality. We include status and trend information where possible, consistent with previous FHM national technical reports. Additional analytical techniques and results, new to the national report, are presented as examples of ways forest health data can be used. This report has eight sections. The first contains introductory material. The next four contain results from analyses of status and change for selected forest health indicators, e.g., several measures of forest fragmentation, mortality- and defoliation-causing insects and diseases, crown condition, and tree mortality, similar to analyses in previous FHM national reports. The next two sections describe analytical techniques and provide information about assessments presented in the national report for the first time, and the final section is a summary.

Keywords: Assessment, criteria and indicators, crown, dieback, drought, fire, forest health, mortality.

The Forest Service, United States Department of Agriculture (USDA), is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.