Forest Health Monitoring 2002 National Technical Report

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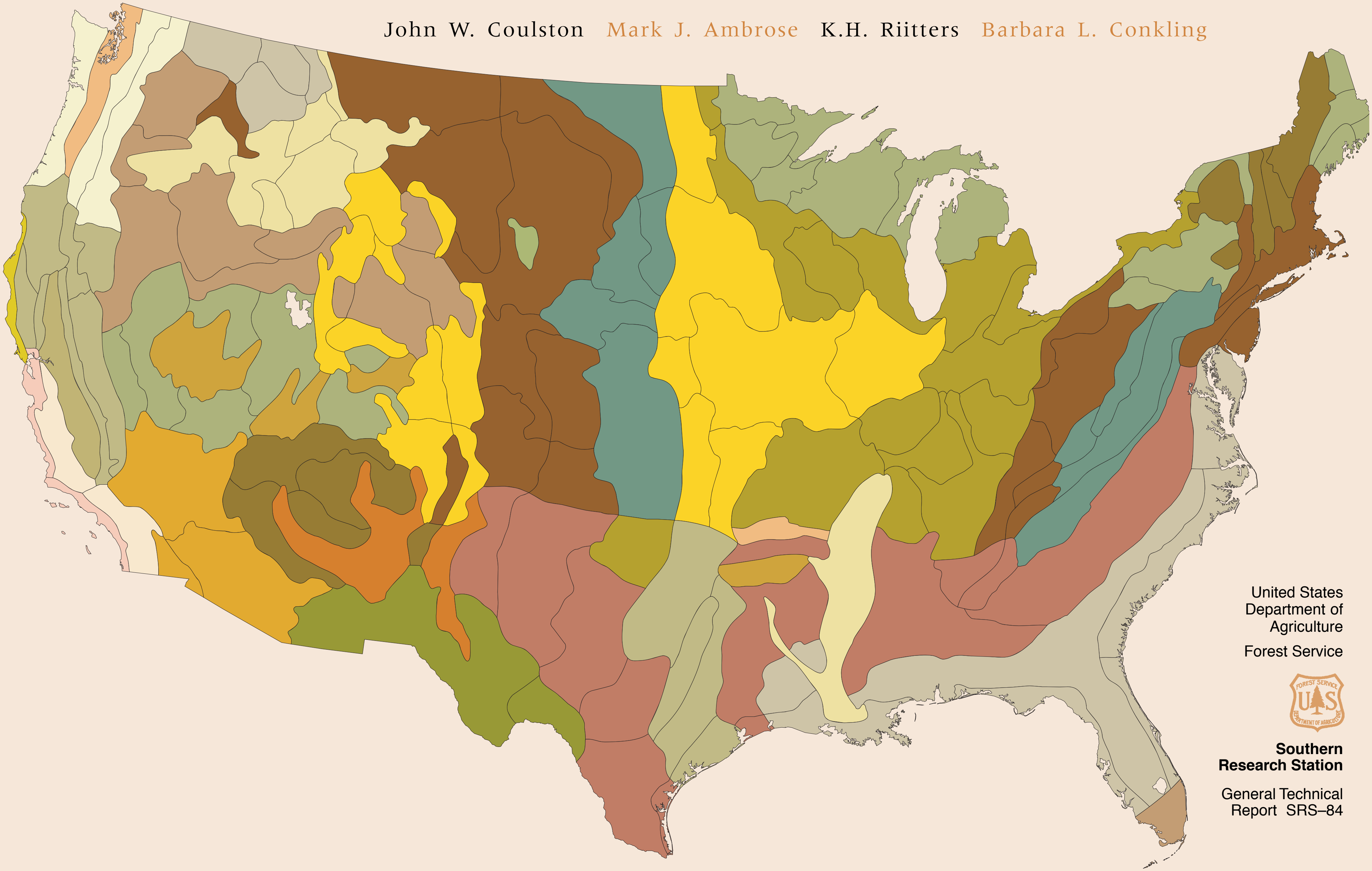

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Forest Service

**Southern
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General Technical
Report SRS–84

Front cover map: Bailey's ecoregion provinces and ecoregion sections for the conterminous 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. This annual report focuses on "Criterion 3—Maintenance of Forest Ecosystem Health and Vitality" from the Criteria and Indicators of Sustainable Forestry of the Santiago Declaration as the reporting framework. The report is composed of five main data sections and two appendices. The "Introduction" provides background information about FHM, details about the conceptual approach to the report, and details about data used in the analyses. The next three sections each focus on a specific indicator from Criterion 3. The first indicator section contains analyses of abiotic, biotic, and anthropogenic disturbances including drought, hurricanes, tornadoes, fire, insects and diseases, introduced species, and land development. The second indicator section contains analyses of air pollution data including nitrate and sulfate wet deposition data and ozone data. The third indicator section contains analyses of tree health data including tree mortality, crown condition, and damage. The final data section is a multivariate analysis, providing an integrated presentation of the data used in the report. Two appendices contain details about the analyses methods and summary data tables.

Keywords: Assessment, bioindicators, climate, criteria and indicators, forest health, mortality, ozone.

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Executive Summary

This report is one in a series of Forest Health Monitoring (FHM) Program annual national technical reports. The annual reports are designed to present results from forest health data analyses from a national perspective. The reporting framework used is the "Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests" (Anon. 1995b). This report focuses on "Criterion 3—Maintenance of Forest Ecosystem Health and Vitality." A multivariate analysis is also included in which 11 individual indicators are combined to produce several composite indicators. An overview of the report is presented in this executive summary, along with selected highlights from various sections.

U.S. Department of Agriculture Forest Service data sources were: FHM ground plot data (1990 through 1999), Forest Inventory and Analysis (FIA) annual phase 3 survey data (2000), Forest Health Protection data (1996 through 2000), and Fire Sciences Laboratory—fire current condition class[1] Other data sources were:

1. National Oceanic and Atmospheric Administration—Palmer Drought Severity Index (1895 through 2000) (National Climate Data Center 1994); hurricane data (1851 through 2000) (National Hurricane Center, National Oceanic and Atmospheric Administration 2000); and tornado data (1961 through 1990) (National Climate Data Center 2000)
2. National Atmospheric Deposition Program (1994 through 2000)[2]
3. U.S. Environmental Protection Agency and Wisconsin Department of Natural Resources—ozone SUM60 data (1999 through 2000). The number of hours when ambient ozone concentrations exceeded 60 parts per billion across the ecoregions was derived from the Aerometric Information Retrieval System database of the U.S. Environmental Protection Agency and summarized by the Wisconsin Department of Natural Resources
4. U.S. Geologic Survey, Earth Resources Observations Systems data (circa 1992)[3]

[1] Fire Science Laboratory. 2000. Current condition classes. Version 1.0. Missoula, MT: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Fire Science Laboratory. Unpublished database. On file with: The Fire Science Laboratory, 800 Block E. Beckwith, Missoula, MT 59807.

[2] National Atmospheric Deposition Program. Database. http://nadp.sws.uiuc.edu/nadpdata/multisite.asp?state=ALL. [Date accessed: August 2001].

[3] U.S. Geological Survey, National Land Cover Data. Database. http://landcover.usgs.gov/natllandcover.asp. [Date accessed: May 18, 2004].

Processes and Agents Beyond the Range of Historic Variation

The range of historic variation, the terminology used in the criteria and indicators (Anon. 1995b), is a vague term if the time scale is not defined. Data similar to those contained in this section have been assessed in relation to the range in variation over the last few decades and centuries (Ciesla and Coulston 2004). In this report we assess available data on abiotic (drought, hurricanes, tornadoes, and fire); biotic (insects and diseases); and anthropogenic (introduced species and land development) disturbances to forested ecosystems and discuss historical variation in terms of geologic time. While we make qualitative comparisons between current summarized disturbance levels and levels that forested ecosystems may have experienced over geologic time, no cause and effect relationships should be inferred from the analyses presented. We present drought and fire information in this summary section; information about hurricanes and tornadoes is found in the full report.

Deviation from historic drought occurrence (drought deviation) represents the deviation of a single 10-year (1991–2000) average from an historic average. Several ecoregion sections in southern California, southern Nevada, and Arizona had a drought deviation of > 7 months (7 months of drought in addition to that expected based on the historical average). The ecoregion section containing the Mojave Desert in southern Nevada and southeast California was the most droughty and had a drought deviation of 19 months. Other areas in the West were also more droughty than expected, including ecoregion sections east of the Cascade Mountains in Washington and Oregon, and parts of Idaho. In the Eastern United States, most ecoregion sections experienced less drought than expected. However, the Allegheny Mountains in central Pennsylvania and central West Virginia and the north and north central east coast of Florida experienced drought deviations of 8 and 12 months, respectively.

Fire is a powerful, selective regulatory mechanism in forest ecosystems. From 1938 to 2000, the areal extent of wildfires varied from approximately 136 900 km^2 in 1938 to approximately 6800 km^2 in 1975. There was a marked reduction in the areal extent of wildfire between 1938 and 1957. After 1957 there was a relative leveling off. However, 2000 was one of the most intense years of fire activity, to date, in the Western United States since 1916 (Ciesla and Coulston 2004).

Using insect and pathogen data, a short-term spatial trend analysis was based on relative exposure (observed vs. expected) on a county basis. The analysis then was used to identify hot spots of mortality- and defoliation-causing agents.

From 1996 through 2000, 44 different species of mortality-causing agents were recorded in the coterminous United States. In the North FHM region, areas with at least triple the expected exposure rate were in the southeast West Virginia area, and in forested areas in central Vermont. In the South FHM region, southern pine beetle was the predominant mortality-causing agent recorded. Most of the areas with greater than three times the expected exposure rate were primarily in the mountains in North Carolina, South Carolina, and Tennessee. The North Central FHM region had triple the expected exposure rate in parts of western Wisconsin and southeast Minnesota, the Black Hills in South Dakota, and parts of the Ozark Highlands in Missouri. The Interior West FHM region had widespread activity of mortality-causing agents with the most intense activity found in the Bitterroot Mountains in Idaho, and in central Colorado. In the West Coast FHM region, forested areas with more than triple the expected exposure to mortality-causing agents were in northern Washington, and in part of the Sierra Nevada in California.

There were 98 different species of defoliation-causing agents recorded in the coterminous United States from 1996 through 2000. In the North FHM region, the most intense defoliation-causing agent activity was in southern Ohio and southwest West Virginia. There were also several areas in Pennsylvania and West Virginia with more than double the expected exposure to defoliation-causing agents. In the South FHM region, there were three hot spots of defoliation-causing agent activity: in the southern extent of the Mississippi Alluvial Basin sections, and portions of two coastal flatlands ecoregion sections near the border between North and South Carolina. In the North Central FHM region, areas with more than triple the expected exposure rates were in western Wisconsin and portions of northern Minnesota. The most intense activity in the Interior West FHM region was in the southern portion of the region. The most intense activity of defoliation-causing agents was in northern New Mexico. There were also several areas in northern and central Arizona with more than three times the expected exposure. In the West Coast FHM region, the most intense activity from defoliation-causing agents was in the Eastern Cascades in Oregon, Washington, and in the Okanogan Highlands in Washington.

Land development and introduced species can move ecosystems out of the range of historic variation quickly. Information about introduced species is discussed in more detail in the full report. However, we consider introduced and exotic species to be synonymous with introduced species and use the following definition: "Any species growing or living outside its natural range of occurrence. Normally this refers to species purposely or accidentally introduced into countries or regions where they do not historically occur" (U.S. Department of Agriculture, Forest Service 2004).

We assessed land development by considering (1) the total length of edge between forest and anthropogenic (urban and agricultural) landcover types; and (2) the percentage of all forest edge that was associated with anthropogenic landcover types using a national landcover map (excluding Alaska, Hawaii, and Puerto Rico) derived from Thematic Mapper imagery (Vogelmann and others 2001). The first indicator takes into account the total amount of forest and anthropogenic landcover types, whereas the second indicator reflects fragmentation of the amount of forest that is present. As expected, ecoregion sections that contain large agricultural or urban areas also contain the most forest-anthropogenic edge. The percentage of forest edge within landscapes that was associated with anthropogenic landcover varied from 0.0 to 100.0, and the national median and average landscape values were 7.2 and 16.2 percent, respectively. We found that the total length of forest-anthropogenic edge is large, and that there is a wide variety of edge conditions within individual ecoregion sections. Interpreting the implications of the analysis is a current research topic.

Forest Land Subjected to Air Pollutants that may Cause Negative Impacts on the Forest Ecosystem

We examined wet nitrate and sulfate deposition from 1994 through 2000, ozone exposure for 1999 and 2000, and ozone-induced foliar injury from 1994 through 2000. The SUM60 ozone index (sum of all hourly concentrations > 60 parts per billion) was used to quantify ozone exposures for the 3-month growing season (June, July, August). Ozone-induced foliar injury was based on a biosite index using ozone bioindicator plot data. Generally wet sulfate and nitrate deposition were highest in eastern ecoregion sections. The eastern ecoregion sections also had four sections classified in the highest risk category according to the biosite index. SUM60 ozone concentrations were highest in the Sierra Nevada foothills section in California, with several relatively high concentrations also found across the Southeast.

Forest Land with Diminished Biological Components Indicative of Changes in Fundamental Ecological Processes and/or Ecological Continuity

This indicator is framed in terms of the conditions of biological components of the forest ecosystem that reflect the state of fundamental ecological processes. However, the national scale data available for this report relate only to trees. In this report, tree mortality and poor tree health (as evidenced by tree damage and crown condition) are analyzed using FHM and FIA phase 3 plot data. Because FHM detection monitoring/FIA phase 3 plots have not been established in all States, these analyses only cover a portion of the coterminous United States.

Two indicators are used in the analysis of mortality: (1) the ratio of annual mortality volume to gross volume growth (MRATIO), and (2) the ratio of the average dead tree diameter to the average live tree diameter (DDLD). The DDLD ratios presented in the report are based on the mortality through the most recent measurement of each plot. The MRATIO values presented represent the annual mortality over the time periods from the earliest plot establishment in each section through 2000. Ecoregion section MRATIO values ranged from 0.0 to 1.3. Because mortality is a discrete event while growth is continuous, the deaths of very large, old trees can produce highly variable MRATIO estimates if the sample has an inadequate number of plots or too few years of data. Care should be exercised in interpreting results, especially where the data span only short time periods, the sample size is small, or the forest growth rates are low. As more years of data are collected and more remeasurement data become available, these two indicators of mortality will provide a better characterization of forest condition.

The basic analysis of the tree health indicators began at the individual tree level and used the most recent measurement of each FHM or FIA phase 3 plot. The crown and damage indicators were used to classify each tree as healthy or unhealthy. Then, for each plot, the percentage of basal area represented by unhealthy trees was determined. The so-called unhealthy trees are those that were diseased, severely damaged, or otherwise severely stressed.

A crown index is used, a variation of the method proposed by Zarnoch and others[4] and Zarnoch and others (2004), that 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. Data are presented using a threshold for unhealthy crowns described in the full report. In the analysis of average percentage of plot basal area associated with trees classified as having unhealthy crowns by ecoregion section, 10 percent or less of the basal area was associated with unhealthy crowns throughout most of the United States. However, a number of plots scattered across the country had a high percent basal area associated with trees with unhealthy crowns. The largest clusters of these plots were in parts of the West, northern New England, and the Lake States.

Crown and damage data were combined for an integrated analysis of tree health. Using the same thresholds, a tree was considered unhealthy if it exceeded either the crown

[4] 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. Unpublished manuscript. 535 p. On file with: Forest Health Monitoring Program National Office, 3041 Cornwallis Rd., Research Triangle Park, NC 27709.

condition or damage thresholds. There are limitations associated with this analysis, which are presented in the full report. However, one of the objectives of the national report is to present different methods of analysis. The power of this analytical approach, which starts by assessing whether or not individual trees are healthy, is that more detailed information about particular tree species can be incorporated into this framework as the information becomes available. The current, relatively simple thresholds can be replaced with more sophisticated decision rules (classifying a tree as healthy or unhealthy) based on tree species as well as damage and crown variables. Current knowledge of certain species can be used relatively easily. Efforts to refine these decision rules can be focused on species that represent the largest percentage of forest basal area. Simpler, more general rules can continue to be used for less common species. As this method is refined, it could be combined with analytical approaches that consider change over time. Using generalized linear models similar to those used in previous FHM reports (Conkling and others 2005; Stolte and others, in press), it will be possible to estimate the change over time in the percentage of basal area represented by unhealthy trees.

Multivariate Analysis of Forest Indicators

Principal components analysis (PCA) often reveals underlying relationships and enables interpretations that otherwise would not be noticed. Eleven indicators for seventy-six ecoregion sections were used. The 11 indicators contain information about drought, insects and pathogens, fire condition class, land development, air pollution, tree damage, crown condition, and mortality. The 76 ecoregion sections cover most of the forested area in the United States and were selected because all indicator data were available for those areas. Of 11 indicators tested in 76 ecoregion sections, a PCA identified at least 3 composite indicators that were used to rank ecoregion sections relative to one another in terms of (1) air pollution and land development; (2) defoliation-causing insect and pathogen activity and fire condition class; and (3) mortality ratio, percent basal area with thin crown, and percent basal area with severe damage. Individual ecoregion sections appeared to have relatively high or low values for composite variables and these indications are expected to be starting points for further indepth investigations.

Introduction

This annual technical report, a product of the Forest Health Monitoring (FHM) Program, presents results of forest health data analyses from a national perspective. The indicators described in the "Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests" (Anon. 1995b) are the report framework, similar to the two most recent FHM national reports (Conkling and others 2005; Stolte and others, in press).

The FHM Program

A main objective of the FHM Program is to determine on an annual basis the status of and changes in indicators of forest condition. In the FHM Program, the U.S. Department of Agriculture, Forest Service (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 2002):

- Detection monitoring—nationally standardized aerial and ground surveys to evaluate the status of 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—projects to enhance understanding of cause and effect relationships and assess specific issues 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.

In addition to FHM's national reporting, reports are also produced by the five FHM regions (e.g., Atkins and others 1999; Burkman and others 1998; Campbell and others 2000; Dale and others 2000; Gatch and others 1999; Koch and others 2001; Morin and others 2001; Rogers and others 1998, 2001). The FHM regions, in cooperation with their respective States, produce "State Highlights" fact sheets (available on the FHM Web site, http://www.fhm.fs.fed.us) and other State reports.

In 1999, the ground plot activities of FHM's detection monitoring component were integrated with the Forest Service's Forest Inventory and Analysis (FIA) plot activities with a goal of maximizing the strengths of both programs. The former (prior to 2000) FHM detection monitoring plots became part of FIA's phase 3 plots, which are a subset of FIA's phase 2 annual inventory plots. Standard tree measurements are made on both phase 2 and phase 3 plots; additional tree and nontree indicators measured on phase 3 plots include crown condition, lichen communities, soils (physical and chemical characteristics), vegetation structure, down woody debris, and ozone biomonitoring. More information about the sampling design is presented in "Appendix A, Supplemental Methods, Analysis of FHM and FIA Ground Plot Data."

Two important decisions that must be made when analyzing monitoring data and presenting the results are choice of assessment unit, and applicability of the data to making cause and effect inferences. In this introductory section, we provide some background information about making these decisions. More specific details about this report are in the section entitled "Details about the Report."

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 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 (subset of the phase 2 plots or the former FHM detection monitoring plots) 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 such as monitoring data to help determine cause and effect relationships. Olsen and Schreuder (1997) noted two kinds of field plots, in addition to monitoring plots, that are important when testing and establishing cause and effect relationships. One supplemental type should have fewer plots 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 where responsiveness and mechanisms could be studied. These kinds of additional plots correspond well with FHM evaluation monitoring studies, 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 one.

Choice of Assessment Unit: Does One Assessment Unit Fit All? *(Conkling and others 2005)*

Rowe and Sheard (1981) stated that maps produced as part of classifying landscapes should be viewed as hypotheses generated from theory that need to be tested and improved. It is also known that assessment results can change when the spatial scale changes (Fotheringham and Wong 1991). Clients for different assessments are interested in various spatial scales, such as counties, States, and regions (Forest Service, FHM, Resource Planning Act, etc.), as well as ecological units such as ecoregion sections, provinces, or divisions. This list of various spatial scales can be divided into two kinds of units—political and ecological. The choice of a unit usually is based on the data's applicability and the client's needs; a given spatial scale in itself is not always useful or inappropriate. The choice of any ecological unit for assessment should be explainable using the purpose of ecological land classification given by Bailey (1983): ". . . to divide the landscape into variously sized ecosystem units that have significance both for development of resources and for conservation of environment." In choosing an ecological unit, refer to the criteria used in formulating the unit. In this report Bailey's (1995) ecoregion sections are used. They are based on climate, vegetation, and soil factors. Ideally, the spatial scale used for analysis is appropriate for both the scale of available data, such as sampling intensity or resolution of remotely sensed data, and the ecological component of interest. It is recognized that any single spatial scale may not be the best for every indicator to be analyzed but does provide a starting, common framework for an ecologically based assessment.

Details about the Report

In this report we used the Santiago Declaration and accompanying criteria and indicators (Anon. 1995a, 1995b) (text is also available at www.fs.fed.us/land/sustain_dev/sd/sfmsd.htm) that were adopted by the Forest Service as a forest sustainability assessment framework (Smith and others 2001; U.S. Department of Agriculture, Forest Service 2001). The criteria and indicators also have been adopted by the Forest Service for strategic planning (U.S. Department of Agriculture, Forest Service 2000). 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

This report focuses on "Criterion 3—Maintenance of Forest Ecosystem Health and Vitality." Each of the three indicators associated with criterion 3 is presented in a separate section. These three indicators correspond to indicators 15, 16, and 17 found in the "National Report on Sustainable Forests—2003" (U.S. Department of Agriculture, Forest Service 2004). In the section entitled "Multivariate Analysis of Forest Indicators," individual metrics are combined to produce additional information. Appendix A provides useful details about analyses that are different from previous reports or useful to have readily available. Appendix B provides supplemental data tables that may be of interest to the reader.

Forest Service data sources were FHM ground plot data (1990 through 1999), FIA annual phase 3 survey data (2000), Forest Health Protection (FHP) (1996 through 2000), and Fire Sciences Laboratory (fire current condition class)[1]. Other data sources were:

1. National Oceanic and Atmospheric Administration—Palmer Drought Severity Index (1895 through 2000) (National Climate Data Center 1994), hurricane data (1851 through 2000) (National Hurricane Center, National Oceanic and Atmospheric Administration 2000), and tornado data (1961 through 1990) (National Climate Data Center 2000)
2. National Atmospheric Deposition Program (1994 through 2000)[2]
3. U.S. Environmental Protection Agency (EPA) and Wisconsin Department of Natural Resources—ozone SUM60 data (1999 through 2000). The number of hours when ambient ozone concentrations exceeded 60 parts per billion across the ecoregions was derived from the Aerometric Information Retrieval System database of the EPA and summarized by the Wisconsin Department of Natural Resources
4. U.S. Geologic Survey Earth Resources Observations Systems data (circa 1992)[3]

Specific field data collection methods for FHM ground plots are described in the 1999 FHM field methods guide.[4] Data collection methods for FIA field plots are presented in volumes 1 and 2 of the FIA national core field guide.[5] [6] These field guides are available on the national FIA Web site http://fia.fs.fed.us/library.htm#Manuals.

When possible, Bailey's ecoregion sections (Bailey 1995) were used as the assessment unit for analysis. Bailey's system (fig. 1) is a hierarchical system of ecological units that divides the United States into ecoregion domains, divisions, provinces, sections,

[1] Fire Science Laboratory. 2000. Current condition classes. Version 1.0. Missoula, MT: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Fire Science Laboratory. Unpublished database. On file with: The Fire Science Laboratory, 800 Block E. Beckwith, Missoula, MT, 59807.

[2] National Atmospheric Deposition Program database. http://nadp.sws.uiuc.edu/nadpdata/multisite.asp?state=ALL. [Date accessed: August 2001].

[3] U.S. Geological Survey, National Land Cover Data database. http://landcover.usgs.gov/natllandcover.asp. [Date accessed: May 18, 2004].

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

[5] U.S. Department of Agriculture, Forest Service. 2000. Forest inventory and analysis national core field guide: field data collection procedures for phase 2 plots. Version 1.4. Vol. 1. Internal report. On file with: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis, 201 14th St., Washington, DC 20250.

[6] U.S. Department of Agriculture, Forest Service. 2000. Forest inventory and analysis national core field guide: field data collection procedures for phase 3 plots. Version 1.4. Vol. 2. Internal report. On file with: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis, 201 14th St., Washington, DC 20250.

subsections, land-type associations, and land types (McNab and Avers 1994). Ecoregion sections typically contain thousands of square miles. Areas within an ecoregion section are expected to have similar geology and lithology, regional climate, soils, and potential natural vegetation, potential natural communities, or both (Cleland and others 1997). Additional details about analysis of the FHM and FIA ground plot data are presented in "Appendix A, Supplemental Methods, Analysis of FHM and FIA Ground Plot Data."

As discussed in previous FHM national reports, i.e., Conkling and others 2005, maps in this report illustrate discussions in the text and spatially display the relative ranking of indicator values. The maps assist in identifying possible regional patterns of the forest health indicator values. In general, the rankings are based on the range of observed values, not on thresholds of "good" or "bad" conditions. In other words, ecoregion sections or plot values for indicators are ranked from relatively low to relatively high for the range of values observed in all ecoregion sections or on plots. For example, the average ecoregion section values in figure 2 range from 1 to 25. The total range (25) is arbitrarily divided into five categories (1 to 5, 6 to 10, 11 to 15, 16 to 20, and 21 to 25), and each ecoregion section is color coded according to the category into which it belongs. This approach allows the reader to evaluate each ecoregion section in comparison to all other ecoregion sections across 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 presentation.

On many of the maps, only the forested parts of ecoregion sections are shaded with the ecoregion section ranking. The actual distribution of forest land thus appears as a backdrop on those maps. The forest land backdrop comes from land-cover maps derived from 1-km-resolution Advanced Very High Resolution Radiometer (AVHRR) satellite imagery (fig. 3). In addition, several maps display State or regional boundaries to help orient readers geographically. Figure captions contain a brief title, the years of data used (where applicable), and a reference to the text or appendix if needed.

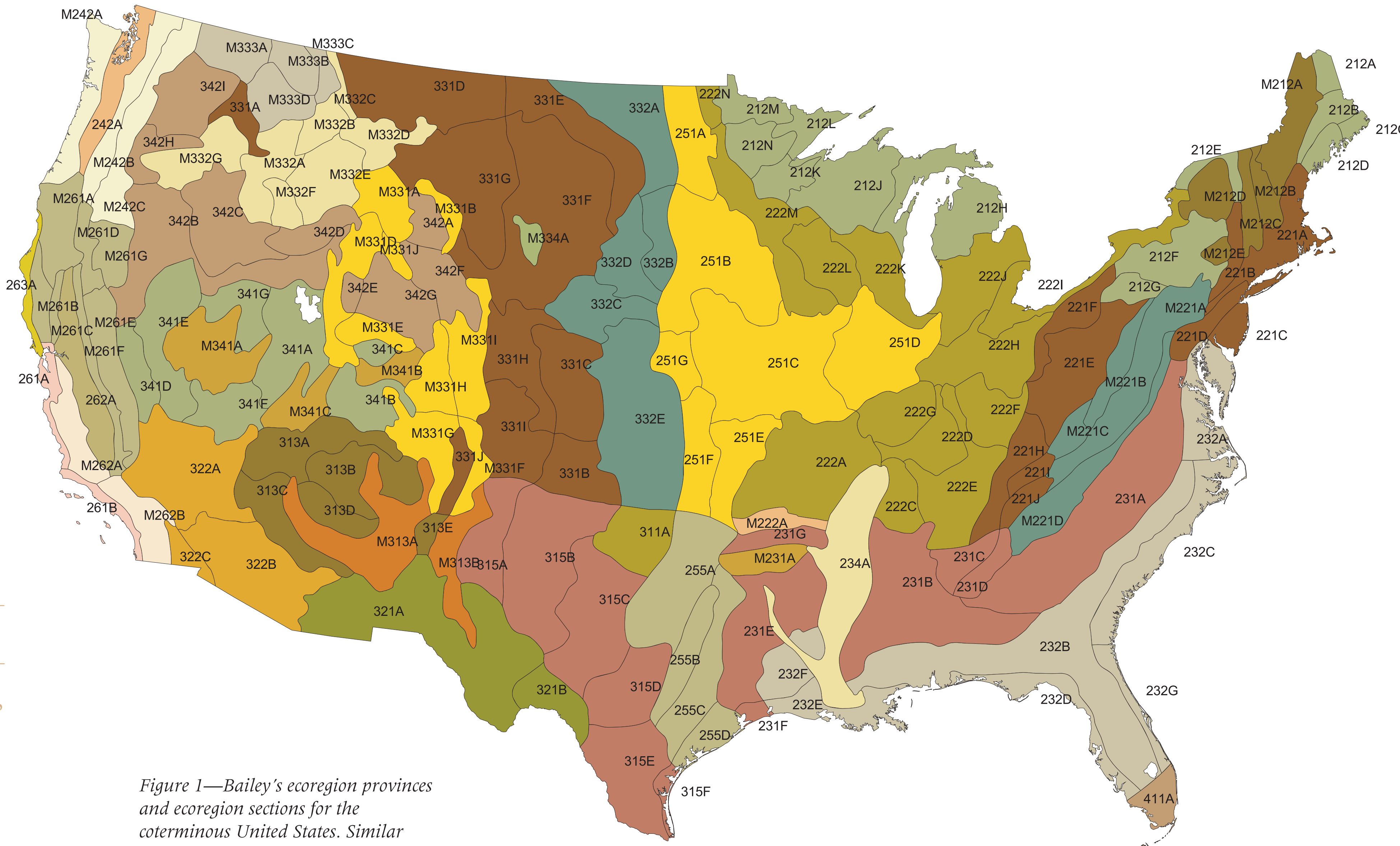


Figure 1—Bailey's ecoregion provinces and ecoregion sections for the coterminous United States. Similar colors in groups are the ecoregion sections within the ecoregion provinces.

Eastern Ecoregion Provinces

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

Western Ecoregion Provinces

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

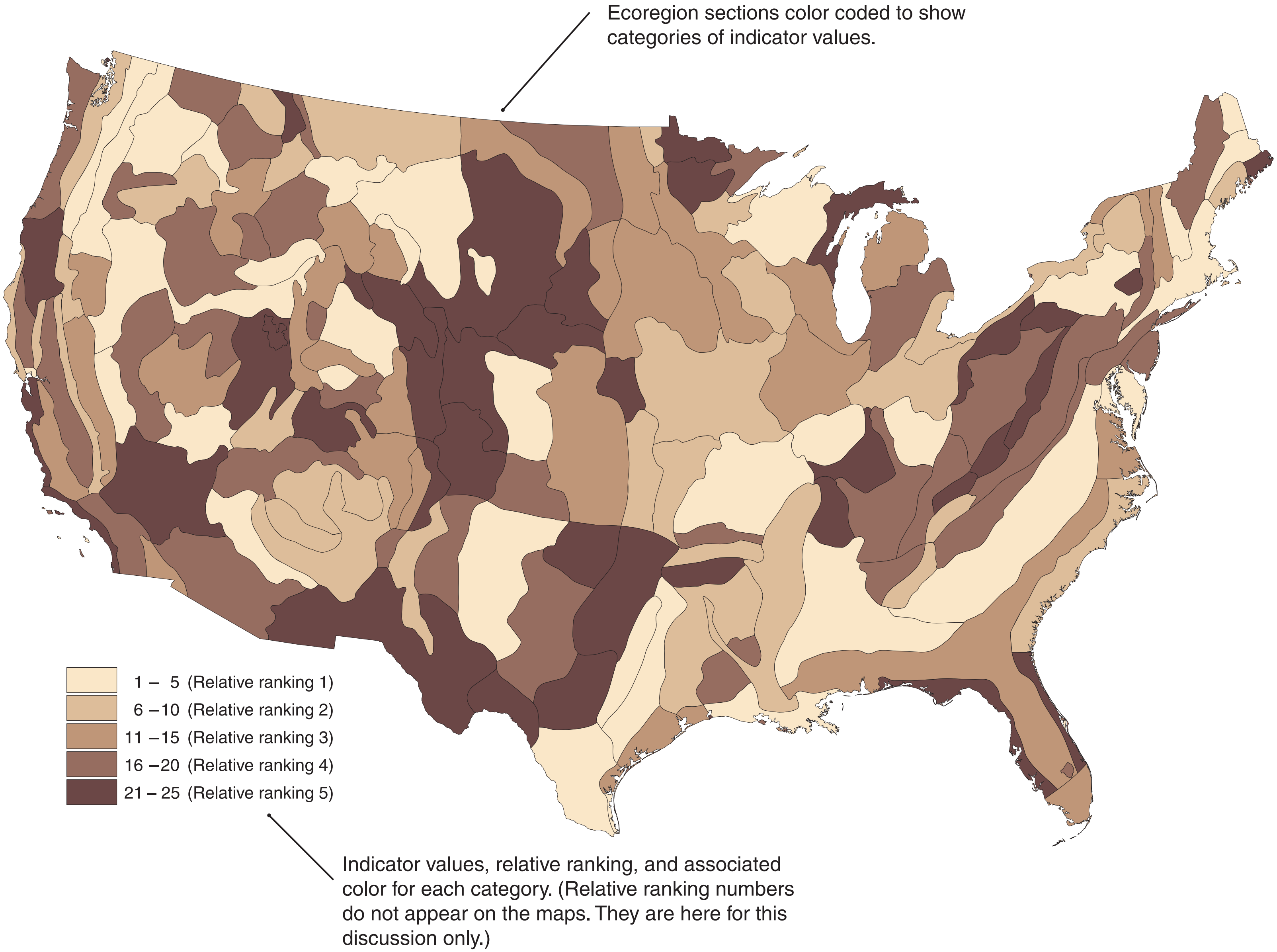


Figure 2—How to read a map in this report.

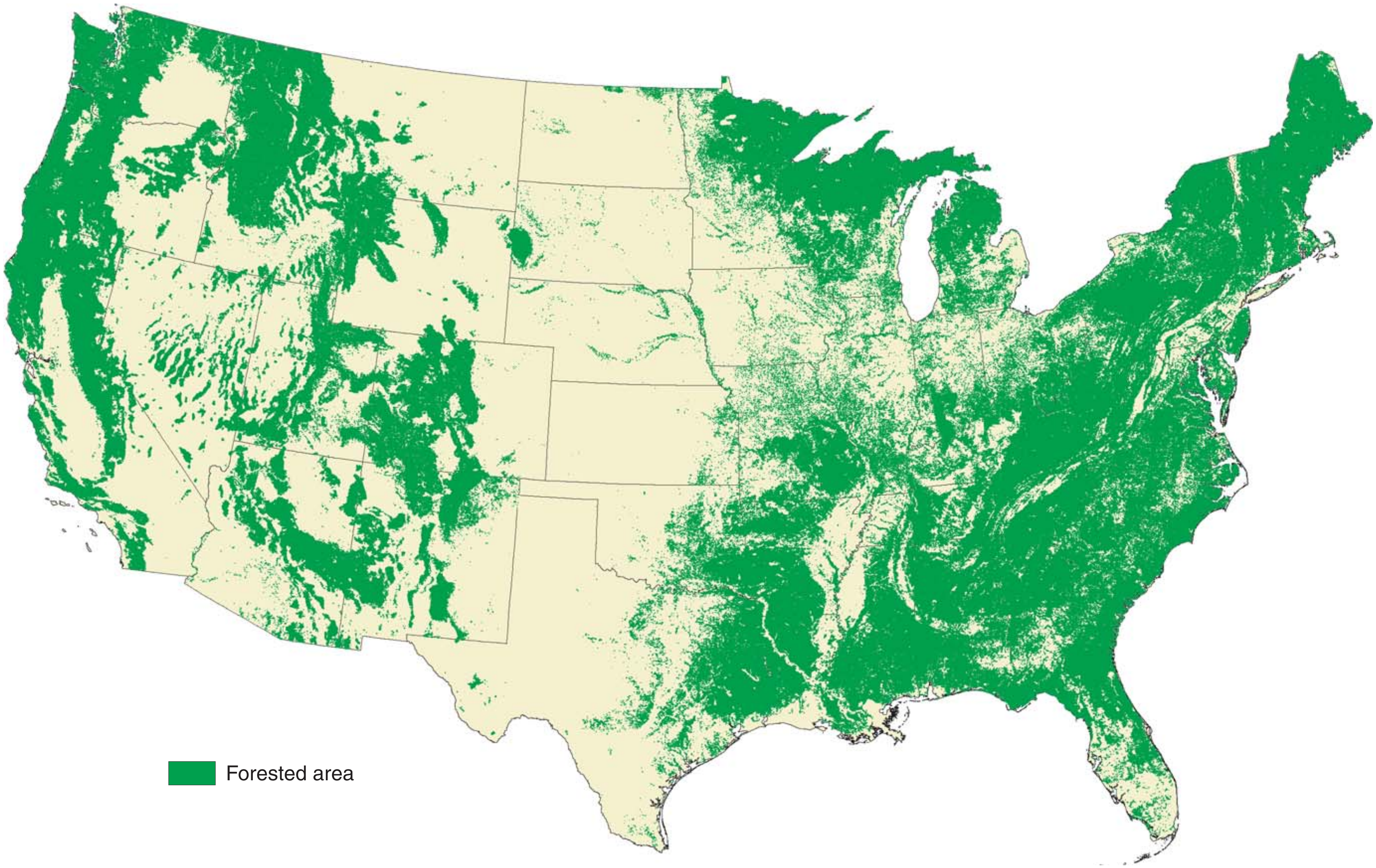


Figure 3—Forest land backdrop derived from Advanced Very High Resolution Radiometer satellite imagery (Zhu and Evans 1994).

Processes and Agents Beyond the Range of Historic Variation

Introduction

The range of historic variation is a vague term if the time scale is not defined. For example, land development over the last decade may be within the range of variation over the past 50 years but is clearly outside the range of variation over the past 10,000 years. On the other hand, current climate change may not be out of the range of variation for the last 3 million years but may be considered out of the range of variation for the last 150 years. Ciesla and Coulston (2004) assessed data that are similar to those contained in this section in relation to the range in variation over the last few decades and centuries. Here we attempt to compare current processes and agents to the possible range in variation over a longer time horizon.

Over geologic time (millions of years), forested ecosystems have responded to processes and agents that led to the current species associations and spatial distribution of forested ecosystems in the United States. The primary processes and agents influencing the composition, structure, and functional processes of forested ecosystems can be classified as abiotic disturbances, e.g., drought, hurricanes, windstorms, fire; biotic disturbances, e.g., insect and pathogen outbreaks; and anthropogenic disturbances, e.g., introduced species and land development (Dale and others 2001). Many of the disturbances that influence processes and agents are related to large-scale climate patterns and, therefore, climate change. Changes in precipitation and temperature can influence the frequency, duration, extent, and intensity of disturbances at local, national, and global scales (Dale and others 2001). For example, precipitation and temperature changes, along with other human activities such as land development, fire suppression, and species introductions, may influence drought cycles, hurricane formation, tornado activity, fire occurrence, and insect/pathogen activity (Dale and others 2001). Most climate change scenarios point to increases in both temperature and precipitation.

Climate change is a naturally occurring phenomenon, but is also influenced by human activities that alter atmospheric concentrations of greenhouse gases (Melillo and others 1995).

Table 1—General circulation models and predictions of change in current average annual temperature and precipitation for the coterminous United States under a doubling of atmospheric CO_2

Name	Reference	Predicted change in current average annual temperature	Predicted increase in average annual precipitation
		°C	*percent*
Oregon State University	Schlesinger and Zhao 1989	3	2.1
Geophysical Fluids Dynamics Laboratory	Manabe and others 1990	4.2	18.9
Goddard Institute for Space Studies	Hansen and others 1988	4.4	5.1
United Kingdom Meteorological Office	Wilson and Mitchell 1987	6.6	11.3
UKMO Hadley Centre	Johns and others 1997	2.8	22.9
UKMO Hadley Centre	Johns and others 1997	3.7	30.7
Canadian Climate Centre	Boer and others 2000	5.2	21.5

Source: Adapted from Hansen and others (2001).

Concentrations of greenhouse gases such as CO_2 and CH_4 have been increasing since the beginning of the industrial revolution in the 1850s. They are one of the large-scale drivers of current climate change scenarios (Kattenberg and others 1996, McNulty and Aber 2001). General circulation models (GCM) are used to predict global climate change in response to increases of greenhouse gases (see table 1 for examples). Generally, these models use a scenario where atmospheric CO_2 doubles, and predict changes in current average temperature from 2.8 to 6.6 °C and increases in rainfall from 2.1 to 30.7 percent (table 1).

While some of these possibilities appear drastic, modern plant taxa have experienced large changes in climate, such as temperature changes greater than several degrees Celsius within a few decades, over the last 2.5 million years (Davis and Shaw 2001).

In this report, we assess available data on abiotic, biotic, and anthropogenic disturbances to forested ecosystems and discuss historical variation in terms of geologic time. We make qualitative comparisons between summarized disturbance levels and levels that forested ecosystems may have experienced over geologic time. Where possible, we use Bailey's ecoregion sections to summarize the information. No cause and effect relationships should be inferred from the analyses presented here. Methods and data sources are presented in the text when necessary; otherwise, they are presented in appendix A.

Abiotic Disturbances—Drought, Hurricanes, Tornadoes, and Fire

Drought is a naturally occurring abiotic disturbance to forest communities and is a function of temperature; precipitation in the form of rainfall, snow, ice, or fog drip; and soil characteristics, such as water-holding capacity. 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). Moderate drought stress tends to slow plant growth, while severe drought stress reduces photosynthesis as well as growth (Kareiva and others 1993). Drought stress in forest communities also influences some insect populations. Mattson and Haack (1987) identified 10 insect families that historically reach outbreak status after droughts. Decomposition of organic matter can be slowed by drought, resulting in more favorable fire conditions. While most GCMs project an overall increase in rainfall, there are indications, based on mechanistic biogeographical models, that climate change may result in increased drought stress in the Southeast, Southern Rocky Mountains, and parts of the Northwest (Dale and others 2001).

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 2000 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 2000, then approximately 36 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 36, and 48 months of drought were recorded in the current decade, then the drought deviation was 48-36 = 12.

In the decade 1991–2000, some ecoregion sections experienced more frequent droughts than expected based on historical averages while others experienced less (fig. 4). Several ecoregion sections in southern California, southern Nevada, and Arizona had a drought deviation of > 7 months (7 months of drought in addition to that expected based on the historical average). Ecoregion Section 322A—Mojave Desert was the most droughty and had a drought deviation of 19 months. Other areas in the West were also more droughty than expected, including ecoregion sections east of the Cascade Mountains in Washington and Oregon, and parts of Idaho (fig. 4). In the Eastern United States, most ecoregion sections experienced less drought than expected. However, Sections M221B—Allegheny Mountains and 232G—Florida Coastal Lowlands (Eastern) experienced drought deviations of 8 and 12 months, respectively (fig. 4).

Hurricanes provide large-scale disturbances for much of the forests in the Eastern United States. Their formation, size, and intensity are regulated by ocean temperature and regional climate conditions (Emanuel 1987). Hurricanes

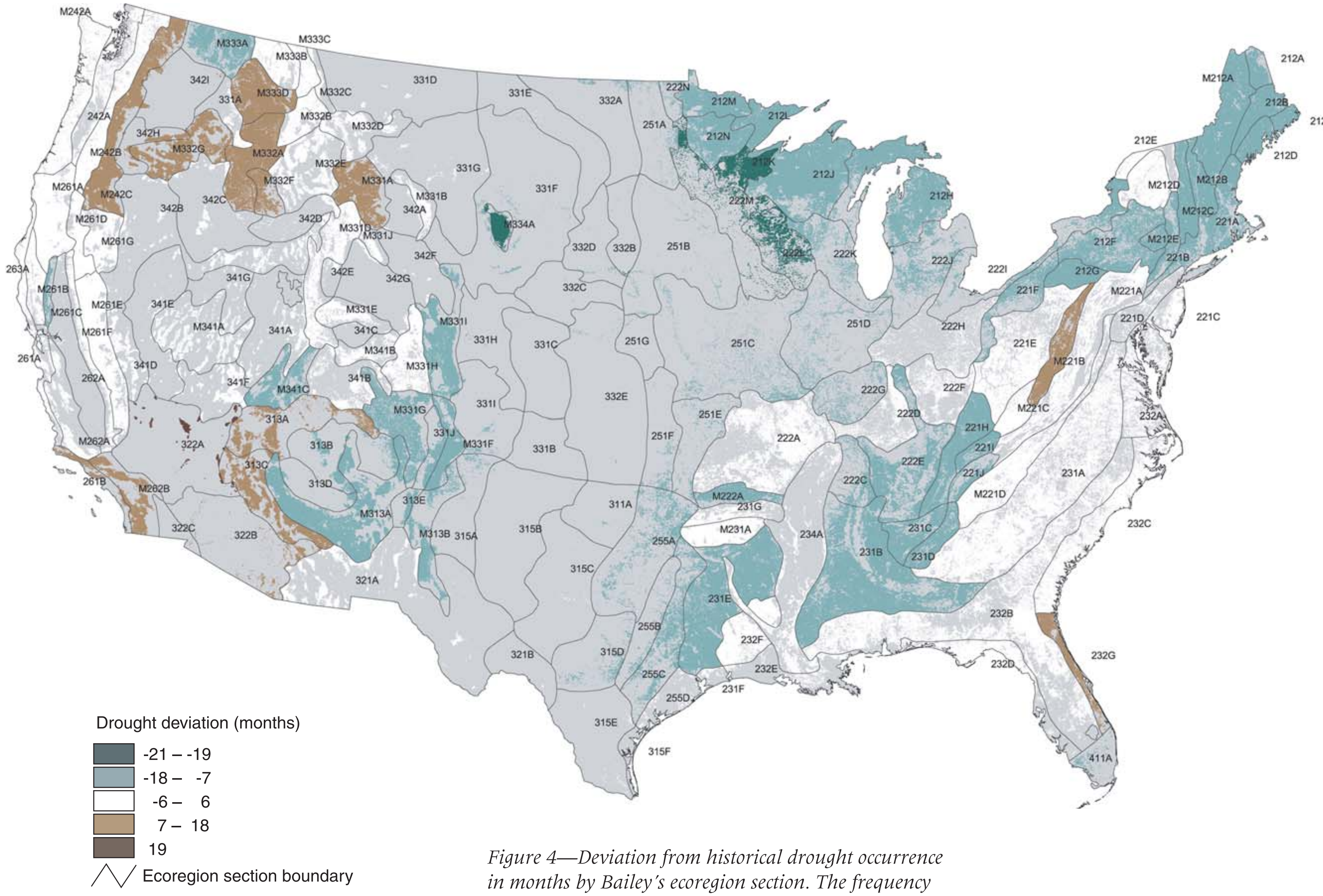


Figure 4—Deviation from historical drought occurrence in months by Bailey's ecoregion section. The frequency of drought from 1895 through 2000 was the historical reference and was compared to the frequency of drought from 1991 through 2000. (See text for explanation.)

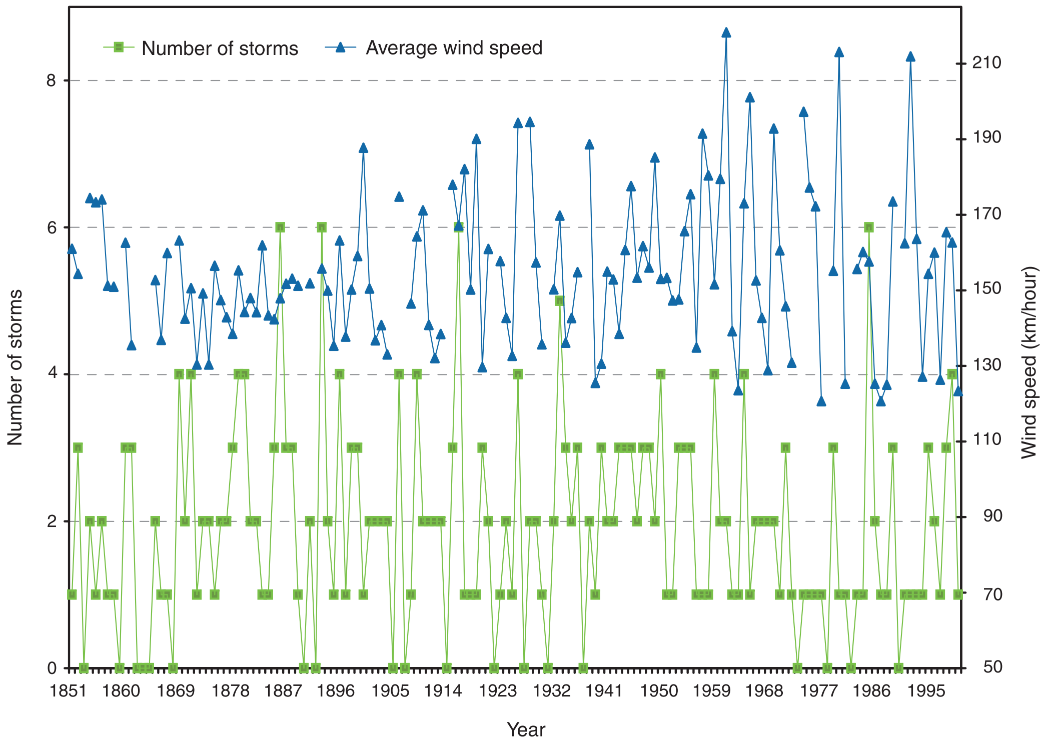


Figure 5—The number of category 1 or greater hurricanes and average wind speed by year for the coterminous United States from 1851 through 2000.

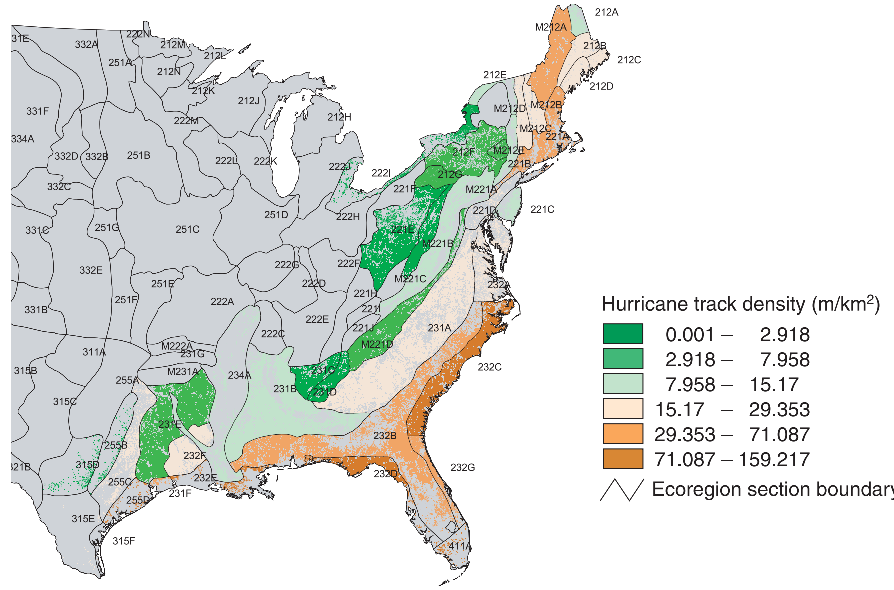
can cause widespread tree mortality, influence successional stage and direction, increase fuel loading, and create openings for insects and pathogens (Dale and others 2001). Most global climate change studies point to an increase in hurricane intensity and possibly frequency due to changes in the global hydrologic cycle and temperature (Walsh and Pittock 1998), however, there are still many uncertainties (Lighthill and others 1994).

Typically, two hurricanes in category 1 (119–153 km/hour) or greater make landfall each year. This number is the median value from 1851 through 2000 of all hurricanes making landfall. Although no hurricanes make landfall in some years, multiple hurricanes occur in other years. For example, six hurricanes made landfall in 1985 (fig. 5). Hurricanes are variable in intensity; for example, in 1961 two hurricanes made landfall with an average wind speed of approximately 218 km/hour. Conversely, in 1977, only one hurricane made landfall, and it had an average wind speed of approximately 121 km/hour (fig. 5).

Hurricanes strike most often in the Southeastern United States. The Everglades, Section 411A, had a storm track density (length of storm tracks per unit of land area) of approximately 159 m/km² from 1851 through 2000 (fig. 6A) with an average wind speed of 169 km/hour (fig. 6B). Section 232C—Atlantic Coastal Flatlands had approximately 94 m/km² of storm tracks and Section 232D—Florida Coastal Lowlands (Western) had approximately 85 m/km² of storm tracks. Both of these sections had an average wind speed of 149.7 km/hour. Gulf coast areas, such as Sections 231F—Eastern Gulf Prairies and Marshes and 232E—Louisiana Coast Prairies and Marshes, also had a relatively high storm track density and average wind speed.

While hurricanes generally make landfall and travel through coastal areas of the Southeast, they also occur occasionally in much of New England. Hurricane tracks can also reach areas over 320 km inland as in Section 212G—Northern Unglaciated Allegheny Plateau in New York. In this report, storm track centers serve as a surrogate for actual hurricane activity. In fact, the impacts of hurricanes may extend hundreds of kilometers from the storm center.

A



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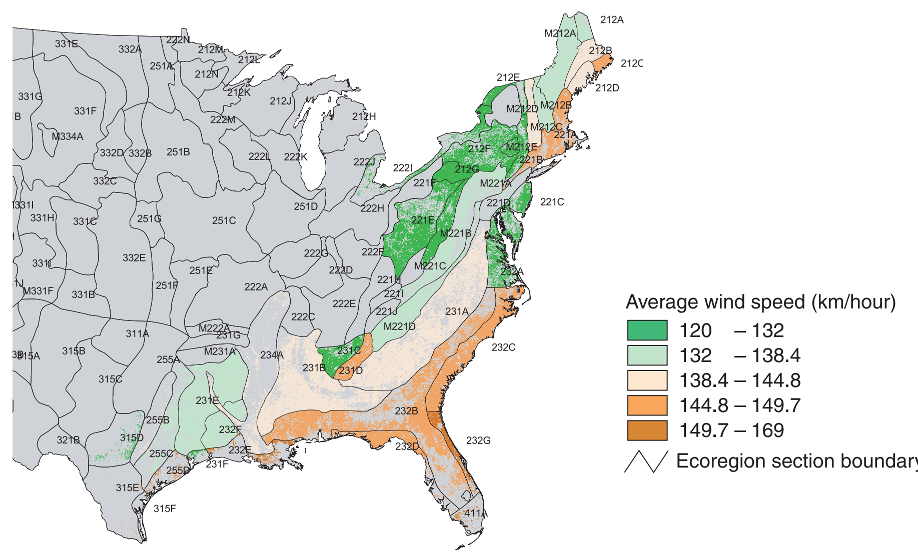

Figure 6—(A) hurricane track density in m/km² and (B) average wind speed in km per hour for forested areas by ecoregion section in which hurricane tracks occurred from 1861 through 2000.

Tornadoes are more localized and random than hurricanes, but they are also important forest disturbances. They can influence many of the same ecosystem characteristics that hurricanes do, but on a smaller scale. Tornadoes are a product of mesoscale climatic conditions. Their formation may be influenced by climate change, but currently these events are below the resolution of GCMs (Dale and others 2001).

From 1961 through 1990, the number of reported tornadoes (Fujita Scale F1 = 118 km/hour or greater) averaged 514 per year. Of the reported storms, 59 percent were classified as F1 (118–181 km/hour), 31 percent as F2 (182–253 km/hour), 8 percent as F3 (254–332 km/hour), 2 percent as F4 (333–418 km/hour), and < 1 percent as F5 (419–512 km/hour). Tornadoes were reported in almost every ecoregion section, but the Central United States experienced most of the activity (fig. 7). Section 251G—Central Loess Plains had the greatest tornado track density (approximately 75 m/km^2). However, there is little forested land in this section. Section 231C—Southern Cumberland Plateau, which is approximately 73 percent forested based on Zhu and Evans (1994), had a tornado track density of approximately 66 m/km^2 (fig. 7). Other forested ecoregion sections that experienced relatively high tornado occurrences (≥ 51 m/km^2) were Sections 222K—Southwestern Great Lakes Morainal; 222F—Interior Low Plateau, Bluegrass; and 231B—Coastal Plains, Middle.

Fire is a powerful, selective regulatory mechanism in forest ecosystems. It is a natural part of the environment, and fire-dependent ecosystems are adapted to 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. Historically, most fires were started by lightning strikes. Humans have altered historic fire regimes through fire suppression, tree harvesting, accidental ignition, and prescribed burning. Changes in either the frequency or the intensity of fire can alter the species composition, age structure, and soil characteristics of a fire-adapted community (Kimmins 1987).

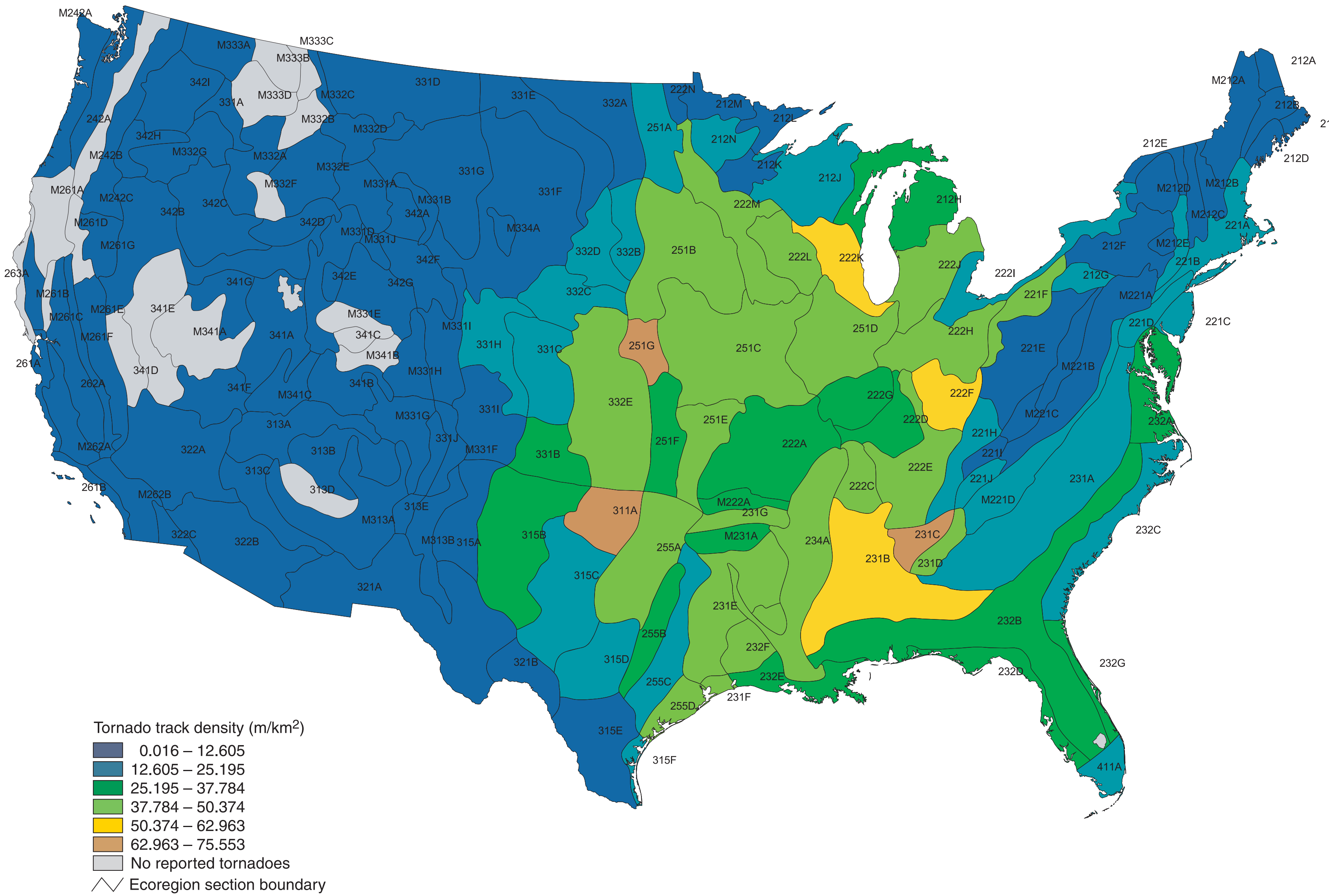

Figure 7—Tornado track density in m/km² by ecoregion section from 1961 through 1990.

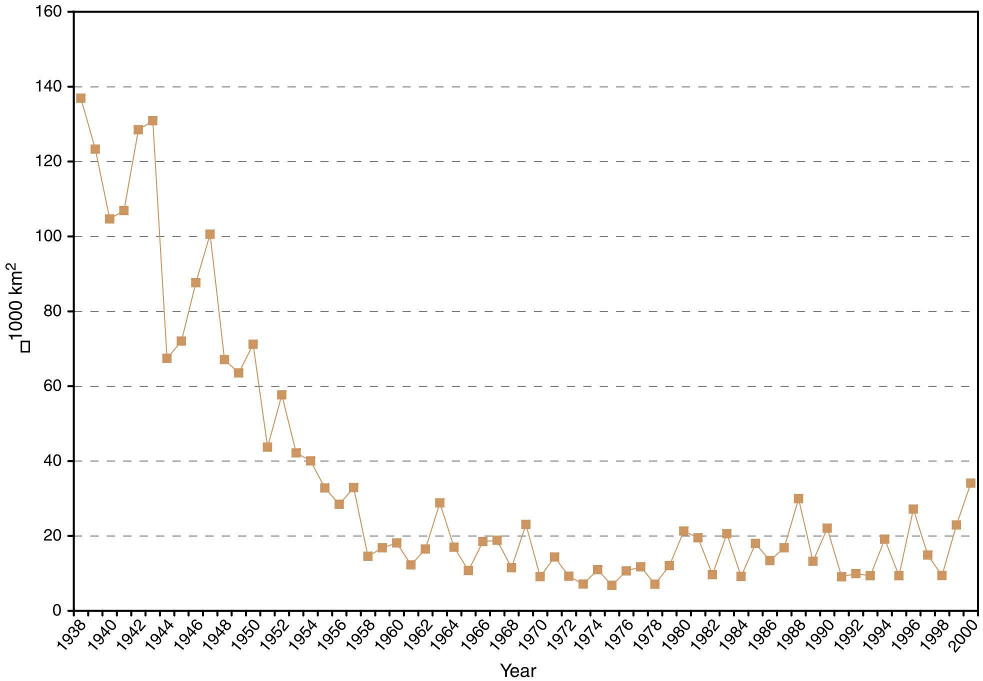

Figure 8—Areal extent of wildfires from 1938 through 2000.

From 1938 to 2000, the areal extent of wildfires varied from approximately 136 900 km^2 in 1938 to approximately 6800 km^2 in 1975 (fig 8). There was a marked reduction in the areal extent of wildfire between 1938 and 1957. After 1957, there was a relative leveling off. However, 2000 was one of the most intense years of fire activity, to date, in the Western United States since 1916 (Ciesla and Coulston 2004). Examining temporal trends in the areal extent of wildfire does not address any change in the intensity of wildfires or any spatial differentiation. Another way to assess fire disturbance is by examining current condition classes.

Current condition classes categorize departure from ecological conditions compatible with historic fire regimes based on five ecosystem attributes (Schmidt and others 2002). The attributes are (1) disturbance regimes, (2) disturbance agents, (3) smoke production, (4) hydrologic function, and (5) vegetative attributes. Three condition classes were assigned to represent departures. Current condition class 1 represents a minor deviation from ecological conditions compatible with historic fire regimes, and condition class 2 represents a moderate deviation. Current condition class 3 represents a major deviation from the ecological conditions compatible with historic fire regimes.

In the coterminous United States, 38.7 percent of forested land was classified in condition class 1 (minor deviation from conditions compatible with historic fire regimes), 37.5 percent was classified in condition class 2 (moderate deviation), and 23.8 percent was classified in condition class 3 (major deviation). Most of the forest area classified in condition class 1 was in the Southeastern United States (fig. 9). Other areas, such as Section M242A—Oregon and Washington Coast Ranges, were also of note with approximately 87 percent of the forest land classified in condition class 1. Several areas were classified as having a major deviation from ecological conditions compatible with the historic fire regime. Many of these areas were in the Lauretian Mixed Forest Province (212) (fig. 9). In the Northern Minnesota and Ontario Section (212M), approximately 80 percent of the forested area was classified in condition class 3. About 75 percent of the forest land in Section 212G—Northern Unglaciated Allegheny Plateau was classified in condition class 3. Sections 212F—Northern Glaciated Allegheny Plateau and 212K—Western Superior had 70 and 65 percent of the forest land, respectively, in condition class 3. In the Interior West, Sections M334A—Black Hills, M333D—Bitterroot Mountains, and 331J—Northern Rio Grande Basin all had approximately 50 percent or more of the forested area classified in condition class 3.

Biotic Disturbances

Insects and pathogens are a natural part of ecosystems and are essential to ecological balance in natural forests (Castello and others 1995). Their populations are influenced by climate, management activities, natural tree defenses, and natural enemies. Nonnative insects and pathogens pose a particular threat because ecosystems often lack natural internal controls of these agents. Insects and pathogens influence forest succession, productivity, and stability through complex ecosystem interactions (Berryman 1986). They affect pattern and process of forested landscapes mostly through tree mortality, reduced tree vigor, or both. These effects may occur at small scales or large scales and at any seral stage (Castello and others 1995).

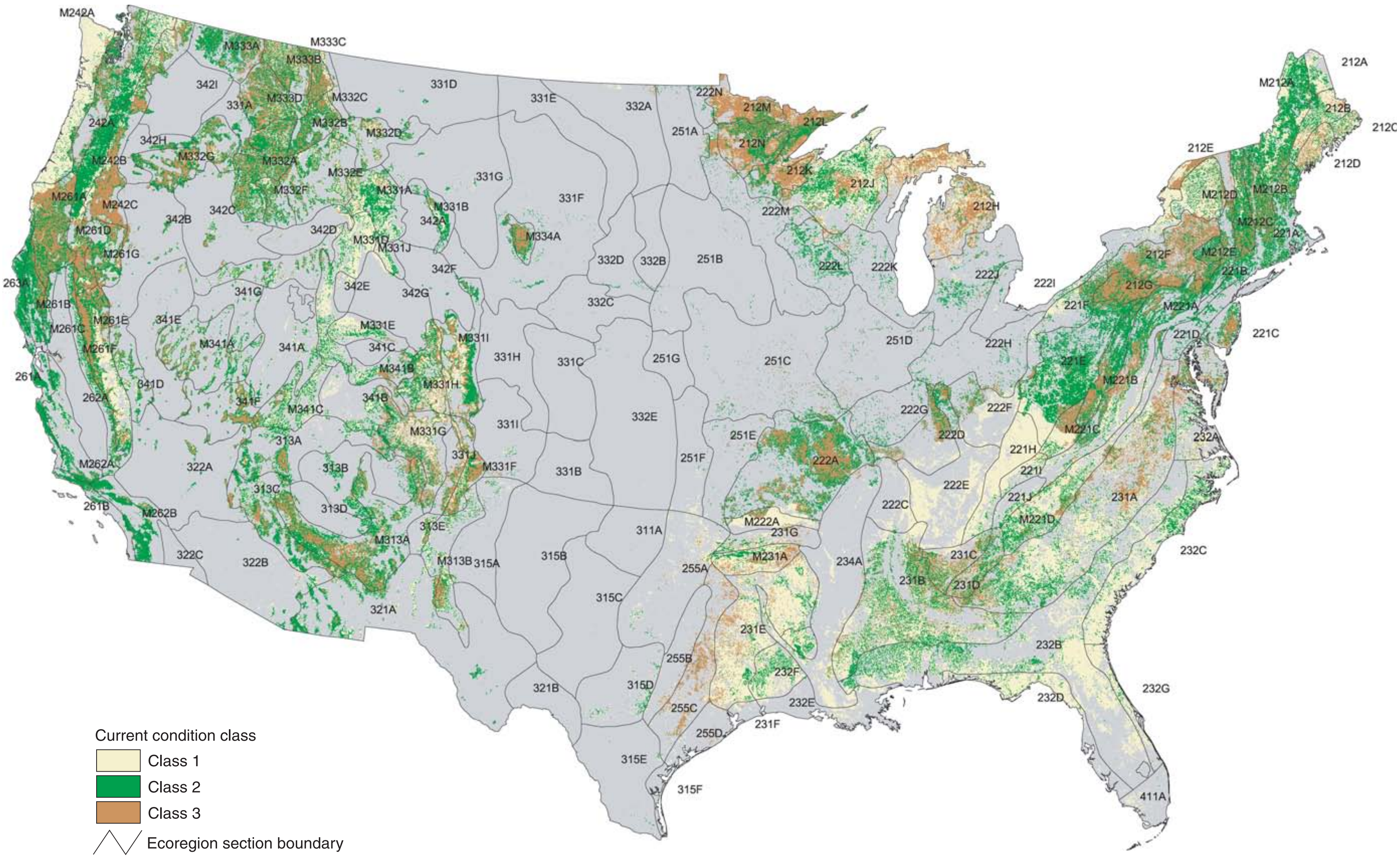

Figure 9—Deviation from ecological conditions compatible with historical fire regimes. (See text for explanation.)

We used the nationally compiled FHP aerial survey data from 1996 to 2000 to assess disturbances from both native and exotic insects and pathogens.[7] [8] Each agent was classified by FHP as mortality- or defoliation-causing. Short-term spatial trends (1996–2000) in exposure to mortality- and defoliation-causing agents were assessed on a county basis within each FHM region (see footnote 7). Counties were used because they constituted the finest consistent spatial resolution of the available data. Exposure was defined as the forested area in acres with mortality- or defoliation-causing agents present. The short-term spatial 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.

Expected amounts of exposure were based on a Poisson model (see Kulldorff 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 agents, and used to identify forested areas within FHM regions that were hot spots as compared to the rest of the region. The actual calculated value ranged from zero to infinity, where less than one represented low relative exposure and less-than-expected defoliation or mortality within the region. A value of greater than one represented more-than-expected exposure to defoliation- or mortality-causing agents within the FHM region of interest. The measure is linear, so a relative exposure value of two indicates an area has experienced twice the exposure expected for the region.

[7] Data were from 1996 through 2000 for all FHM regions except the South, where data were from 1998 through 2000.

[8] U.S. Department of Agriculture, Forest Service, Forest Health Protection. Aerial survey data. On file with: Forest Health Technology Enterprise Team, Information Technology, 2150 Centre Ave., Building A, Suite 331, Fort Collins, CO 80526–1891.

From 1996 through 2000, 44 different species of mortality-causing agents were recorded in the coterminous United States. In the North FHM region, the most intense activity was recorded in parts of Sections M221B—Allegheny Mountains and M221A—Northern Ridge and Valley (fig. 10). Forested areas in the southern portion of Section M212C—Green, Taconic, Berkshire Mountains also had triple the expected exposure rates. In the South FHM region, southern pine beetle was the predominant mortality-causing agent recorded. Section 231A—Southern Appalachian Piedmont had the most intense exposure. However, other southern ecoregion sections, such as 221J—Central Ridge and Valley, 221I—Southern Cumberland Mountains, 221H—Northern Cumberland Plateau, and M221D—Blue Ridge Mountains, had widespread areas of forest with greater than twice the expected exposure to mortality-causing agents. The North Central FHM region had only a few hot spots of activity. Triple the expected exposure rates were found in parts of Sections 222L—North-Central U.S. Driftless and Escarpment, M334A—Black Hills, and parts of 222A—Ozark Highlands. The Interior West FHM region had widespread activity of mortality-causing agents (fig. 10). The most intense activity was found in Sections M333D—Bitterroot Mountains, M331I—Northern Parks and Ranges, and M331H—North-Central Highlands and Rocky Mountain. In the West Coast FHM region, forested areas with more than triple the expected exposure to mortality-causing agents were in ecoregion Sections M333A—Okanogan Highlands, M242C—Eastern Cascades, and M261E—Sierra Nevada.

The other class of insects and pathogens examined were defoliation-causing agents. There were 98 different species of defoliation-causing agents recorded in the coterminous United States from 1996 through 2000. In the North FHM region, the most intense defoliation-causing agent activity was in the southern extent of Section 221E—Southern Unglaciated Allegheny Plateau (fig. 11). There were also several areas along Sections M221A—Northern Ridge and Valley and 212G—Northern Unglaciated Allegheny Plateau with more than double the expected exposure to defoliation-causing agents. In the South FHM region, there

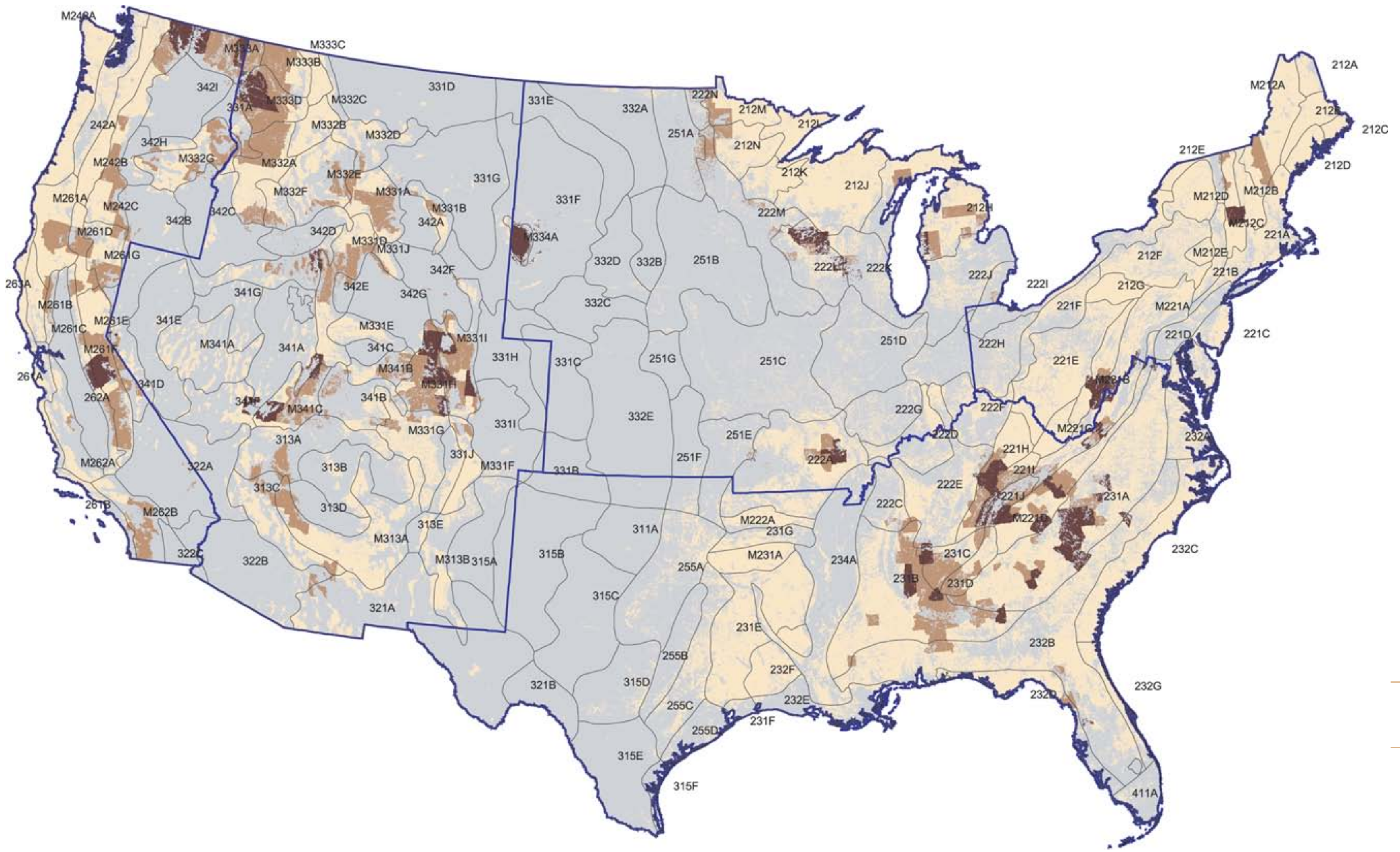

Figure 10—Relative exposure of forests to mortality-causing agents by FHM region from 1996 through 2000. (See text for explanation.)

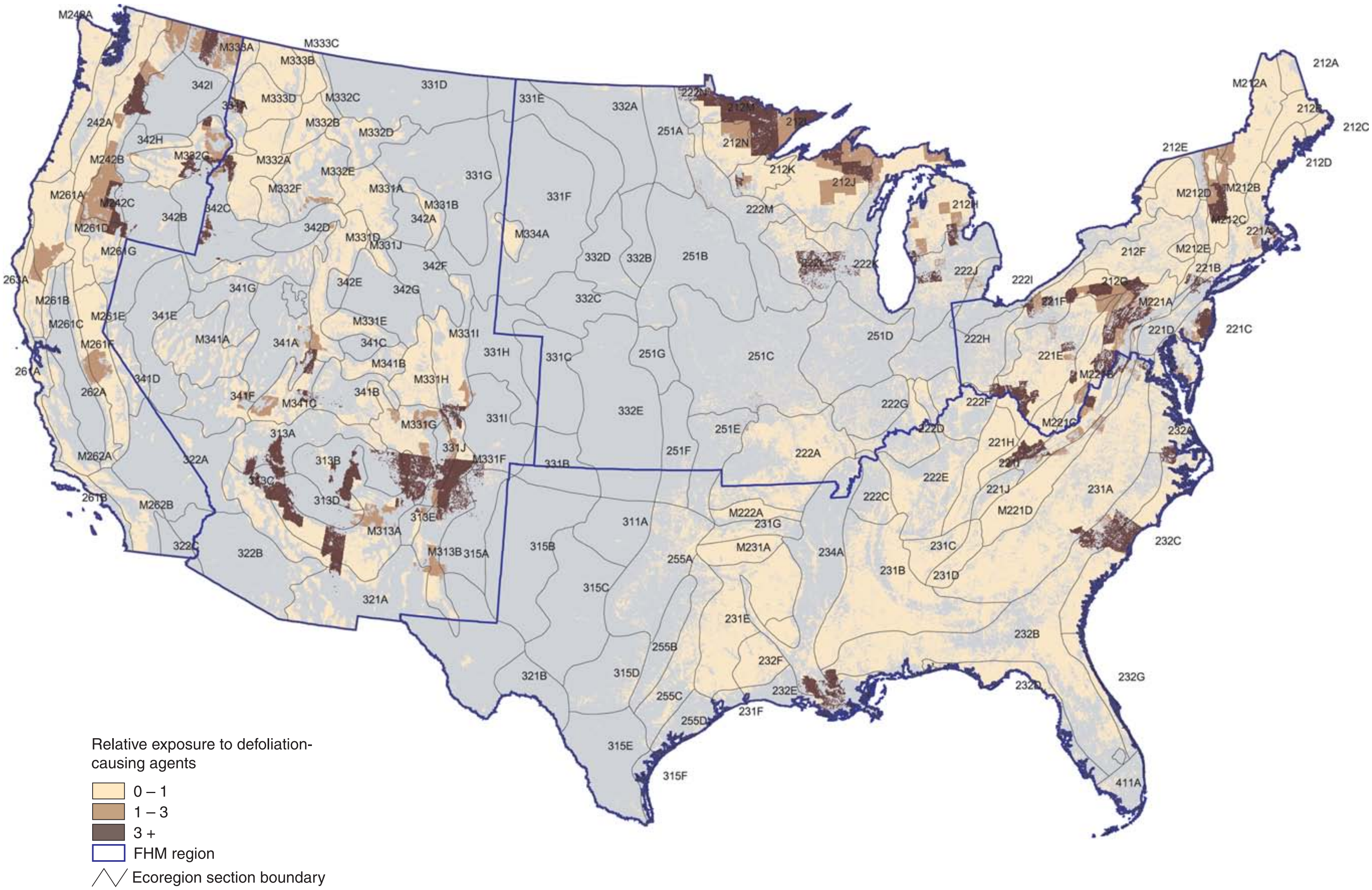

Figure 11—Relative exposure of forests to defoliation-causing agents by FHM region from 1996 through 2000. (See text for explanation.)

were three hot spots of defoliation-causing agent activity. The most intense activity was in Section 232E—Louisiana Coast Prairies and Marshes and the southern extent of the Mississippi Alluvial Basin sections. Portions of Sections 232C—Atlantic Coastal Flatlands and 232B—Coastal Plains and Flatlands, Lower also had over three times the expected exposure rates for the region (fig. 11). In the North Central FHM region, the most intense defoliation-causing agent activity was in Section 222L—North-Central U.S. Driftless and Escarpment. However, Sections 212L—Northern Superior Uplands and 212M—Northern Minnesota and Ontario also had portions of the forested area with more than triple the expected exposure for the region. The most intense activity in the Interior West FHM region was in the southern portion of the region (fig. 11). The most intense activity of defoliation-causing agents was in Sections M331F—Southern Parks and Rocky Mountain Ranges, 331J—Northern Rio Grande Basin, and M331G—South-Central Highlands. There were also several areas in Section M313A—White Mountain—San Francisco Peaks—Mogollon Rim with more than three times the expected exposure. In the West Coast FHM region, the most intense activity from defoliation-causing agents was in Sections M242C—Eastern Cascades and M333A—Okanogan Highlands.

Anthropogenic Disturbances—Introduced Species and Land Development

Introduced species, e.g., plants, animals, insects, and pathogens, can alter forest ecosystems rapidly under favorable conditions. We consider introduced and exotic species to be synonymous and use the following definition: “Any species growing or living outside its natural range of occurrence. Normally this refers to species purposely or accidentally introduced into countries or regions where they do not historically occur” (U.S. Department of Agriculture, Forest Service 2004). Diversity, nutrient cycles, forest succession, and fire frequency and intensity in some ecosystems can be influenced by the introduction of species (Dale and others 2001). While species are introduced mainly through human activity, the successful invasion of any ecosystem also depends on climatic conditions, openings for the

Table 2—Partial list of introduced insects and diseases in the United States

Common name	Scientific name	Host affected	Type of damage
Introduced insects			
Gypsy moth	*Lymantria dispar* (Linnaeus)	Broadleaf trees	Defoliation
Hemlock woolly adelgid	*Adelges tsugae* (Annand.)	Hemlock	Mortality
European pine shoot beetle	*Tomicus piniperda* (L.)	Pines	Shoot damage
Asian long-horned beetle	*Anoplophora glabripennis* (Motschulsky)	Broadleaf trees	Wood borer
Introduced diseases			
White pine blister rust	*Cronartium ribicola* Fisch.	5-needle pines	Mortality
Dutch elm disease	*Ophiostoma ulmi* (Buisman) Nannf.	Elm	Mortality
Beech bark disease	*Nectria coccinea var. faginata Loh., Wats, & Ay*	Beech	Decline and mortality
Diseases of unknown origin			
Dogwood anthracnose	*Discula destructiva*	Dogwood	Mortality
Butternut canker	*Sirococcus clavigignenti-juglandacearum*	Butternut	Mortality
Port-Orford-cedar root disease	*Phytophthora lateralis*	Port-Orford-cedar	Mortality
Pitch canker	*Fusarium subglutinans* (f. sp. *pini*)	Southern pines	Dieback and mortality
Sudden oak death	*Phytophthora ramorum*	Tanoak, oak	Dieback and mortality

introduced species, and the introduced species' ability to gain a competitive advantage in its new environment. Most introduced species do not survive because the environmental conditions at their point of arrival are unfavorable.

Several introduced insects and diseases have become established in forested ecosystems of the United States (table 2). Gypsy moth is one of the most widely distributed introduced insects in the United States and can defoliate most broadleaf trees. Other introduced insects such as the hemlock woolly adelgid, the European pine shoot beetle, and the Asian long-horned beetle have become established in forested areas. Several diseases found in forested ecosystems are a result of introduced species. Beech bark disease, which is caused by a combination of agents, can deform and kill American beech trees. It is gradually spreading across the Northeastern States. Other diseases, such as the recently discovered sudden oak death, have unknown origins. Sudden oak death can cause dieback and kill tanoaks, oaks, and other species. The Forest Service is implementing a monitoring program to investigate this disease.

Land development clearly creates unnatural ecosystems because pristine ecosystems had no agricultural or urban lands. There are many impacts from land development. For example, before land was developed, species persisted only where they had competitive advantages in natural ecosystems. After land development, exotic species can become established on soils bared by clearing activities. The interfaces between forest and urban land, and between forest and agricultural land, are of particular concern (Kareiva and others 1993).

We assessed land development by considering (1) the total length of edge between forest and anthropogenic (urban and agricultural) landcover types, and (2) the percentage of all forest edge that was associated with anthropogenic landcover types using a national landcover map (excluding Alaska, Hawaii, and Puerto Rico) that was derived from 0.09-ha/pixel resolution Thematic Mapper imagery (Vogelmann and others 2001). The first indicator takes into account the total amount of forest and anthropogenic landcover types, whereas the second indicator reflects fragmentation of the amount of forest that is present.

We divided the landcover map into approximately 140,000 nonoverlapping landscapes of size 56.25 km^2. Within each landscape, the 124,500 edges between adjacent pairs of pixels were examined to identify edges that had forest on one side or the other. Then, the total forest edge was further categorized in terms of the landcover of the second pixel in the pair. If the second pixel was forest, the edge was labeled as “forest-forest.” If the second pixel was either urban or agriculture, the edge was labeled as “forest-anthropogenic.” Otherwise, the edge was “forest-other” (“other” included water, barren ground, grassland, shrubland, and wetland). Edges not involving forest pixels (the "other-other" edges) were excluded from this analysis.

The land development analysis was limited to the 126,716 landscapes that contained forest. Within each landscape, the total length of forest-anthropogenic edge equals the number of forest-anthropogenic edges multiplied by 30 m (the length of a pixel edge). The percentage indicator is the number of forest-anthropogenic edges, divided by the sum of forest-forest, forest-anthropogenic, and forest-other edges. Ecoregion section average values of the two indicators were computed over all the landscapes contained within each ecoregion section.

The national total length of forest-anthropogenic edge was about 15.5 million km. Individual landscapes contained between 0.0 and 1200.4 km of forest-anthropogenic edge; median and average landscape values were 28.8 and 122.1 km, respectively. Ecoregion section average landscape values ranged from 0.3 to 495 km. As expected, ecoregion sections that contain large agricultural or urban areas also contain the most forest-anthropogenic edge. The percentage of forest edge within landscapes that was associated with anthropogenic landcover varied from 0.0 to 100.0, and the national median and average landscape values were 7.2 and 16.2 percent, respectively. We found that the total length of forest-anthropogenic edge is large, and that there is a wide variety of edge conditions within individual ecosections. Interpreting the implications of the analysis is a current research topic. A fuller analysis of forest fragmentation is contained in the 2003 national report on sustainable forests (Darr 2004).

Discussion

We address a portion of the disturbances that influence forest ecosystems. Disturbances such as permanent flooding, salinization, small-scale windstorms, ice storms, and landslides are not included in this report. Similarly, no information about domestic animals' influence on forested ecosystems was included. As consistent, national-scale data about these disturbances are developed and become available, the data will be included in future analyses.

Abiotic disturbances have always influenced forest ecosystems, and ecosystems are generally adapted to the disturbance regime under which they developed. As global climate patterns change, the occurrence and intensity of some disturbances such as drought, hurricanes, and tornadoes may also change. Present plant taxa have previously experienced these types of climatic changes. For example, during the Pliocene (approximately 3 million years ago), the climate was generally warmer (about 1 °C) and changing faster (average annual change of 1.4 °C annually) in the Northern Hemisphere than it is today (Chandler and others 1994). Some of the adaptations to climate change include shifts in species ranges and forest composition (Iverson and Prasad 2002). Melillo (1999) points out that the composition of one-third of the World's forests could markedly change in response to the climate change associated with a doubling of atmospheric CO_2. While climate change and disturbances associated with climatic events may lead to a spatial rearrangement of plant taxa, it does not appear that these changes are out of the range of historic variation.

Historically, fire occurrence was partially regulated by climate, climatic disturbances, and the local forest community structure. Climate shifts based on GCMs generally point to an increase in the season severity rating of fire hazard over most of the United States. However, Bergeron and Archambault (1993) found some historical studies suggesting that fire frequency decreased with increased precipitation despite warmer temperatures during the Holocene. Currently, fire occurrence is also regulated by fire suppression and other management activities. Fire suppression without active management can alter the fire regime under which the community developed [see Monnig and Byler (1992) for lodgepole pine example]. Note that the degree of ecosystem alteration depends on the relative importance of fire in the ecosystem of interest; and that as the frequency of fire changes, the intensity of fire may also change. It is unclear if fire occurrence and intensity are out of the range of historic variation because most of the paleoecological studies are based on analysis of charcoal covering only the last 8,000 years and small spatial scales [see Clark (1990) for example].

Insect and pathogen populations and activity are regulated partly by climatic factors and ecosystem structure as well as their own internal regulatory processes (population dynamics). Climate shifts can influence interactions between plants and insects, plants and pathogens, or both by influencing nutritional requirements and food quality (Kareiva and others 1993). Insect and pathogen activity can also be influenced by fire suppression. In some cases, lack of fire causes ecosystem stress and weakens natural plant defenses. This situation may allow insect and pathogen outbreaks to last longer and be more severe. However, it is not clear at this time whether insect and pathogen activity is out of the range of historic variation.

Anthropogenic disturbances are clearly out of the range of historic variation. Land development and introduced species can move ecosystems out of the range of historic variation quickly. Historically, species migrated in short, incremental steps and became established in new areas where they had competitive advantages. Today, with the aid of humans, they can move long distances over a short time. Further, because of land development, more openings are available for nonnative species to become established in new environments.

Disturbances, whether anthropogenic or natural, play a role in the overall health and vitality of forested ecosystems. These disturbances help form the current composition, structure, and functional processes of forested ecosystems. Comparing disturbances and their interactions to the range of historic variation is difficult and cannot be completed without a definition of the range of historic variation. We consider a geologic time scale, but several other reference periods can be used (e.g., Ciesla and Coulston 2004). As disturbance regimes change, forest ecosystems are likely to move slowly toward a new equilibrium.

Forest Land Subjected to Air Pollutants

That May Cause Negative Impacts on the Forest Ecosystem

Introduction

Air pollution effects on terrestrial ecosystems are an important environmental issue in the United States. Acid deposition and ozone are primary concerns. Acid deposition can affect soil and water acidity (Driscoll and others 2001), and ozone can cause foliar injury (Chappelka and Samuelson 1998, Cleveland and Graedel 1979, Lefohn and Pinkerton 1988). Low dosages of air pollutants can have negligible effects on forest ecosystems. Moderate dosages may reduce growth, change species composition, and alter insect or disease interactions. High dosages, such as those associated with a major point source, may affect hydrology, nutrient cycling, erosion, and overall ecosystem stability. These impacts can influence forest productivity and diversity (Kareiva and others 1993).

The main pollutants affecting forested ecosystems are sulfur (S), nitrogen (N), and tropospheric ozone (Driscoll and others 2001, Hakkarienen 1987). Emissions of gaseous sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are wet deposited as sulfate and nitrate in forested ecosystems by rain, snow, and sleet. Inputs of S and N also can occur as dry deposition (not discussed in this report), or from cloud/fog drip, which is most common at high elevations and in coastal areas. Plant uptake of tropospheric ozone occurs during gas exchange. These air pollutants and their effects are an issue across forested landscapes because of long-range transport of contaminated air masses. For example, prevailing West-to-East winds are responsible for pollutants emitted in the Midwest being deposited in New England (Driscoll and others 2001).

Sulfur can generate acidity when it enters ecosystems. The main terrestrial concern about these inputs is the depletion of base cations, such as calcium, magnesium, and potassium (Ecological Society of America 1999). However, base cation depletion and release of acid cations, i.e., hydrogen and aluminum, ultimately depend on the soil's ability to neutralize strong acid inputs (Driscoll and others 2001). There is evidence that S is accumulating in Northeastern U.S. soils (Driscoll and others 1998). While there have been decreases in S deposition in recent years, watershed mass balances in the Northeast have shown that loss of S exceeds inputs from deposition, suggesting that S has accumulated in the soil. DeHayes and others (1999) hypothesized that acid deposition causes stress to trees and is a concern to forest productivity and health. Acid deposition may interfere with calcium nutrition and calcium-dependent physiological processes that play a role in plant responses to numerous environmental stresses, including low temperature.

In most temperate forests, growth is limited by insufficient supplies of available N. However, accumulation of N in soils and N saturation are concerns because N saturation can lead to base cation leaching, decreased plant function, loss of fine root biomass, and decreases in symbiotic mycorrhizal fungi (Ecological Society of America 1999).

Tropospheric ozone is produced from photochemical reactions of precursors such as NO_x and hydrocarbons. Ozone can impact tree physiology and growth, forest succession, and forest species composition, and causes visible injury on some forest tree species (Hakkarienen 1987, Miller and Millecan 1971, Skelly and others 1987, Treshow and Stewart 1973). Ozone-induced tree stress may also influence forest insect and pathogen activity. Economic impacts are possible if growth rates of commercially important tree species are reduced. Ozone sensitivity varies among tree species. Some species also demonstrate a genetically variable response. Bennett and others (1994) suggested this type of species-specific tree decline explains the apparent elimination of hypersensitive white pine genotypes from the population.

Forest landscapes are highly variable in their sensitivity to pollution, and complex interactions exist among pollutants. In the case of acid deposition, high-elevation areas with shallow soils and a low buffering capacity are particularly sensitive (Ecological Society of America 1999). Lower elevation forests with deeper soils generally are not as sensitive, but there are exceptions. Land use history also influences sensitivity to acid deposition (Ecological Society of America 1999). Some tree species such as black cherry are very sensitive to ozone exposure (Krupa and Manning 1988). Others such as sugar maple are tolerant (Renfro 1992).

Several environmental conditions such as light, temperature, relative humidity, and soil moisture ultimately determine ozone uptake and plant response (McCool 1998). Interactions among air pollutants also are important in identifying the overall impacts on forest ecosystems. For example, Takemoto and others (2001) hypothesize that increased N supply from deposition could moderate for several decades the harmful effects of tropospheric ozone on trees growing in N-deficient soils of California's mixed-conifer forests. In other instances, empirical studies provide evidence of additive effects, synergistic effects, or no interaction among pollutants (for example, Izuta 1998, Shan and others 1996). Pollutant interactions, inherent variability, and lack of understanding of the total ecosystem response to air pollution force large-scale assessments to be simplistic and to overlook many of the details understood at smaller spatial scales. However, participants in the "Roundtable on Sustainable Forests" (2000) considered air pollutants to have a significant cumulative impact on forest ecosystems by affecting regeneration, productivity, and species composition.

Brief Methods

We examined wet nitrate and sulfate deposition from 1994 through 2000, ozone exposure for 1999 and 2000, and ozone-induced foliar injury from 1994 through 2000. The SUM60 ozone index (sum of all hourly concentrations > 60 parts per billion) was used to quantify ozone exposures for the 3-month growing season (June, July, and August). Ozone-induced foliar injury was based on a biosite index (BI) ("Appendix A, Supplemental Methods, Ozone Biomonitoring"). Average values of wet sulfate and nitrate deposition, SUM60 ozone, and the BI were then calculated for each ecoregion section. The following specific thresholds for the BI were used:

Biosite index categories, risk assumption, and possible impact

BI category	Assumption of risk	Possible impact
1. BI < 5 Little or no foliar injury	None	Tree-level response Visible injury to leaves and needles
2. BI ≥ 5 to < 15 Low foliar injury	Low	Tree-level response Visible and invisible injury
3. BI ≥ 15 to < 25 Moderate foliar injury	Moderate	Tree-level response Visible and invisible injury
4. BI ≥ 25 Severe foliar injury	High	Structural and functional changes Visible and invisible injury

BI = biosite index.

These thresholds were based on information presented in[9] Coulston and others (2003) and Smith and others (2003). No thresholds were applicable across ecoregion sections for wet nitrate and sulfate deposition and SUM60. In these cases, we identified ecoregion sections that could be classified as outliers by examining the upper 5 percent of the normal density function for each variable. Identifying the outliers provided information about areas that had much higher deposition than the mean deposition. For more information, see "Appendix A, Supplemental Methods, Wet Deposition and SUM60 Ozone."

Results

In the coterminous United States, the average ecoregion section received 8.4 kg/ha/year of wet sulfate deposition from 1994 through 2000. Section 221E—Southern Unglaciated Allegheny Plateau had the highest deposition rate—an average of 23.6 kg/ha/year deposited over the 7-year period (fig. 12). Generally, wet sulfate deposition was highest in eastern ecoregion sections where 20 sections were classified as outliers (fig. 12). These sections extended from M221D—Blue Ridge Mountains to 212F—Northern Glaciated Allegheny Plateau and west to 222G—Central Till Plains, Oak-Hickory.

Wet nitrate deposition was also highest in the Eastern United States, and many of the areas classified as outliers with respect to sulfate deposition were also classified as outliers with respect to nitrate deposition (fig. 13). Section 222I—Erie and Ontario Lake Plain had the highest wet nitrate deposition rate where an average 18.9 kg/ha/year were deposited from 1994 through 2000. During this period, the average wet nitrate deposition rate across ecoregion sections was 7.4 kg/ha/year.

SUM60 ozone concentrations were highest in Section M261F—Sierra Nevada Foothills where the average exposure for 1999 and 2000 was 50.7 parts per million-hours (fig. 14). However, relatively high concentrations were also found across the Southeast. Two distinct groups of ecoregion sections were classified as outliers. One group was in the Eastern United States and ranged from Section 222C—Upper Gulf Coastal Plain to Section 231A—Southern Appalachian Piedmont. In the Western United States, 10

[9] Smith, G.C. 1995. FHM 2nd ozone bioindicator workshop—summary of proceedings. 12 p. Unpublished manuscript. On file with: U.S. Department of Agriculture Forest Service, Forest Health Monitoring Program, 3041 Cornwallis Rd., Research Triangle Park, NC 27709.

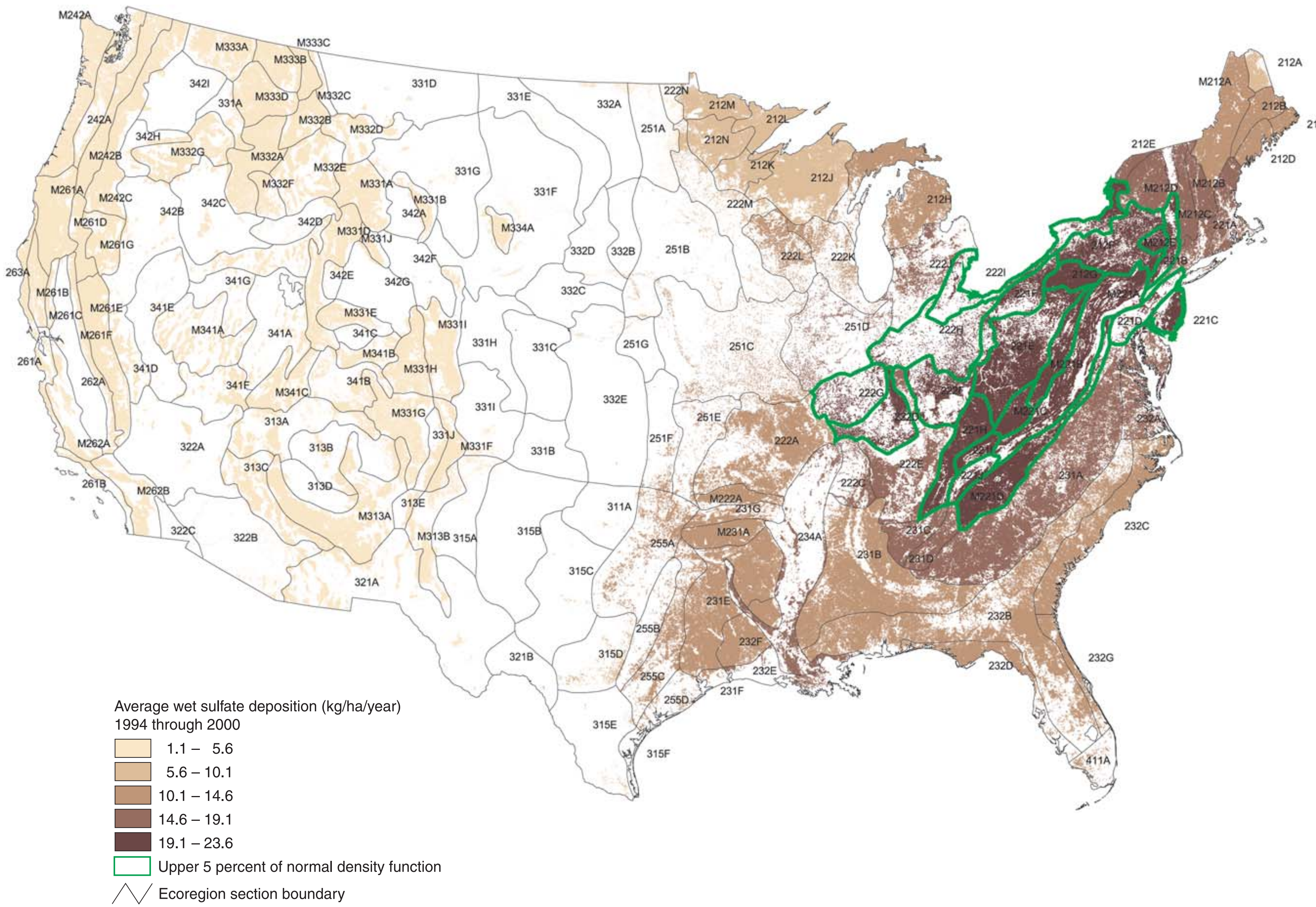

Figure 12—Average wet sulfate deposition (kg/ha/year) from 1994 through 2000.

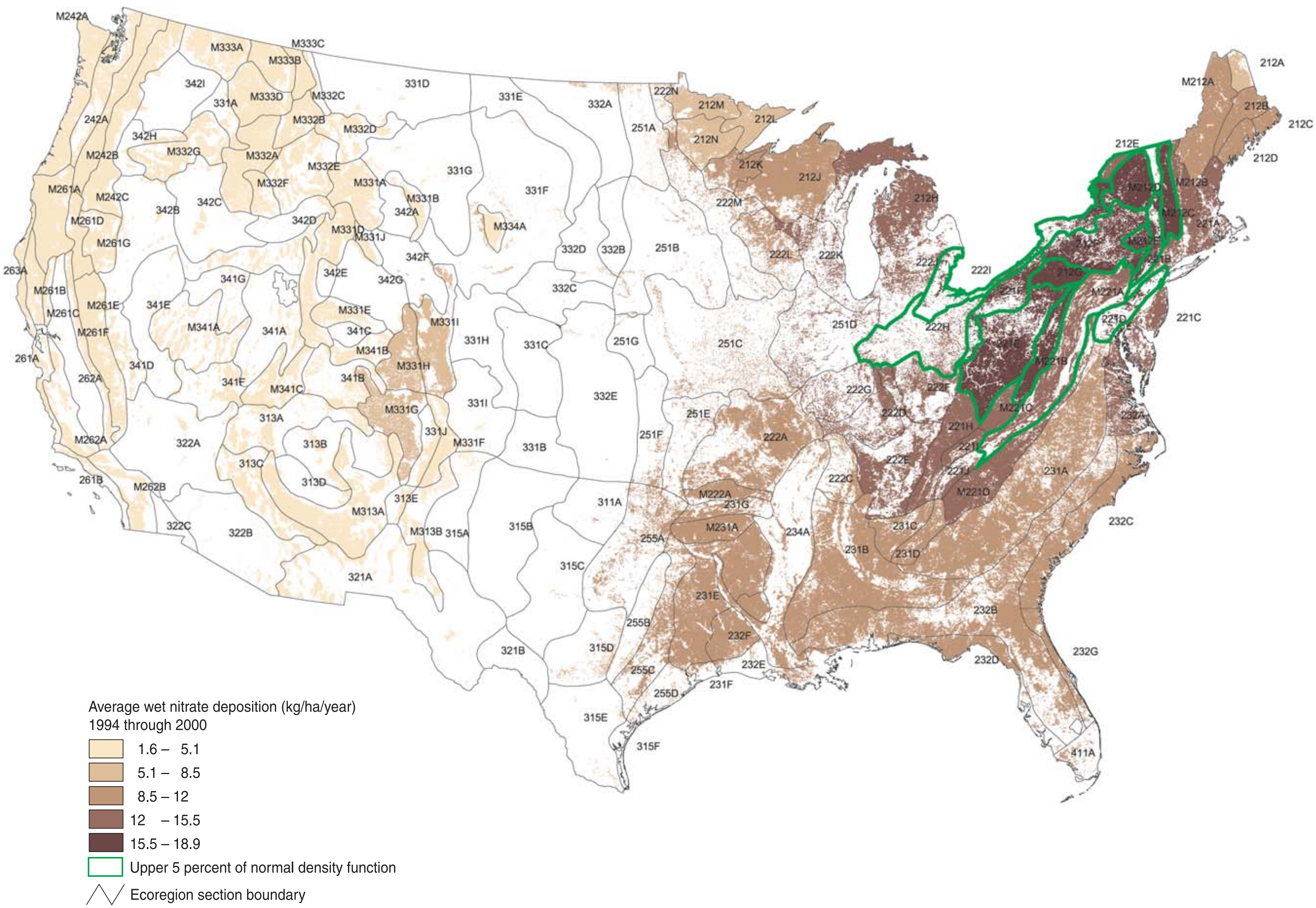

Figure 13—Average wet nitrate deposition (kg/ha/year) from 1994 through 2000.

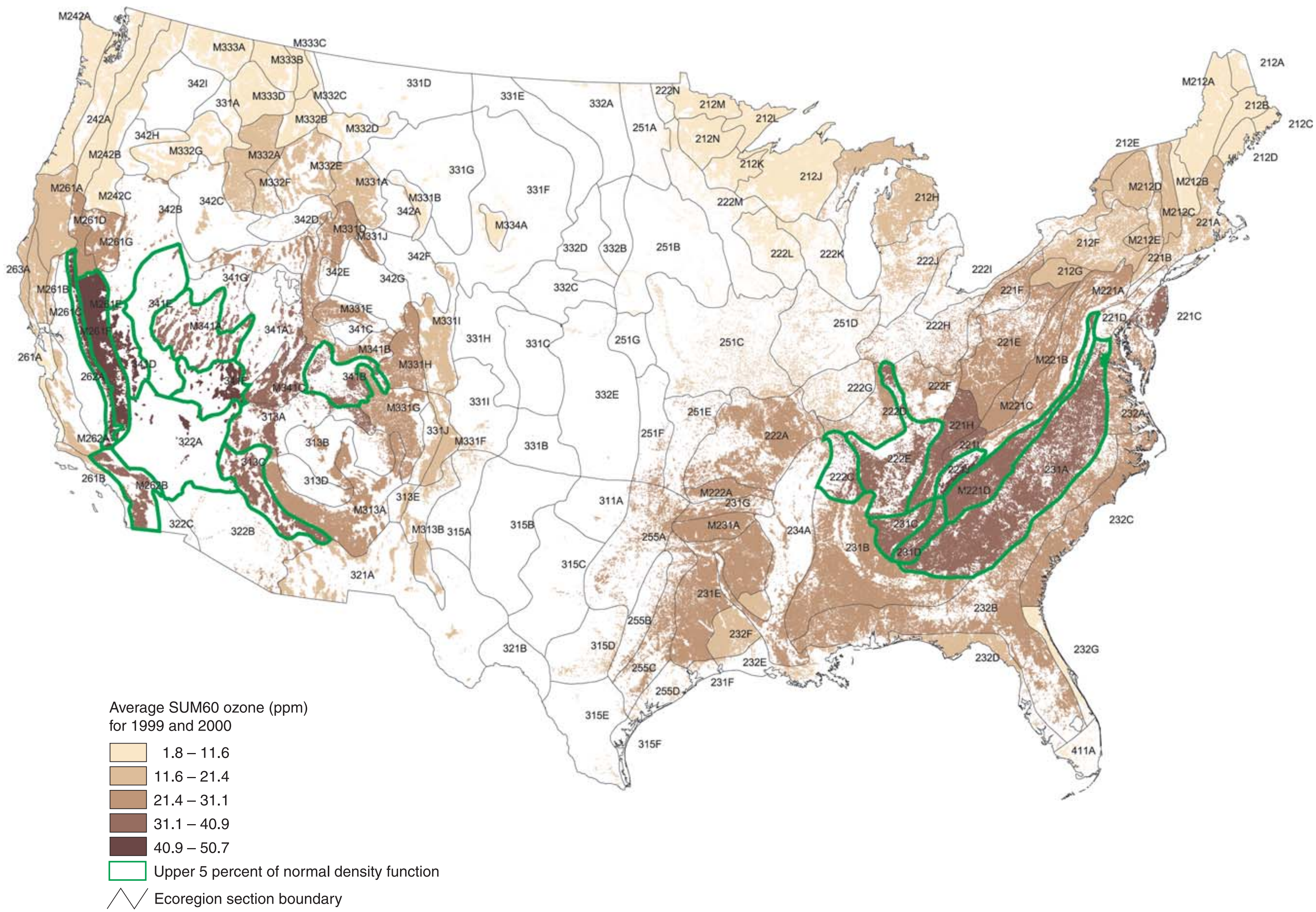

Figure 14—Average SUM60 ozone in parts per million for 1999 and 2000.

ecoregion sections ranging from the Sierra Nevada Foothills (M261F) to the Northern Canyon Lands (341B) were classified as outliers (fig. 14).

While SUM60 ozone concentrations were relatively high in several ecoregion sections, ozone-induced foliar injury was not recorded everywhere. The average ecoregion section had a BI of 4.28 (1994–2000), which falls in the lowest risk category. In the Eastern United States, four ecoregion sections were classified in the highest risk category (BI > 25), and Section 222G—Central Till Plains, Oak-Hickory had the highest average BI (fig. 15). Section M261F—Sierra Nevada Foothills was classified as low risk and was the only western ecoregion section classified with any risk association.

Discussion

National Acid Precipitation Assessment Program (NAPAP) (1998) recognized several ecosystems as sensitive to acid deposition and as receivers of high-deposition rates. These included high-elevation spruce-fir forest, Colorado alpine meadows, and southern California urban forest. NAPAP's (1998) findings correspond with the results for the Eastern United States in this report. High-elevation spruce-fir forests generally are found in Sections M212C—Green, Taconic, Berkshire Mountains; M212D—Adirondack Highland; M221D—Blue Ridge Mountains; and M221A—Northern Ridge and Valley. Each of these ecoregion sections was classified as an outlier with respect to wet nitrate and/or wet sulfate deposition (figs. 12 and 13). The analysis presented here did not identify ecoregion sections in either Colorado or California as outliers, but only wet deposition was considered. Ecosystem sensitivity to acid deposition could not be addressed on a national level in this report.

Ozone concentrations were highest in the West and Southeast. Section M261F—Sierra Nevada Foothills experienced the highest 3-month growing-season ozone concentrations in the United States (fig. 14), and mixed-conifer forests in the Sierra Nevada have suffered stress from air pollution since the 1970s (Peterson and Arbaugh 1992). In these areas, ponderosa and Jeffrey pine are particularly sensitive to ozone. Increased sensitivity of ponderosa pine to bark beetles resulting from air pollution was

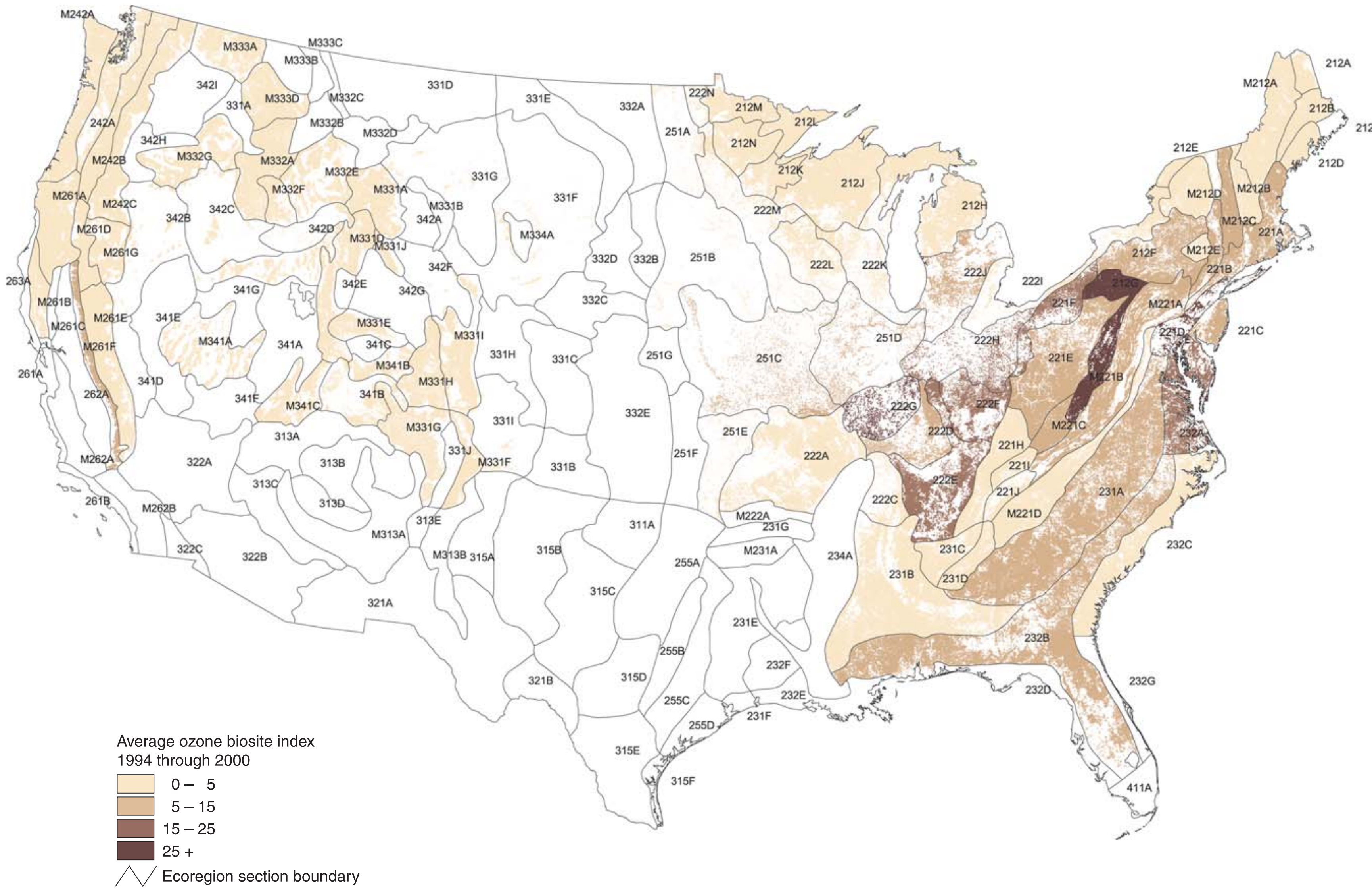

Figure 15—Average ozone biosite index by ecoregion section from 1994 through 2000.

documented as early as 1968 (Cobb and others 1968). Little ozone injury was recorded in these areas (fig. 15), but bioindicator sites are lacking in the ponderosa pine forests of southern California (Conkling and others 2005). In the Southeast, ozone concentrations are of particular concern for the loblolly-shortleaf forest type (Chappelka and Samuelson 1998, Taylor 1994). Dougherty and others (1992) suggested that at ambient levels of ozone in the South, an average, mature plantation-grown loblolly pine tree has a 3 percent loss of gross primary production. Based on 1994 through 2000 ozone biomonitoring data, Sections M221B— Allegheny Mountains and 212G— Northern Unglaciated Allegheny Plateau were classified in the highest risk category. Coulston and others (2003) found black cherry to be the ozone-sensitive species most at risk in these areas.

Ozone bioindicator data are the only nationally consistent information on plant injury from air pollution in the field, and this analysis shows that plant injury is not observed everywhere. Sulfate, nitrate, and ozone are known to be important stressors to forest ecosystems at smaller scales and numerous reports describe these impacts (for example, Bennett and others 1994, Takemoto and others 2001). While tree growth is not negatively affected in most cases, the additional stress can open the door for several secondary stressors such as insects and pathogens as Smith (1974) suggests, and Cobb and others (1968) document. Further, the cumulative effects of air pollution on forested ecosystems are not known. Subtle changes can create competitive advantages that over time may change the composition of forest ecosystems and their corresponding fauna (Kareiva and others 1993). In addition, there are interactions among pollutants that in some circumstances can mitigate the effects of the individual pollutants involved (Takemoto and others 2001); in other cases impacts can be cumulative (Shan and others 1996).

Forest Land with Diminished Biological Components

Indicative of Changes in Fundamental Ecological Processes and/or Ecological Continuity

Introduction

The rationale for this indicator is to evaluate the status of fundamental ecological processes that are essential to continued ecosystem health and vitality. However, because measuring most ecological processes directly is extremely difficult, the indicator is framed in terms of the conditions of biological components of the forest ecosystem that reflect the state of fundamental ecological processes.

Clearly, since forest ecosystems include the entire suite of forest biota, data about the entire range of forest species potentially could be incorporated into this indicator. However, the national scale data available for this report relate only to trees. In this report, tree mortality and poor tree health (as evidenced by tree damage and crown condition) are analyzed. In the future, information on other forest biota should be incorporated into the indicator.

Monitoring of some other components of forest ecosystems is being implemented on FIA phase 3 plots. Understory vegetation monitoring should provide information on biodiversity, changes in understory communities, and invasive exotics. Lichen monitoring should eventually indicate the effects of air pollution, climate change, or both on the lichen community and (possibly) on the fungal community (McCune and others 1997, 1998; Neitlich and others 1999; Stolte and others 1993). Monitoring of down woody debris will provide information on fuel loading affecting fire cycles (frequency and intensity), wildlife habitat, and carbon cycling. As of 2000, however, insufficient data had been collected on these three indicators to include them in a national scale analysis. Data on other forest ecosystem components from sources other than FIA also may be included in future analyses as these data become available on a national scale. Advances in basic research relating those biological components to ecological issues will also be required before such data can be integrated into our analyses.

Tree Mortality

Tree mortality is a natural part of any forest ecosystem. FHM estimates annual mortality, in terms of wood volume per acre, based on trees and saplings that have died since plot establishment. However, because growth rates vary by forest type and environmental conditions, a simple measure of mortality volume is not a good national scale indicator of forest health. For example, a greater tree volume may die in a healthy forest in the Southeast than the total live volume of some dry western forests. A more useful national mortality indicator is the ratio of annual mortality volume to gross volume growth (MRATIO) (Conkling and others 2005). 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 general method for estimating the MRATIO is described in appendix A. For more details on the method, see the "Forest Health Monitoring 2001 National Technical Report" (Conkling and others 2005).

The MRATIO 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. The ratio of the average dead tree diameter to the average live tree diameter (DDLD ratio) also 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). The DDLD ratio is most useful for analyzing mortality in regions that also have high MRATIOs. High DDLD values in regions with very low MRATIOs 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.

The following tabulation shows the years of FHM and FIA phase 3 plot data that were used for this analysis:

Years of FHM and FIA phase 3 plot data available for the mortality analyses

Years	States
1990–2000	CT, MA, NH, RI, VT
1990–1999	ME
1991–2000	AL, DE, GA, MD, NJ, VA
1992–1999	CA
1992–2000	CO
1994–1999	MI, MN, WI
1995–2000	WV
1995, 1998–99	PA
1996–1999	IN
1996–2000	ID
1997–2000	IL, OR, WA, WY
1998–2000	NC, SC
1999–2000[a]	NV, NY, TN, UT

[a] Results not reported for ecoregions sections located entirely within these States.

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 were collected using the FIA five-panel sampling design with no annual overlap (Bechtold and Patterson, in press).

An MRATIO estimate will be unreliable if it is based on few remeasured plots, data spanning very short time intervals, or both. Therefore, MRATIO values are reported only for ecoregion sections that are, at least partially, in States where at least two panels had been remeasured; i.e., in some portion of the ecoregion section the data span at least 3 years, and at least two-fifths of the plots had been remeasured. Values are also reported for ecoregion sections in Pennsylvania, where data were available from a single panel remeasured twice over a period of 5 years. (For more details about the FIA sampling method, see "Appendix A, Supplemental Methods, Analysis of FHM and FIA Ground Plot Data".)

Figure 16 shows MRATIOs by ecoregion section and plot-level DDLD ratios. The MRATIO values shown represent the annual mortality over the time periods from the earliest plot establishment in each section through 2000. The DDLD ratios are based on the mortality through the most recent measurement of each plot. This mortality analysis provides the most accurate picture of forest condition in areas where the number of forested sample plots is large relative to the size of the ecoregion section and the diversity of the forests found in the section, and where the age of stands at maturity is not extremely large relative to the time period spanned by the available data. Because mortality is a discrete event while growth is continuous, the deaths of very large, old trees can produce highly variable MRATIO estimates if the sample has an inadequate number of plots or too few years of data. Such MRATIO values can be difficult to interpret. For example, the MRATIO was very high (1.172) for ecoregion Section M261B—Northern California Coast Ranges. The reason for the high MRATIO was the death of one very large (52-inch diameter at breast height) Douglas-fir tree in 1998. The volume associated with that single dead tree was twice the remaining live volume on the plot. The data available for this analysis are inadequate for determining the rate at which such large trees die. To get a more accurate estimate of mortality rates in areas such as that one, with very large, old trees, we need more intensive sampling, much longer measurement periods, or both. Until more remeasurement data are collected from plots in this ecoregion section, one should not draw any strong conclusions from this MRATIO value. In general, one must exercise care in interpreting these results, because a sample that is adequate for characterizing some forests may be inadequate for forests such as the one described above.

Appendix table B.1 provides mortality summary statistics by ecoregion section. The reader should use these statistics together with the information in the above tabulation, which gives the years of data used in the analysis, when interpreting these results. For example, in Section M261B—Northern California Coast Ranges described above, the sample was relatively small (16 plots) and 9 years of data

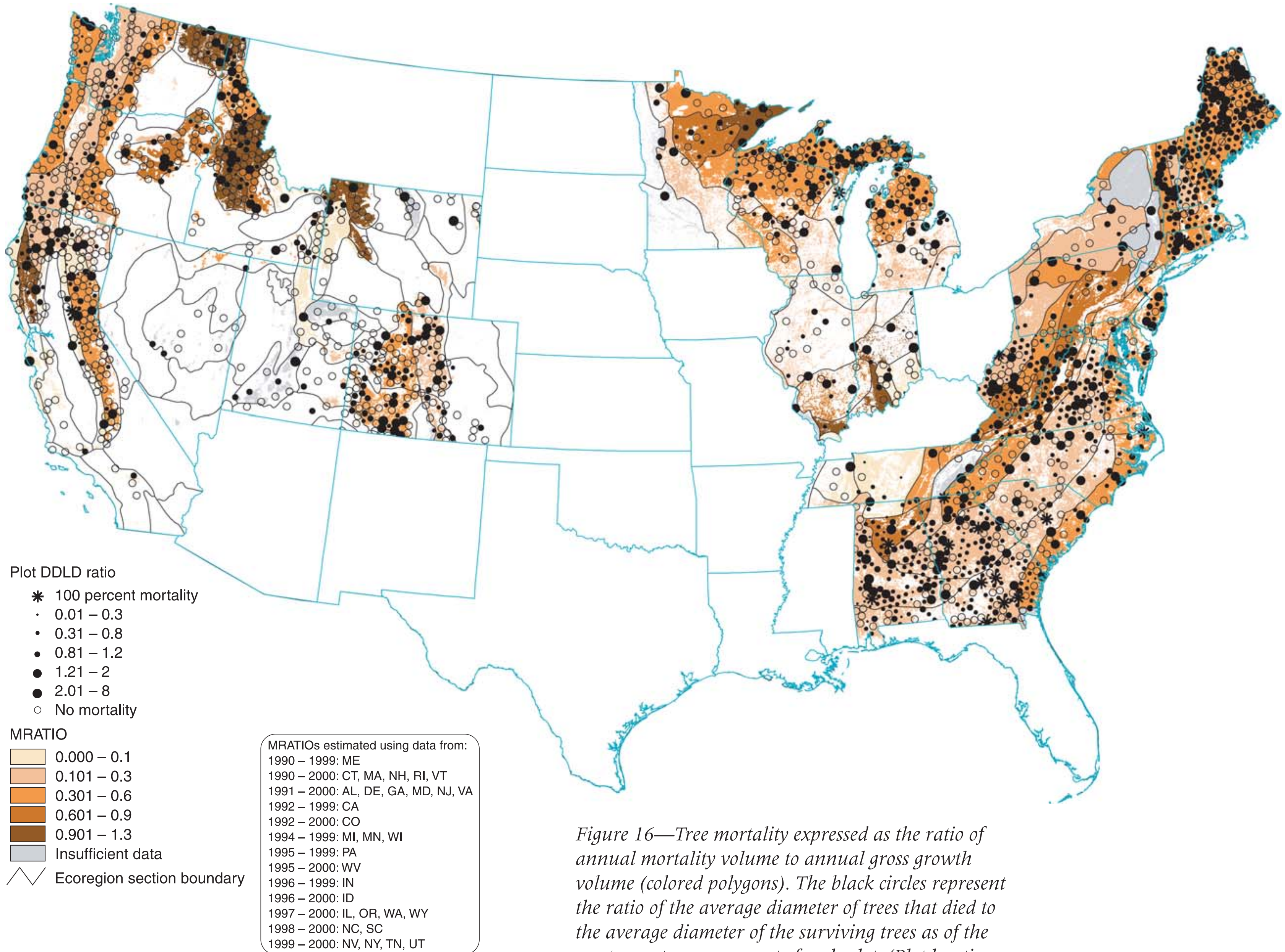

Figure 16—Tree mortality expressed as the ratio of annual mortality volume to annual gross growth volume (colored polygons). The black circles represent the ratio of the average diameter of trees that died to the average diameter of the surviving trees as of the most recent measurement of each plot. (Plot locations are approximate.)

were used. Only 7 of 16 plots experienced any mortality. The MRATIO is high, but so is its standard error, indicating high uncertainty in the estimate of mortality relative to growth. DDLD values ranged from 0.243 to 7.017 in this ecoregion section and plot mortality values ranged from 0.44 to 809.83 $feet^3$ per acre per year with a median value of 14.51 $feet^3$ per acre per year. These statistics indicated that on a few plots very large trees were dying. The large standard error of the MRATIO suggests that a larger sample might be necessary to accurately characterize this region.

There is greater uncertainty associated with the MRATIO estimate for any ecoregion section located mostly in States where not all panels of plots have been remeasured. There are two reasons for this: (1) the estimate was based on a small sample (few plots), and (2) the mortality and growth rates from which the MRATIO was calculated were estimated over a short time period. These factors are most likely to impact the results in the dry parts of the Western United States because (1) the number of forested plots may already be relatively small in ecoregion sections that are partially or mostly steppe, savannah, or open woodland; and (2) it can be difficult to estimate growth rates over short time intervals where forest growth is slow (diameter increments between measurements may be very close to the detection limit).

In such areas, MRATIO estimates may change a great deal from year to year as additional panels are remeasured. These changes generally do not represent genuine recent changes in forest condition between the last two measurement years. Rather, the newer MRATIO estimate should be considered to be a better characterization of the forest based on an expanded data set.

For example, in ecoregion Section M333A—Okanogan Highlands in northeastern Washington and northern Idaho, the MRATIO estimate changed greatly from 1999 (fig. 17A) to 2000 (fig. 17B). It is an area of relatively slow tree growth, so estimating mortality relative to growth is difficult. The MRATIO estimate was 0.957 in 2000 but only 0.230 in 1999 (Conkling and others 2005). The total number of remeasured plots increased from 26 in 1999 to 31 in 2000, and the number of plots with any

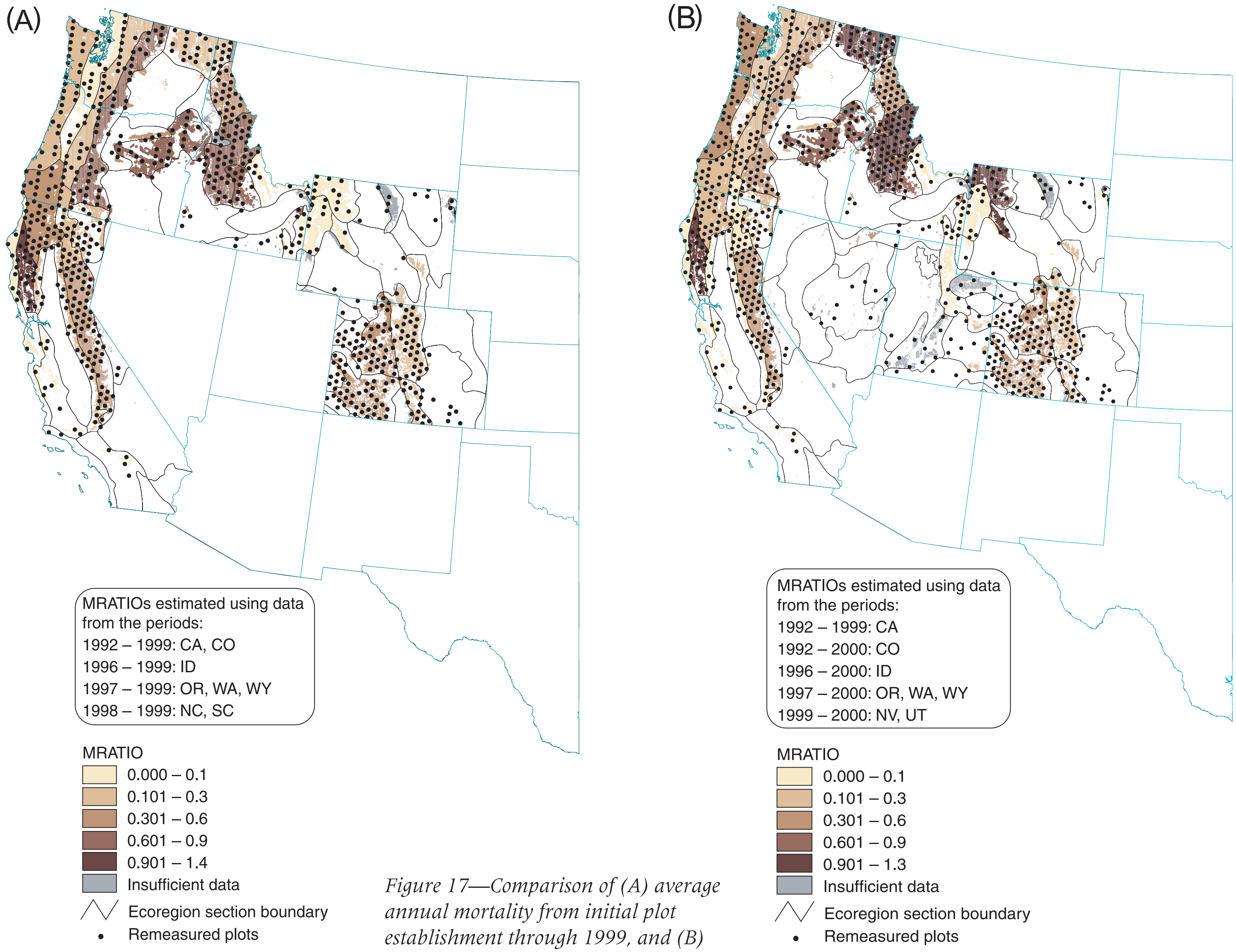

Figure 17—Comparison of (A) average annual mortality from initial plot establishment through 1999, and (B) average annual mortality from initial plot establishment through 2000. (Plot locations are approximate.)

mortality increased from 9 to 13. Four of the five plots remeasured in 2000 had mortality, but that mortality may have occurred anytime between when the plots were first measured (1996 for Idaho, 1997 for Washington) and their remeasurement in 2000. Thus, the change from an MRATIO of 0.230 to 0.957 does not mean that there was huge mortality from 1999 to 2000. Rather, the smaller dataset collected through 1999 produced a lower estimate of average annual mortality from 1996 onward than the larger dataset including 2000 data.

Even in those regions where all panels have been remeasured, these analyses are not designed so that values from the 1999 and 2000 analyses can be compared in order to determine change from 1999 to 2000. While changes in the MRATIO results between these 2 years is due to the addition of data from plots remeasured in 2000, any mortality detected on plots measured in 2000 may have occurred anytime between 1996 and 2000 (or between plot establishment and 2000 if the plots were established after 1996). Thus one cannot attribute any changed results simply to events occurring from 1999 to 2000. At some future date, after growth and mortality data have been collected for a much longer time, it will be possible to calculate MRATIOs for nonoverlapping time periods and look at changes in mortality rates.

The reader is advised to consult appendix table B.1 before drawing any conclusions from figure 16 alone, especially where the period of estimation is short, the sample size is small, and forest growth rates are low. The standard errors shown in appendix table B.1 are high in many cases. In sections where estimates are made for relatively short time intervals, the standard error associated with both the growth rate estimate and the mortality rate estimate will be high. Therefore, the standard error on the MRATIO will be high. Better estimates of MRATIOs will be possible in future years as more years of data are accumulated. In addition, once FIA phase 2 plots are remeasured, data from that more intensive sample can be incorporated into this analysis. For information on calculation of the standard error, see "Appendix A, Supplemental Methods, Tree Mortality."

Tree Health

FIA field crews collect crown and damage data from each tree occurring on phase 3 plots. After indicators of tree health and vitality are calculated using these data, there are many possible approaches to analyzing the indicators. In prior years these indicators were aggregated to the plot level, and then the forests of a region were evaluated based on the current average plot values for the region and the annual change in these plot values. Such an approach is most useful if clear linkages are known between specific indicators and specific forest health conditions.

The main advantage to that approach is that by focusing on plot-level aggregates, we were able to develop a method that made efficient use of the FHM and FIA rotating-panel design to estimate change over time. The main weakness of the approach is that plot-level aggregates of individual-tree based indicators are not readily interpretable and may hide stressed individuals that are averaged with a large number of healthy trees. For example, a tree having 25-percent dieback is obviously severely stressed. However, 25-percent average dieback on a plot is much more difficult to interpret. Such a condition could mean that all the trees are severely stressed or that just a few trees in an otherwise healthy stand are almost dead. Also, because levels of concern for indicators vary by tree species, interpreting an average plot-level indicator for a mixed species stand can be very difficult. Plot-level indicators also are only directly comparable within an area with very similar forest types.

For this report, we used an alternative approach. The basic analysis of these indicators began at the individual tree level. The analysis used the most recent measurement of each FHM or FIA phase 3 plot. The crown and damage indicators were used to classify each tree as healthy or unhealthy. Then, for each plot, the percentage of basal area represented by unhealthy trees was determined. The so-called unhealthy trees are those that were diseased, severely damaged, or otherwise severely stressed.

The years of FHM and FIA phase 3 plot crown and damage data that were available from each State are shown in the following tabulation:

Years of FHM and FIA phase 3 plot crown and damage data available for the analyses

Years	States
1990–2000	CT, MA, NH, RI, VT
1990–1999	ME
1991–2000	AL, DE, GA, MD, NJ, VA
1992–2000	CA, CO
1994–1999	MI, MN, WI
1995–2000	WV
1995, 1998–99	PA
1996–1999	IN
1996–2000	ID
1997–2000	IL, OR, WA, WY
1998–2000	NC, SC
1999	MO
1999–2000	NV, NY, TN, UT
2000	AR, KY, LA

The most recent data from each plot were used. Data from 1990 through 1999 were collected by FHM; data from 2000 were collected by FIA.

Crown Condition—Crown condition is an important indicator of individual-tree and forest-stand health. Generally, trees with large, full crowns have the potential to maximize gross photosynthesis because they are able to capture a large portion of the solar radiation available in a growing season (Stolte 1997). Changes to fundamental ecological processes, such as soil nutrient cycling, that negatively impact forest productivity and tree health may be reflected in diminished crown condition. Crown condition may also deteriorate in response to a variety of stressors: biotic and abiotic, natural and anthropogenic, and chronic or transient.

FIA measures several variables that relate to the amount and fullness of foliage and the vigor of the apical growing points of the crown. Two of these variables are the mortality of the terminal twigs in the sun-exposed portions of tree crowns (dieback) and the transparency of the foliage of the whole tree crown to sunlight (sparseness of the crown foliage). Crown dieback is recorded as the percent mortality of the terminal portion of branches that are > 1 inch in diameter and in the upper, sun-exposed portion of the crown (Burkman and others 1995). Foliar transparency is recorded as the percent of sky visible through the live, normally foliated portion of the crown. Both are determined via ocular estimates to the nearest 5 percent.

These two variables can be combined to produce a composite foliage index for each tree. Using a variation of the method proposed by Zarnoch and others[10] and Zarnoch and others (2004), an index, hereafter referred to as the ZB-index is, given by the formula (Ambrose 2004):

$$Z = [1 - (1 - \frac{T}{100})(1 - \frac{D}{100})] \qquad (1)$$

where

Z = ZB-index ($0 \le Z \le 1$)
T = percent transparency ($0 \le T \le 100$)
D = percent dieback ($0 \le D \le 100$)

The 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 = 0.25 would have 75 percent of the foliage that the ideal, fully foliated tree would have.

Use of equation 1 assumes that a fully foliated tree would have zero dieback and zero transparency. However, zero transparency has only rarely been recorded for any tree. Most trees of almost all species measured had transparencies of 10 to 20 percent. Therefore, considering 15 percent transparency to be normal for most tree species, an adjusted ZB-index can be formulated:

$$Z_a = [1 - (1 - \frac{(T-15)}{100})(1 - \frac{D}{100})] \quad \text{if } T \ge 15 \qquad (2)$$

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

where

Z_a = adjusted ZB-index

[10] 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. Unpublished manuscript. 535 p. On file with: Forest Health Monitoring Program National Office, 3041 Cornwallis Rd., Research Triangle Park, NC 27709.

Use of Z_a assumes that any transparency up to 15 percent is healthy. Only the amount that the transparency exceeds 15 percent is taken as an indicator of poor health.

Preliminary analyses were performed using several threshold values for the adjusted ZB-index. A threshold value of 0.25 was selected to indicate trees that were unhealthy. This threshold value was selected because (1) it is biologically reasonable (most people would agree that a tree with either 40 percent transparency or 25 percent dieback is unhealthy); and (2) using this threshold does not classify all U.S. forests as healthy, nor does it classify the vast majority of U.S. forests as unhealthy. See the section entitled "An Integrated Analysis of Tree Health" for a discussion of how these threshold values may be refined in the future.

The two components of the ZB-index can also be analyzed independently. Because different species have different crown responses to various environmental stressors, such analyses by species group may enable crown condition to be used as a more direct indicator of changes to ecological processes. For example, we know that hardwoods often experience dieback in response to short-term, transient stressors such as drought. However, softwoods usually exhibit dieback only if they are severely damaged or diseased. Therefore, a softwood tree having dieback of 10 percent or greater was considered to be unhealthy, regardless of the overall adjusted ZB-index value. Thus, in this crown analysis, 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.

Figure 18 shows the average percentage of plot basal area associated with trees classified as having unhealthy crowns by ecoregion section. In most of the United States, 10 percent or less of the basal area was associated with unhealthy crowns. The percentage of basal area on each

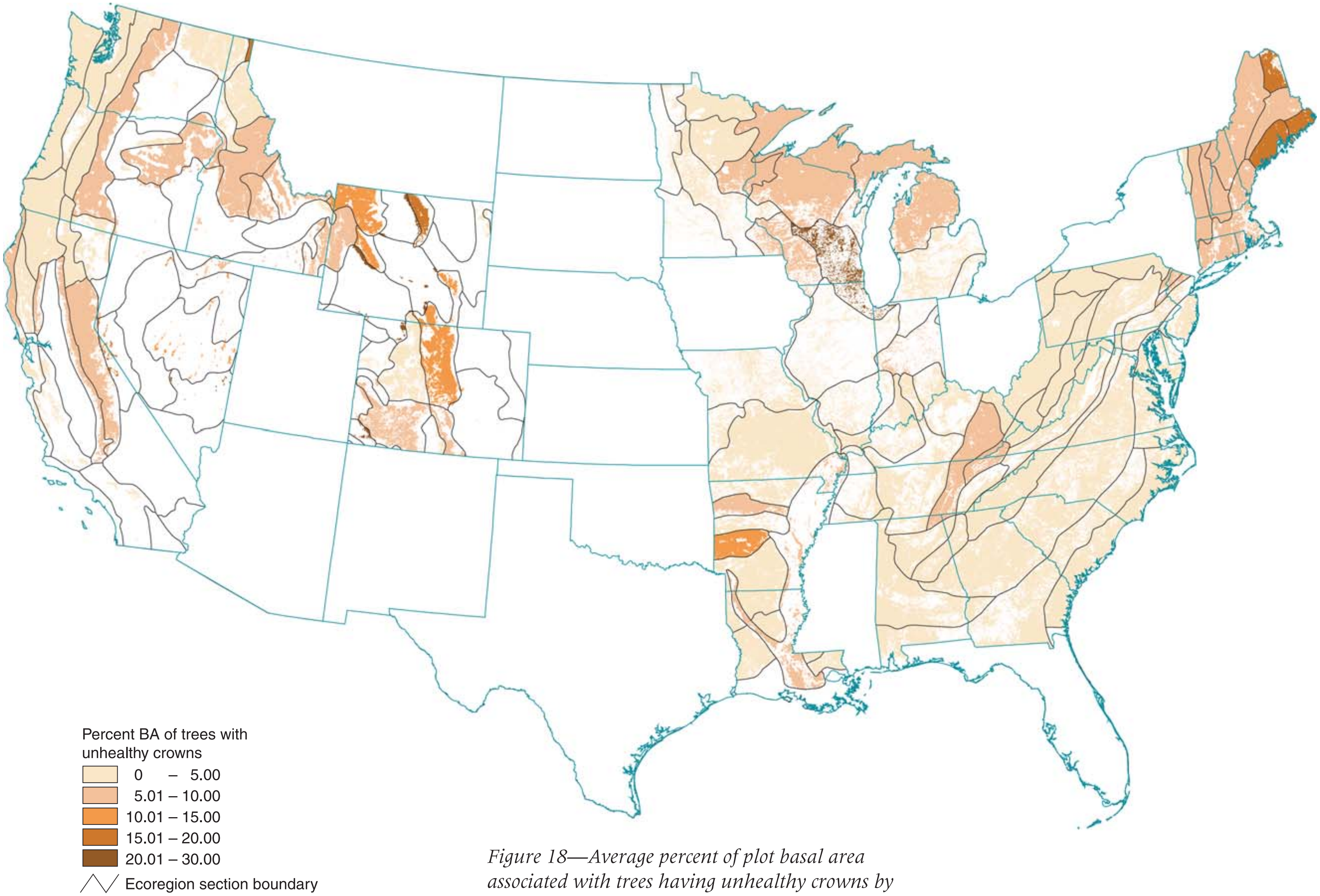

Figure 18—Average percent of plot basal area associated with trees having unhealthy crowns by ecoregion section. A crown was considered to be unhealthy if its adjusted ZB-index was ≥ 0.25 or if the tree was a softwood and it had dieback of ≥ 10 percent.

plot associated with trees with unhealthy crowns is shown in figure 19. Most plots had only a very low percentage of basal area associated with trees having unhealthy crowns. However, a number of plots scattered across the country had a high percent basal area associated with trees with unhealthy crowns. The largest clusters of these plots were in parts of the West, northern New England, and the Lake States.

The crown condition analysis provides only one view of tree health. Crown data were also combined with tree damage data to produce a more integrated analysis of tree health (see "An Integrated Analysis of Tree Health").

Tree Damage—Damage caused by pathogens, insects, storms, and human activities can significantly affect the growth, reproduction, and mortality of trees (Stolte 1997). To be recorded, damages must meet or exceed set thresholds, e.g., > 20 percent bole circumference with an open wound; > 30 percent of the foliage damaged > 50 percent) (Mielke and others 1995). These thresholds are intended to limit damage scoring to conditions considered serious enough to increase the probability that a tree will be infected by lethal pathogens (damage such as open wounds or broken branches); that a tree will die prematurely (damage such as the presence of pathogenic conks, cankers, or broken roots); or that the growth and/or reproduction of the tree will be seriously depressed (damage such as high defoliation or broken branches).

A damage severity index (DSI) score was determined for each damaged tree. The DSI score was determined based on three variables: (1) the type of damage symptom, (2) the location of the damage on the tree, and (3) the severity of the damage.[11] A DSI score was assigned to each damage based on these three variables according to look-up tables (see table 3 for an example). The index value associated with each particular combination of damage type, location, and severity was determined following several workshops of Federal, State, and university experts in forest pathology and entomology (Conkling and others 2005).

Up to three damages per tree were scored. The DSI scale runs from zero to a theoretical maximum of 300, with zero indicating no

[11] Mielke, M.E. 1999. Forest health monitoring damage indicator report. Presented to the Forest Health Monitoring Management Team. 10 p. On file with: Manfred Mielke, Forest Health Monitoring Specialist, U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry, 1992 Folwell Avenue, St. Paul, MN 55108.

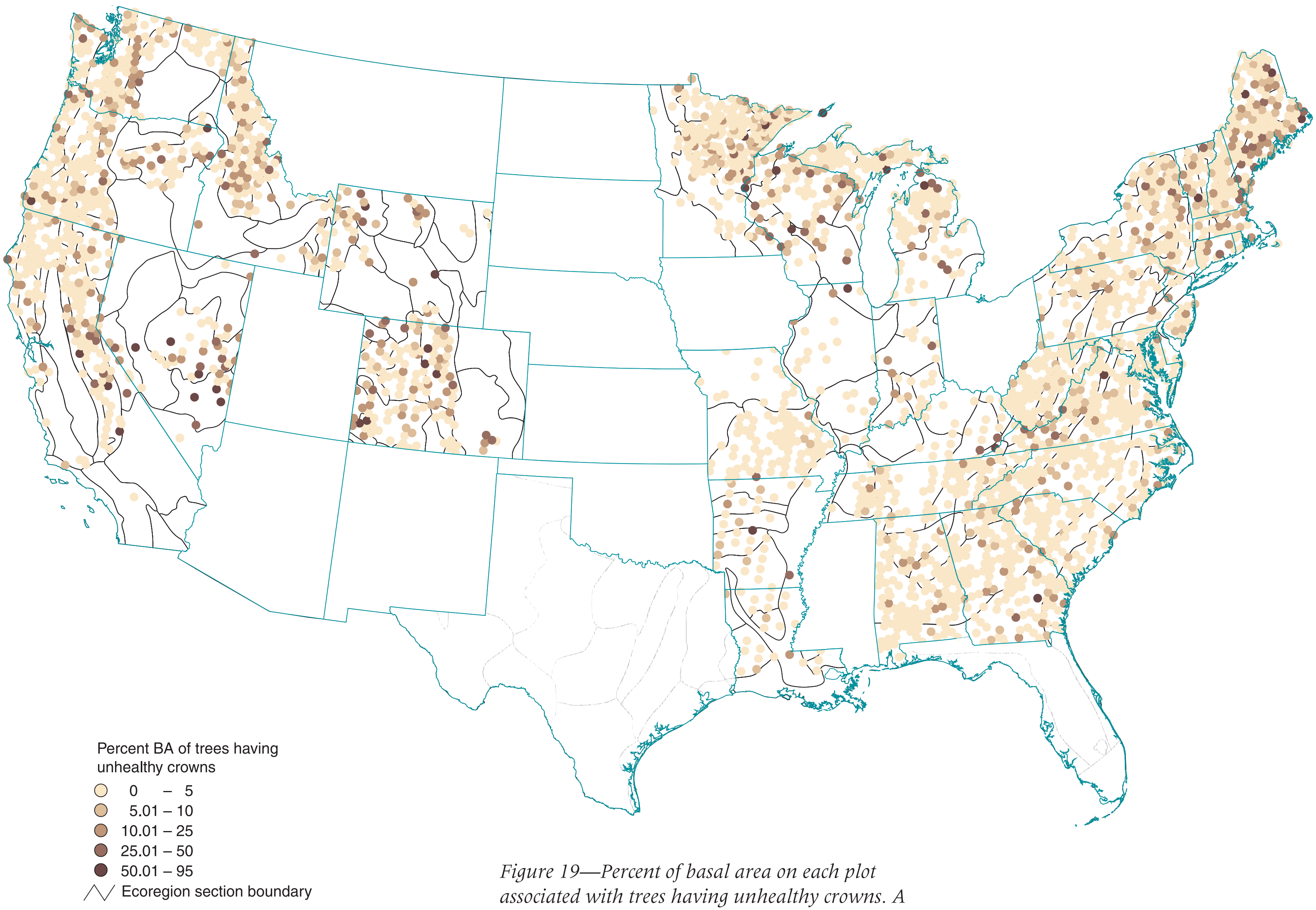

Figure 19—Percent of basal area on each plot associated with trees having unhealthy crowns. A crown was considered to be unhealthy if its adjusted ZB-index was ≥ 0.25 or if the tree was a softwood and it had dieback of ≥ 10 percent. (Plot locations are approximate.)

Table 3—Sample Damage Severity Index values by type, location, and severity rating: damage types 1 and 3 (cankers/galls and wounds)

Severity	Location						
Circumference affected	Roots	Roots, stump, lower bole	Lower bole	Lower and upper bole	Upper bole	Crown-stem	Branches
percent							
20–29	20	20	20	20	20	10	5
30–39	30	30	30	30	30	15	10
40–49	40	40	40	40	40	20	15
50–59	50	50	50	50	50	25	25
60–69	60	60	60	60	60	30	40
70–79	70	70	70	70	70	35	55
80–89	80	80	80	80	80	40	70
90–99	90	90	90	90	90	45	85

damage above the minimum threshold, and 300 indicating three damages of maximum severity. However, individual tree damage index scores rarely exceed 90; trees usually die before their damage level gets much higher.

Quality assurance (QA) analyses[12] have found some limitations to the damage indicator data. Field and audit crews do not always agree on the type, severity, or location of tree damage. For this reason, an analytical approach was selected that sought to minimize the effect of these inconsistencies on the results. For this analysis,

[12] Pollard, J.E.; Smith, W.D. 2001. Forest health monitoring 1999 plot component quality assurance report. Research Triangle Park, NC: U.S. Department of Agriculture Forest Service, National Forest Health Monitoring Program. 304 p. On file with: U.S. Department of Agriculture Forest Service, Forest Health Monitoring Program, P.O. Box 12254, Research Triangle Park, NC 27709.

only a DSI score of 45 or greater was considered to indicate serious damage to the tree. This value was chosen as a reasonable threshold for selecting trees that are so severely damaged that there is little doubt that the damage is real and relatively severe. Although field and audit crews often differed in how they scored damages, an analysis using the QA data from 1998 through 2000 has shown that auditors generally found those trees that had DSI scores of 45 or more according to the field crews' evaluations to be truly damaged.[13] The field crew and auditor might disagree as to the exact type, location, or severity of the damage, but if the field crew data produced a DSI of 45 or more, the auditor usually agreed with the field crew that the tree was indeed damaged. Thus, this analysis quantifies the percent of basal area on each plot that is represented by trees that are so severely damaged that there can be little doubt that the tree really is damaged.

The aim of this approach is to avoid sounding a "false alarm" for areas where damage is actually very minor (or nonexistent). A potential weakness to this approach is that any real damage of a severity that falls in the range where auditors and field crews often disagree ($0 < DSI < 45$) is ignored. Therefore, early signs of a growing forest health problem may be missed.

The average percent basal area represented by severely damaged trees was calculated for each ecoregion section (fig. 20). The percentage of basal area on each plot represented by severely damaged trees is shown in figure 21. The figure shows a large number of plots throughout the United States on which more than half of the basal area was associated with damaged trees.

An Integrated Analysis of Tree Health

Damage and crown condition were combined for an integrated analysis of tree health. Using the same thresholds as in the previous sections, a tree was considered unhealthy if it exceeded either the damage or the crown condition thresholds. Again, for each ecoregion section and each plot the percentage of basal area associated with unhealthy trees was calculated

[13] Personal communication. 2002. William Smith, Assessment Coordinator, U.S. Department of Agriculture Forest Service, Southern Research Station, 3041 Cornwallis Road, Research Triangle Park, NC 27709.

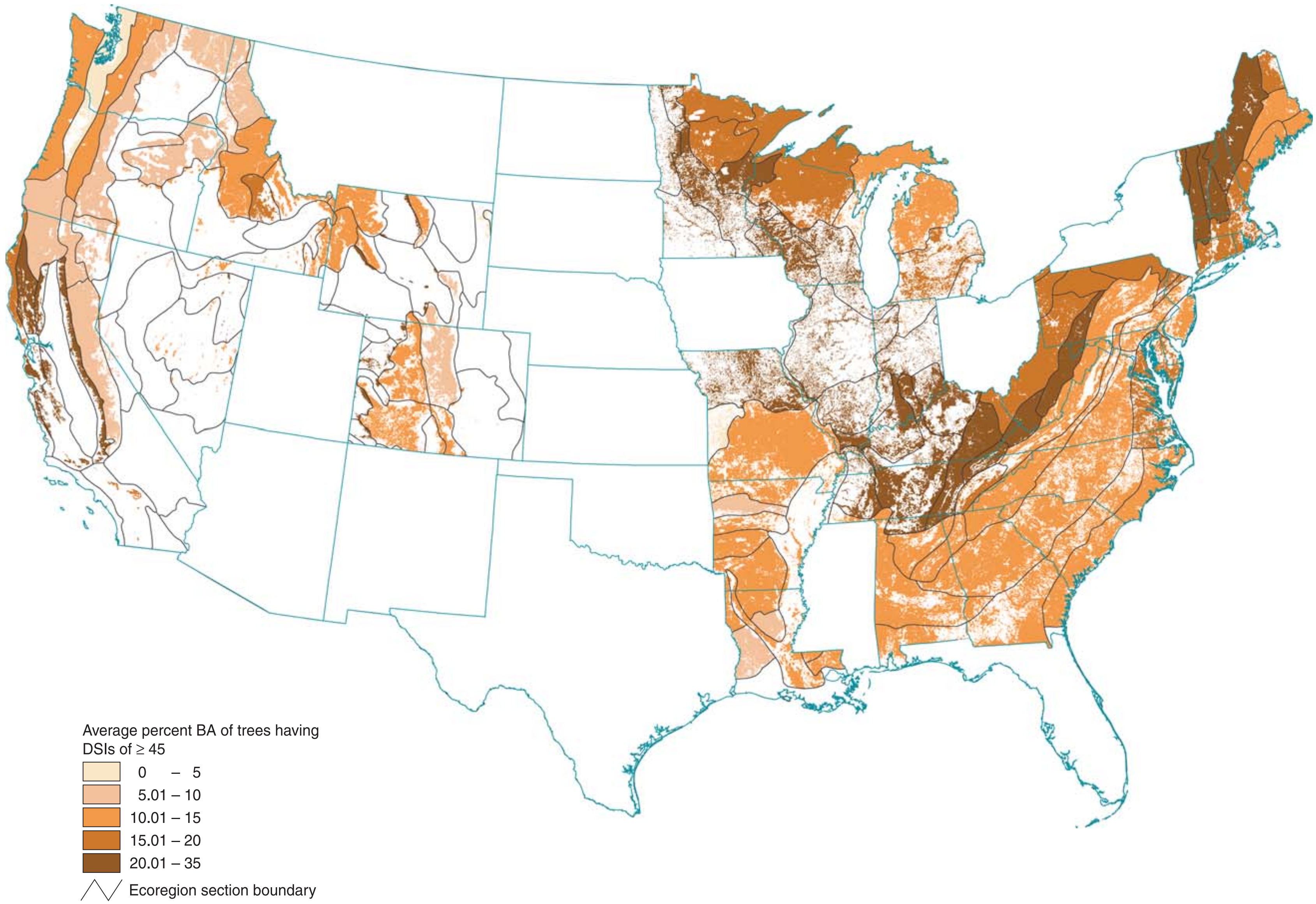

Figure 20—Average percent of plot basal area associated with trees having Damage Severity Index scores of ≥ 45 by ecoregion section.

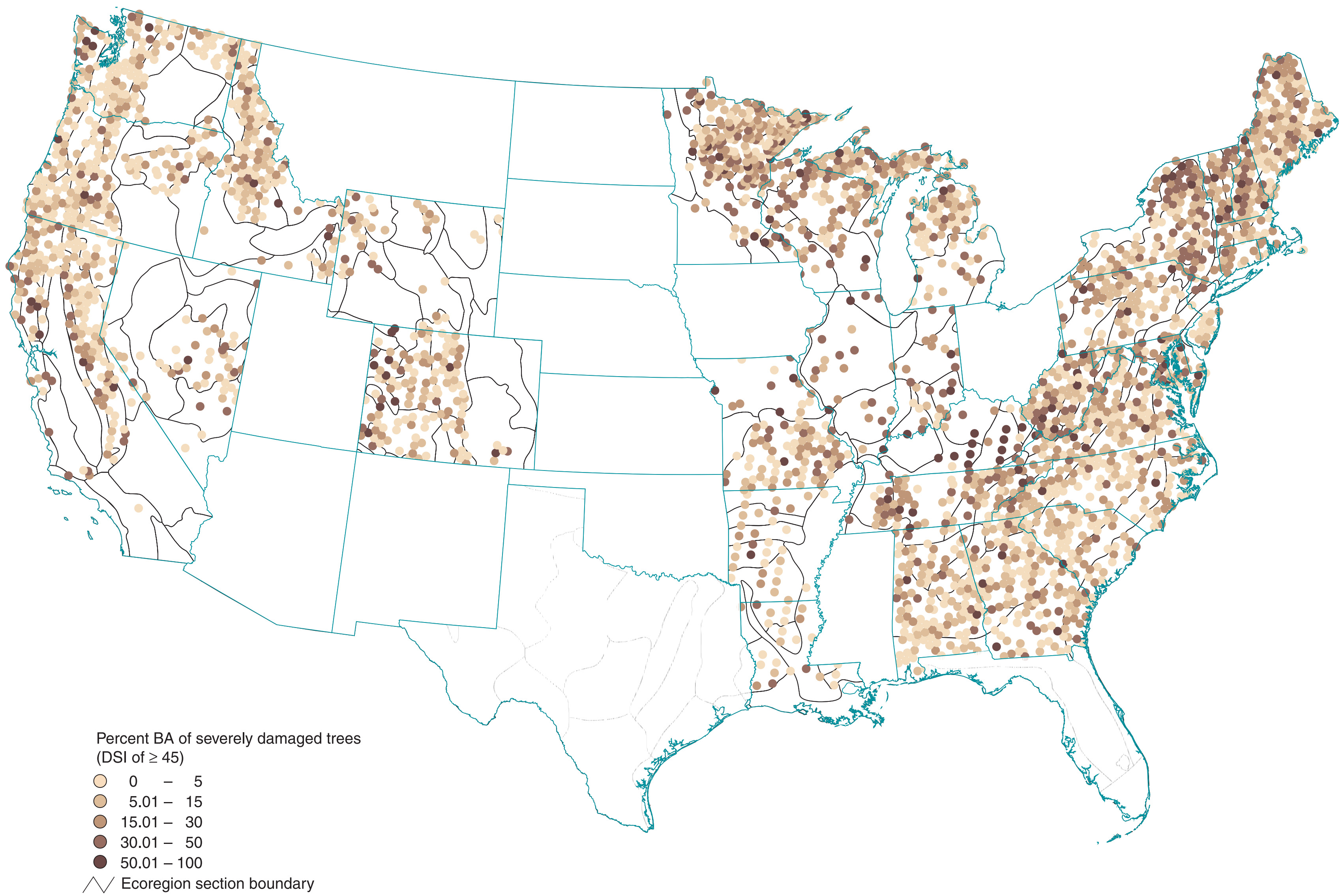

Figure 21—Percent of basal area on each plot associated with trees having Damage Severity Index scores of ≥ 45. (Plot locations are approximate.)

(figs. 22 and 23). Areas that had a high percentage of basal area associated with unhealthy trees may have been experiencing high levels of stressors. Past management in these areas may also have resulted in a large number of older, senescent stands.

Comparison of figures 22 and 23 (showing the results of the integrated analysis) with figures 18 through 21 (showing the individual components) reveals that most of the unhealthy tree basal area was associated with damaged trees rather than with trees having unhealthy crowns. These results, which can be seen more clearly in appendix table B.2, suggest that the damage indicator may be more sensitive to the types of forest health problems common in the United States or that the threshold values used for the two indicators need to be better calibrated.

One limitation of this analysis is that the thresholds selected were somewhat arbitrary. Few reasonable people would disagree with calling a tree unhealthy if it has extremely high dieback or transparency. However, lower tree-level indicator values, which have not been considered to be unhealthy in this analysis, may, in fact, be indicative of health problems. Also, it is clear that any precise thresholds are likely to vary by species. Some tree species can tolerate relatively high damage levels, while others may quickly succumb to disease once they are damaged. Crown response to environmental stressors also may vary greatly by species.

The power of this analytical approach, which starts by assessing whether or not individual trees are healthy, is that more detailed information about particular tree species can be incorporated into this framework as the information becomes available. The current, relatively simple thresholds can be replaced with more sophisticated decision rules (classifying a tree as healthy or unhealthy) based on tree species as well as damage and crown variables. Damage to some species may be evaluated based on the type and severity of the particular damage rather than just on the DSI score. For example, when a canker is present on either slash pine or loblolly pine, it is usually due to fusiform rust. However, fusiform rust is much more likely to kill slash pine than loblolly. So, an improved decision rule might classify slash pines

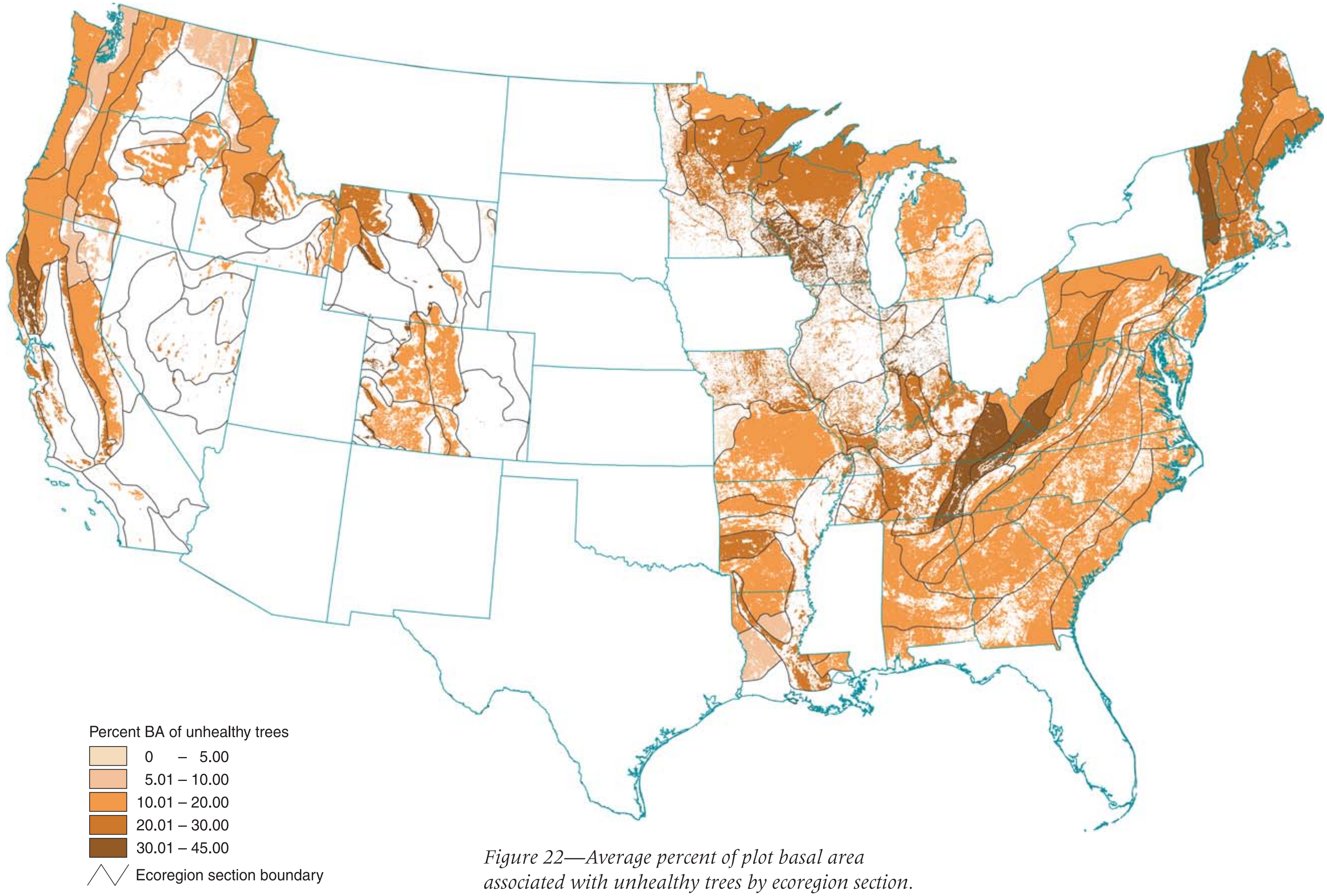

Figure 22—Average percent of plot basal area associated with unhealthy trees by ecoregion section. A tree was considered to be unhealthy if its Damage Severity Index score was ≥ 45 or its adjusted ZB-index was ≥ 0.25 or if the tree was a softwood and it had dieback of ≥ 10 percent.

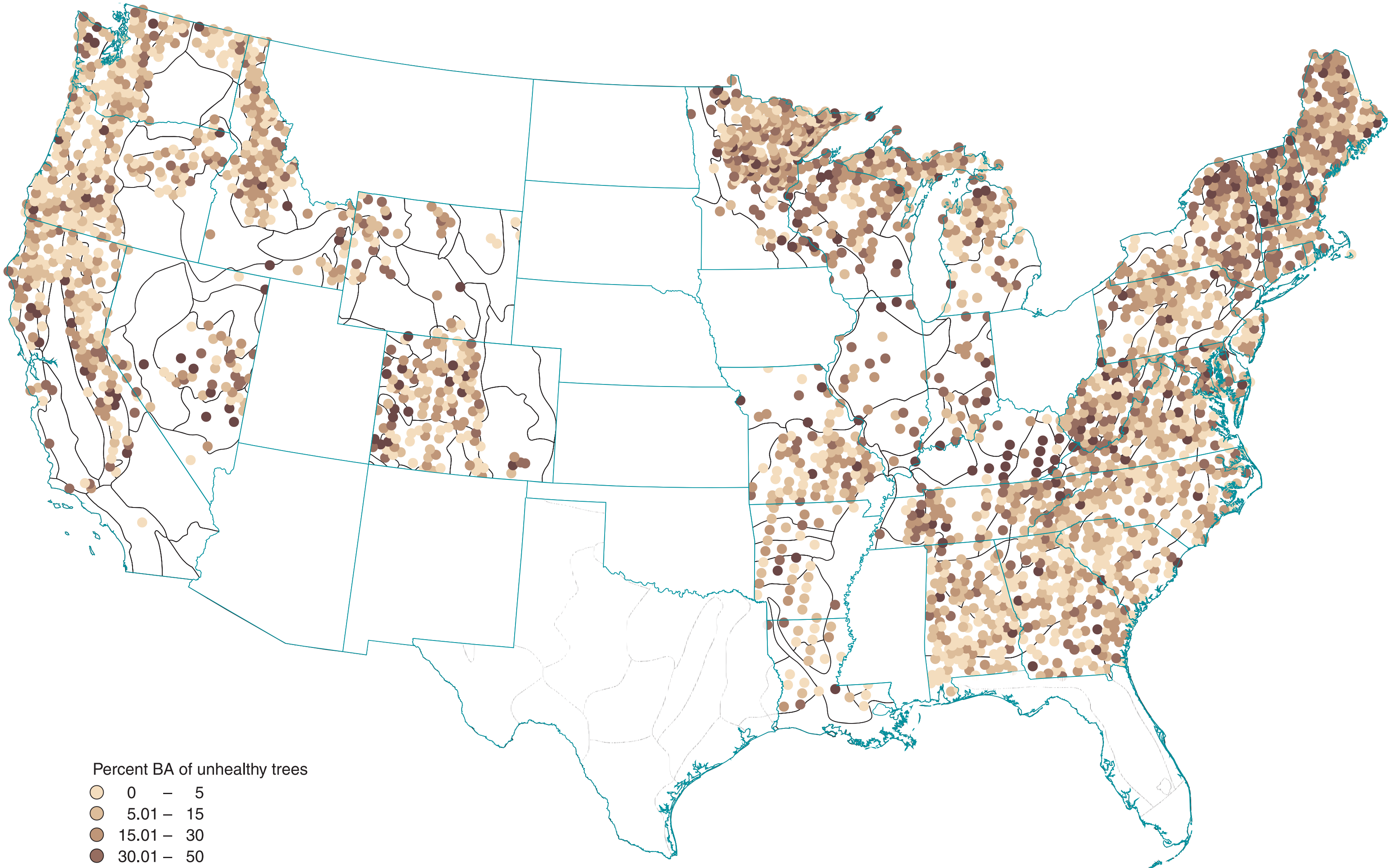

Figure 23—Percent of basal area on each plot associated with unhealthy trees. A tree was considered to be unhealthy if its Damage Severity Index score was ≥ 45 or its adjusted ZB-index was ≥ 0.25 or if the tree was a softwood and it had dieback of ≥ 10 percent. (Plot locations are approximate.)

as unhealthy if a canker of any size was present, but would classify loblolly as unhealthy only if the canker was above a certain severity.

Several measured crown variables are not used in the present analysis because they are not readily interpretable across a range of tree species. However, it may be possible to use them, either singly or as part of a composite indicator, in future analyses evaluating those species for which their meaning is fairly well understood. For example, composite variables representing crown volume and/or crown surface area (Zarnoch and others 2004) might be useful for evaluating the health of some species.

Current knowledge of certain species can be used relatively easily. Efforts at refining these decision rules can be focused on species that represent the largest percentage of forest basal area. Simpler, more general rules can continue to be used for less common species. As this method is refined, it could be combined with analytical approaches that consider change over time. Using generalized linear models similar to those used in previous FHM reports (Conkling and others 2005; Stolte and others, in press), it will be possible to estimate the change over time in the percentage of basal area represented by unhealthy trees.

A Multivariate Analysis of Forest Indicators

Although we have not much discussed relationships among the indicators and do not address particular cause-effect hypotheses in this report, we recognize significant correlations among some indicators that are worth exploring in a multivariate framework. A multivariate analysis can elucidate the correlation structure and, therefore, help identify how many independent pieces of information there are; this may serve to better focus subsequent analyses. A multivariate analysis is also valuable for constructing composite statistical indicators of forest health that help to summarize overall ecoregion conditions.

Principal components analysis (PCA) (e.g., Johnson and Wichern 1982) is a fairly standard multivariate technique for data reduction and interpretation. PCA often reveals underlying relationships and enables interpretations that otherwise would not be noticed. Eleven indicators for 76 ecoregion sections were used. The 11 indicators contain information about drought, insects and pathogens, fire condition class, land development, air pollution, tree damage, crown condition, and mortality. The 76 ecoregion sections cover most of the forested area in the United States and were selected because all indicator data were available for those areas.

Each indicator was standardized to a mean of zero and variance one. A PCA was then performed on the standardized indicators. The resulting axes represent principal components that are composites of one or more of the original indicators and serve to summarize the information contained in those indicators. Different indicators have different “loadings” or correlations with each component, so each component can be interpreted in terms of the specific indicators that have high loadings with that component. In addition, a score can be calculated for each component in each ecoregion section. The component scores represent the value of the corresponding composite indicators. Details of the computations are provided in standard multivariate analysis textbooks (for example, see Johnson and Wichern 1982).

Five significant principal components were identified by the analysis using the criterion that the eigenvalue for a component is greater than one. Taken together, these 5 components accounted for 76.2 percent of the total covariance among indicators for the 76 ecoregion sections. As a result, the original 11 indicators could be condensed into 5 independent principal components explaining 76.2 percent of the original covariance. Table 4 shows the loadings of each original indicator on each component; the first four components will be interpreted below in terms of the indicators that have high loadings. Component 5 will not be discussed because it was almost entirely loaded by one variable.

Principal component 1 explained 31.5 percent of the total sample variance. Because air pollution indicators such as wet sulfate, nitrate, and ozone injury had the greatest loadings (table 4), component 1 was interpreted as a composite indicator of air pollution variables. Figure 24A displays the component 1 scores for each ecoregion section and is a spatial representation of component 1. Ecoregion sections in the North and North Central regions had the highest scores (more “air pollution”), while ecoregion sections in the West Coast and Interior West had the lowest scores. The South region had moderate scores.

While component 1 was mostly a function of air pollution variables, the land development variable also had its greatest loading in factor 1 (table 4). There was more anthropogenic edge in areas of relatively high air pollution. One reason was that the more developed (urban and agricultural) areas of the North and North Central regions also experienced more air pollution.

Principal component 2 accounted for an additional 13.1 percent of the total sample variance. This component was a composite of fire condition class, defoliation-causing insect and pathogen activity, and to a lesser extent mortality ratio (table 4). Ecoregion sections in the South and the northern parts of the Interior West generally had the lowest component scores (fig. 24B). The highest component 2 score was observed in the Northern Superior Uplands

Table 4—Principal components analysis loadings of each original indicator on each component

Indicator	Principal component 1	2	3	4	5
Nitrate deposition	**0.499**	0.010	-0.042	0.059	0.131
Sulfate deposition	**0.492**	0.032	0.098	0.044	0.105
Ozone injury	**0.408**	0.177	0.297	0.028	-0.019
Anthropogenic edge	**0.403**	-0.094	-0.107	-0.125	-0.110
Percent forest in fire condition class 3	-0.002	**0.632**	-0.293	-0.082	-0.105
Defoliation-causing insect and pathogen activity	0.001	**0.455**	**-0.460**	0.123	0.176
Mortality ratio	-0.054	**0.390**	0.225	**0.626**	0.075
Drought deviation	-0.183	0.185	**0.661**	0.129	-0.064
Percent basal area with thin crown	-0.223	-0.325	-0.293	**0.523**	0.039
Percent basal area with severe damage	0.303	-0.244	-0.109	**0.513**	-0.028
Mortality-causing insect and pathogen activity	-0.059	-0.039	0.077	-0.106	**0.951**
Cumulative variation explained (%)	31.5	44.6	57.0	66.9	76.2

Each component was interpreted based on which variables had high loadings (denoted by boldface type).

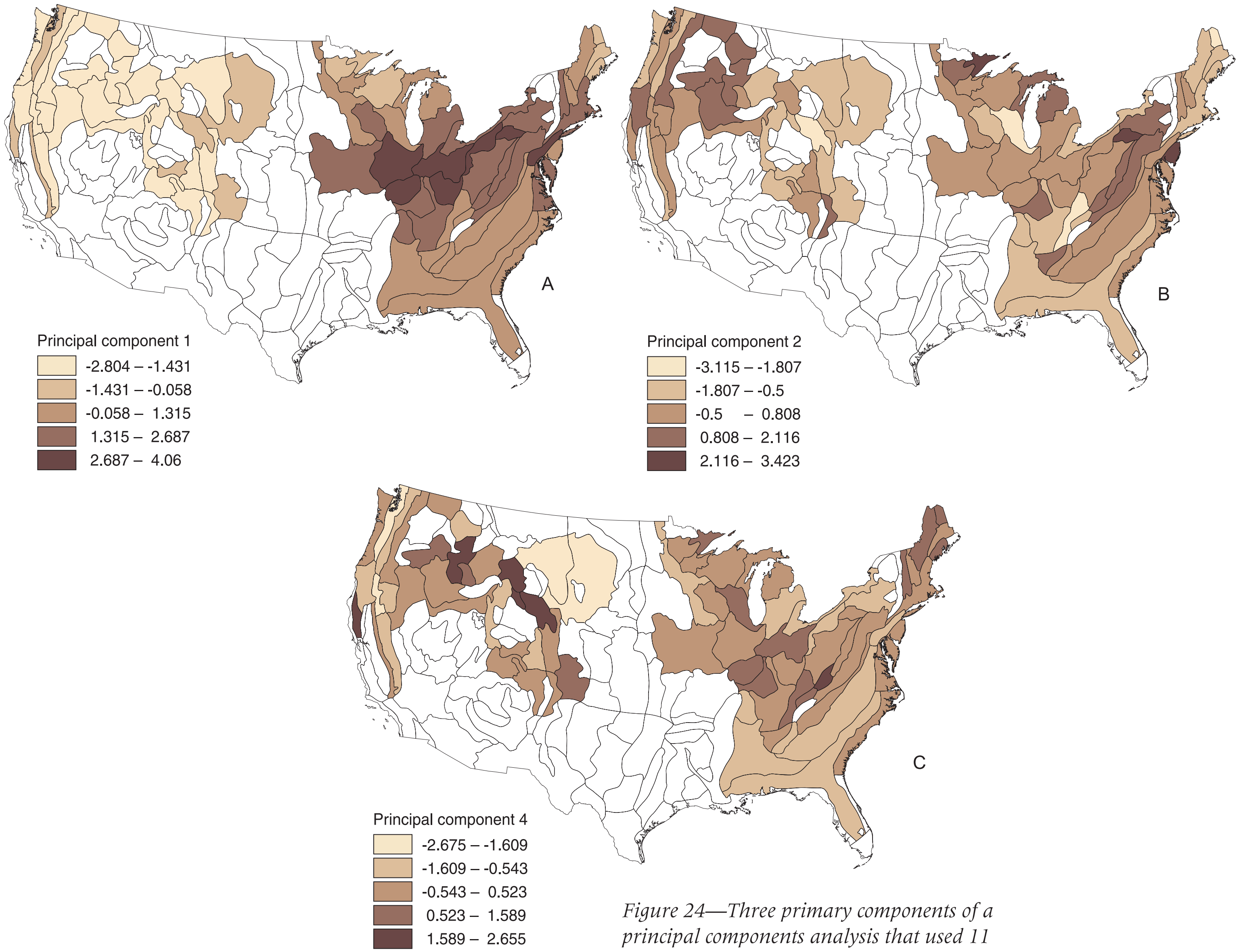

Figure 24—Three primary components of a principal components analysis that used 11 indicators for 76 ecoregion sections. These three summarized about 54 percent of the statistical information contained in the original 11 indicators. (See text for additional information.)

(Section 212L). The Northern Unglaciated Allegheny Plateau (Section 212G) and Upper Atlantic Coastal Plain (Section 221C) also had relatively high component 2 scores.

The third principal component explained 12.4 percent of the variation and was most heavily weighted by drought deviation and defoliation-causing insect and pathogen activity. The weights of defoliation-causing insect and pathogen activity and drought deviation had different signs and, therefore, the component score represented the difference between these two indicators. Interactions such as this are difficult to interpret in a PCA. As a result, this component requires further investigation. Because this component was not interpretable, it is not discussed or included in figure 24.

Principal component 4 was a composite of the mortality ratio, the percentage basal area with severe damage, and the percentage basal area with thin crowns. It accounted for 9.9 percent of the total sample variance. Several ecoregion sections in the Western United States had relatively high component 4 scores (fig. 24C). The only eastern ecoregion section with a relatively high component 4 score was Section M221C—Northern Cumberland Mountains.

In summary, of 11 indicators tested in 76 ecoregion sections, a PCA identified at least 3 composite indicators that were used to rank ecoregion sections relative to one another in terms of (1) air pollution and land development; (2) defoliation-causing insect and pathogen activity and fire condition class; and (3) mortality ratio, percent basal area with thin crown, and percent basal area with severe damage. Individual ecoregion sections appeared to have relatively high or low values for composite variables and these indications are expected to be starting points for further indepth investigations.

A Brief Look Forward

FHM annual national technical reports will continue to provide results of national indicator analyses. Each year we will be able to make better estimates of tree growth and mortality as additional data are available from the FIA phase 3 plots. Change will be calculated for a larger part of the coterminous United States as additional panels of plots are measured and the data become available.

We will continue to present analysis techniques that are applicable to large datasets and spatial scales. Included will be analyses of individual indicator data as well as integrating analyses such as multivariate analyses. Because sharing data analysis techniques and methods is one of the objectives of FHM national reports, we will continue to include example applications of techniques in future reports.

We encourage readers to consider the national context and perspectives in this report. Specific forest health concerns in regions or States can be investigated by accessing the reports and "Forest Health Highlights" listed in the "Introduction" of this report, and by visiting the Web sites of FHM (http://www.fhm.fs.fed.us) and the Forest Service (http://www.fs.fed.us/).

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APPENDIX A

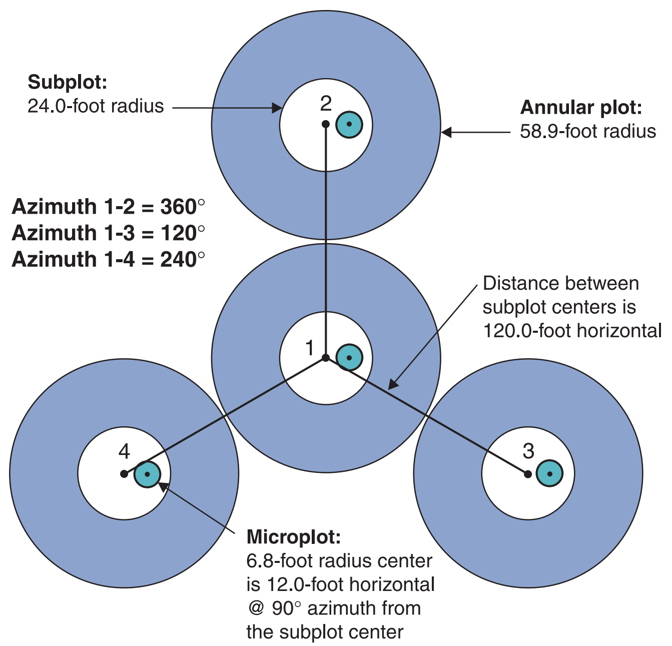
Supplemental Methods

Analysis of FHM and FIA Ground Plot Data

Plot data were stratified using Bailey's ecoregion sections (Bailey 1995, Freeouf 1997, McNab and Avers 1994, Miles and Goudey 1997) to conduct the analyses presented in this report. The minimum level of analysis was the mean plot value of each variable, metric, or both by ecoregion section[1]. If an ecoregion section contained an insufficient number of plots for analysis, we combined its plot data with that from an adjacent section in the same ecoregion province.

The FHM Program strives to use the wealth of data collected by FIA. FIA's phase 3 contains many forest health indicators that formerly were measured on ground plots of the FHM detection monitoring system. FIA adopted the hexagonal grid used by FHM to establish a systematic grid of annual survey plots (phase 2) that 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 the phase 2 plots (Bechtold and Patterson, in press). The plot design for phase 3 plots is shown in appendix figure A.1.

There was some discontinuity between the data collected from the FHM detection monitoring plots (data collected 1990 through 1999), and the data collected on the FIA phase 3 plots (data collected in 2000). 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 different locations from the FHM plots. Data from these 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 properly collocated with the FHM plots, no 2000 data from California were used in this analysis.



Appendix figure A.1—Common plot design for phases 2 and 3.

[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). Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 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 recorded on FHM plots died or were logged. Because FIA treated all plots measured in 2000 as new installations, even if FHM previously had measured them, 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 the mortality estimates for periods ending in 2000 (appendix table B.1).

Because not all trees measured in 2000 could be matched with previously measured trees, 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 in the 2000 data
   a. if a treatment code indicated that there had been any logging on or adjacent to the plot, the analyst assumed the tree had been cut
   b. otherwise, the analyst assumed that the tree had died

2. A new tree occurred on the tree list for the phase 3 plot in 2000 that was not recorded on the FHM plot
   a. if the tree diameter at breast height was < 5 inches, the analyst assumed the tree was ingrowth on the microplot
   b. if the tree diameter at breast height was at least 5 inches and < 6.5 inches, the analyst assumed the tree was ingrowth on the subplot
   c. otherwise, the analyst considered the tree as missed by FHM crews on previous visits to the plot, and the tree was dropped from the analysis. However, in future analyses the analyst will estimate the diameters of missed trees for the years that they were missed.

Data for year 2000 were not available for all phase 3 plots when this report was written.

Drought Deviation

The National Climate Data Center (NCDC) calculates the Palmer Drought Severity Index (PDSI) monthly by climate division for the coterminous United States (National Climate Data Center 1994). The PDSI is an empirically derived index based on total rainfall, the periodicity of rainfall, and soil characteristics. The PDSI ranges from +7 to -7. Values from zero to -0.5 are associated with normal conditions. The PDSI values from -2.0 to -3.0 are associated with moderate drought, -3.0 to -4.0 with severe drought, and < -4.0 with extreme drought. The NCDC archive has monthly estimates of PDSI from 1895 to present (National Climate Data Center 1994).

Moderate, severe, and extreme drought occurrence from 1991 through 2000 was compared to the historic (1895 through 2000) moderate, severe, and extreme drought occurrence using the following equation (Stolte and others, in press):

$$D_{dk} = \sum_{j=1}^{n}\left(D_{t1jk} * A_{kj} / A_k\right) - \Delta\left(\sum_{j=1}^{n}\left(D_{t2jk} * A_{kj} / A_k\right)\right)$$

where

D_{dk} = drought deviation (in months) for the k^{th} ecoregion section

D_{t1jk} = the number of months of drought in climate division *j* within ecoregion section *k* for the *t1* period (1991 through 2000, 120 months)

D_{t2jk} = the number of months of drought in climate division *j* within ecoregion section *k* for the *t2* period (1895 through 2000; 1,272 months)

A_{kj} = the forested area of ecoregion section *k* within climate division *j*

A_k = the total forested area in ecoregion section *k*

Δ = adjustment used to put *t2* on the same basis as *t1*. In this case, 120 divided by 1,272 or 0.09434.

Average Wind Speed of Hurricanes

The National Oceanic and Atmospheric Administration, National Hurricane Center monitors hurricane, tropical storm, and tropical depression activity. They published these data as part of the national atlas of the U.S. project (National Hurricane Center 2000).

We calculated the average wind speed of all hurricanes (1851 through 2000) in each ecoregion section using the following equation:

$$W_k = \sum_{s=1}^{n}((L_{sk} * W_{sk})/(\sum_{s=1}^{n} L_{sk}))$$

where

W_k = the average wind speed (km/hour) of hurricanes in ecoregion section k

L_{sk} = length of line segment s with ecoregion section k

W_{sk} = wind speed associated with line segment s within ecoregion section k

Because the average wind speed analysis was based on data compiled in Geographic Information System format, each line representing a storm track was made up of s segments. Curved lines are actually a series of very small, straight-line segments (s). Those line segments were then intersected with the ecoregion coverage and at each point of intersection, a line segment was split that defined L_{sk} and W_{sk}. This analysis was only based on storm track centers even though hurricanes can be hundreds of kilometers wide.

Storm Track Density of Hurricanes and Tornadoes

Tornado track data from 1961 through 1990 from the NCDC (2000) were used to estimate the storm track density of hurricanes and tornadoes. Storm track density (m/km^2) for both hurricanes and tornadoes was calculated for each ecoregion section using the following equation:

$$D_k = \sum_{s=1}^{n} L_{sk} / A_k$$

where

D_k = the track density in m/km^2 of either hurricanes (1851 through 2000) or tornadoes (1961 through 1990) for ecoregion section k

L_{sk} = the length (m) of line segments s within ecoregion section k

A_k = the area (km^2) of ecoregion section k

The storm track density of hurricanes and tornadoes was based on storm track centers.

Wet Deposition and SUM60 Ozone

Inverse distance squared weighted interpolation (Isaaks and Srivastava 1989) was used to estimate values of wet sulfate, nitrate, and SUM60 ozone for forested areas identified by Zhu and Evans (1994). Data from 1994 through 2000 were used for nitrate and sulfate deposition. Data from 1999 and 2000 were used for SUM60.

For discussion purposes, the normal density function was used to identify outliers (ecoregion sections with high values). The distributions of nitrate, sulfate, and SUM60 ozone all had Shapiro-Wilks statistics > 0.9 but slightly deviated from the normal distribution. The general form of the normal density function is:

$$\frac{1}{\sqrt{2\pi s}} e^{-\left(\frac{(x-\bar{x})^2}{2s^2}\right)}$$

where

s = standard deviation of nitrate, sulfate, or SUM60 ozone across ecoregion sections

$\bar{x}$ = mean of nitrate, sulfate, or SUM60 ozone across ecoregion sections

x = the value of nitrate, sulfate, or SUM60 ozone for the ecoregion section of interest

Ecoregion sections that fell in the outer most 5 percent of the right tail are discussed in the section "Forest Land Subjected to Air Pollutants that may cause Negative Impacts on the Forest Ecosystem."

Ozone Biomonitoring

The proportion of leaves with ozone injury and the mean severity of symptoms on injured foliage that were recorded for 10 to 30 plants of up to 3 species at each biomonitoring site (biosite) were used to calculate a BI (see footnote 9) (Coulston and others 2003, Smith and others 2003). BI was defined as:

$$1000(m^{-1}\sum_{j=1}^{m} n_j^{-1} \sum_{i=1}^{n_j \geq 10} a_{ij}s_{ij})$$

where

m = the number of species evaluated

n_j = the number of plants of the j^{th} species

a_{ij} = the proportion of injured leaves on the i^{th} plant of the j^{th} species

s_{ij} = the average severity of injury on the i^{th} plant of the j^{th} species

This index was classified into four risk categories that represent a relative measure of impacts from ambient ozone exposure (see tabulation on page 37).

The number of measurement years per biosite varied from one to seven. Some biosites in Massachusetts and Maine had seven annual measurements, while Tennessee biosites were measured in 2000 only. The average BI for all measurements (1994 to 2000) within each ecoregion section was used in this analysis.

Tree Mortality

MRATIO estimates were made using tree and sapling data from FHM and FIA plots. Diameters were measured for all trees in the dataset, but heights were only measured for a number of site trees (dominant or codominant trees) on each plot.

Individual heights were estimated for those trees whose heights were not measured using published, regional height/diameter equations of various forms[2] (e.g., Ek and others 1984, Garman and others 1995, Moore and others 1996). Greater accuracy in estimation was obtained by conditioning the equation through the measured heights of site trees. This approach commonly has been used in growth and yield models (Clutter and others 1983).

[2] Bechtold, W.A.; Zarnoch, S.J. 1996. FHM mensuration engine. Version 1.5. [Not paged]. On file with: U.S. Department of Agriculture, Forest Service, Southern Research Station, P.O. Box 2680, Asheville, NC 28802.

When a tree occurring on the plot was not represented by a site tree of the same species, the procedure was modified. Height was estimated using the dominant heights and diameters of species present on the plot and then adjusted using site-index species conversion factors (e.g., Ek and others 1984). For example, if the site index for the site tree species was 100 and the equivalent site index of the subject tree was 80, the estimated height of the subject tree was reduced by 20 percent (Smith and Conkling 2005).

Once heights had been estimated for each tree, stem volumes were estimated using published volume equations. The particular volume equation used depended on tree species and the region of the country where the plot was located.

Total gross volume was expressed on a per-acre basis for each plot. The gross growth (annual change in gross volume) was then estimated for each ecoregion section using a generalized least squares (GLS) model. For more details on the GLS model, see "Forest Health Monitoring 2001 National Technical Report" (Conkling and others 2005).

Using the same procedure, the volumes of trees that died since plot establishment were estimated. Volumes for dead trees were estimated based on the last measurement of the tree when it was alive; no growth was assumed from the time the tree was measured alive and when the tree was determined to be dead. Mortality was modeled as the annual change in accumulated dead volume using the same GLS procedure used to model growth.

The mortality rate was divided by the previously derived gross volume growth rate to give the mortality ratio (MRATIO) (Conkling and others 2005). The variance of the MRATIO for each ecoregion section was taken to be

$$v_{mratio} = \frac{m^2}{g^2}\left(\frac{v_m}{m^2} + \frac{v_g}{g^2}\right)$$

where

v_{mratio} = variance of the MRATIO

v_m = variance of the mortality rate

v_g = variance of the gross growth rate

m = mortality rate

g = gross growth rate

This formula assumes mortality and gross growth to be independent. Although this assumption is, strictly speaking, not correct and leads to a slight overestimate of the variance, preliminary data analysis shows the correlation between growth and mortality to be (small enough to be) negligible.

For each plot, a DDLD ratio was calculated using data through the most recent measurement of each plot (Smith and Conkling 2005). The DDLD was calculated as the ratio of the quadratic mean diameter at breast height of trees that had died since plot establishment, to the quadratic mean diameter at breast height (at the most recent plot measurement) of surviving trees on the plot. If there were no live trees on the plot because the area had been logged, the DDLD was calculated as the ratio of the quadratic mean diameter at breast height of dead trees to the quadratic mean diameter at breast height of cut trees, where cut diameters are taken from previous measurement of the plot.

In the West, if the forest on the plot was of a type dominated by western woodland species, the DDLD was calculated as the ratio of the quadratic mean root-collar diameter of dead trees to the quadratic mean root-collar diameter of live trees on the plot. The DDLD also was calculated using root-collar diameters if the only observed mortality was of western woodland species, even if the forest type was predominantly nonwoodland species. No DDLD was calculated if all mortality was in woodland species and all survivors on the plot were nonwoodland species, or vice versa.

Appendix B

Supplemental Tables

Appendix table B.1—Summary of mortality statistics by ecoregion section

Ecoregion section code	Plots	Plots with mortality	Observations	Mortality	Growth	MRATIO	Std. error MRATIO	DDLD ratio Mean	DDLD ratio Minimum	DDLD ratio Maximum	DDLD ratio Std. error	Annual plot mortality volume[a] Median	Annual plot mortality volume[a] Minimum	Annual plot mortality volume[a] Maximum
	- - - - - - - - - - number	*- - - - - - - - - -*		*ft³ per acre per year*								*- - - - ft³ per acre per year - - - -*		
212A	13	9	41	37.53	101.93	0.368	0.1272	1.331	0.523	2.491	0.6080	57.13	3.65	140.72
212B	29	23	100	31.81	88.11	0.361	0.0970	0.917	0.287	1.864	0.4324	18.19	2.17	163.06
212C, 212D	26	24	93	33.16	79.67	0.416	0.0822	0.797	0.180	1.802	0.3518	29.04	1.85	108.37
212E	3	2	11	49.72	103.82	0.479	0.2218	1.990	1.334	2.646	0.9277	50.46	17.25	83.66
212F	14	6	31	16.69	100.86	0.165	0.0874	1.190	0.331	3.293	1.1247	80.00	42.43	530.67
212G	5	3	13	48.53	101.29	0.479	0.1307	1.889	0.851	2.454	0.8996	52.38	29.16	70.90
212H	79	50	187	37.29	62.74	0.594	0.1782	1.103	0.207	4.636	0.9484	24.85	0.58	621.33
212J	72	44	166	33.44	68.96	0.485	0.1258	0.827	0.156	2.070	0.4856	21.78	1.66	203.92
212K	10	8	25	27.26	56.15	0.485	0.1667	0.707	0.295	1.449	0.3835	16.05	8.85	103.48
212L	8	7	23	48.71	45.16	1.079	0.3301	1.126	0.452	1.916	0.5444	43.47	14.59	83.13
212M	4	1	12	28.05	61.30	0.458	0.4228	3.458	3.458	3.458	0.0000	107.28	107.28	107.28
212N	10	7	28	42.38	65.17	0.650	0.2507	0.637	0.408	1.085	0.2241	32.58	2.66	137.71
221A	46	43	171	22.64	71.96	0.315	0.0510	0.771	0.171	2.148	0.4606	20.55	0.84	110.13
221C, 221D	16	13	52	20.74	52.89	0.392	0.2269	0.913	0.291	2.612	0.6400	9.36	4.47	186.85
221E, 221F	38	27	136	19.31	92.88	0.208	0.0535	0.733	0.109	2.393	0.5683	18.01	1.53	1,337.23
221H, 221I	6	5	16	26.09	81.76	0.319	0.2841	1.178	0.441	1.770	0.4840	47.57	5.25	615.37
222C	5	2	10	85.12	1,607.81	0.053	0.0336	2.088	0.377	3.800	2.4202	212.79	136.60	288.98
222D	6	4	13	86.54	76.71	1.128	0.4476	0.842	0.273	1.263	0.4347	110.82	7.40	198.46
222E, 222F	19	10	44	15.77	166.12	0.095	0.0359	0.625	0.226	1.348	0.4012	31.69	4.13	225.41
222G	8	6	16	145.75	193.88	0.752	0.4738	1.043	0.217	1.781	0.6185	25.36	14.66	388.83
222H	9	8	18	98.31	107.15	0.917	0.4330	1.194	0.257	3.151	0.9787	55.39	6.10	363.01
222I, 222J	26	17	58	17.63	73.10	0.241	0.0820	0.846	0.176	1.695	0.4850	22.56	1.09	181.97
222K	12	4	27	7.83	63.73	0.123	0.0760	1.498	0.788	2.206	0.5795	38.59	26.64	98.97
222L	11	4	23	21.77	49.56	0.439	0.3017	0.899	0.266	1.741	0.6588	51.94	10.33	225.42
222M, 222N	9	5	25	14.05	55.54	0.253	0.1174	1.062	0.528	1.602	0.4080	19.17	4.96	53.27

continued

Appendix table B.1—Summary of mortality statistics by ecoregion section (continued)

Ecoregion section code	Plots	Plots with mortality	Observations	Mortality	Growth	MRATIO	Std. error MRATIO	DDLD ratio: Mean	DDLD ratio: Minimum	DDLD ratio: Maximum	DDLD ratio: Std. error	Annual plot mortality volume[a]: Median	Annual plot mortality volume[a]: Minimum	Annual plot mortality volume[a]: Maximum
	number			*ft^3 per acre per year*								*ft^3 per acre per year*		
231A	163	125	458	27.53	120.23	0.229	0.0369	0.728	0.055	2.498	0.4893	29.70	0.69	1,367.28
231B	65	56	205	31.62	114.37	0.276	0.0575	0.771	0.115	2.254	0.5324	20.46	0.98	218.58
231C	19	18	61	70.63	84.45	0.836	0.2443	0.775	0.281	2.578	0.5201	40.97	5.37	347.87
231D	12	11	38	28.13	102.18	0.275	0.1028	0.720	0.234	1.221	0.3428	15.54	1.08	97.32
232A	38	27	113	39.30	122.99	0.320	0.0753	0.706	0.121	2.100	0.4402	44.51	3.64	325.40
232B	94	63	270	25.83	115.05	0.225	0.0498	0.672	0.085	2.077	0.3922	27.35	0.73	900.23
232C	43	28	103	32.67	95.03	0.344	0.1040	1.070	0.224	4.744	1.0185	48.36	3.67	353.14
242A	23	6	49	26.13	199.50	0.131	0.0900	0.678	0.274	0.971	0.2673	14.84	2.29	173.72
251C, 251D	17	6	35	40.21	137.96	0.291	0.1656	0.635	0.290	0.939	0.2566	126.13	17.82	289.00
263A	8	4	20	7.42	182.66	0.041	0.0219	0.900	0.229	2.026	0.7796	17.50	0.49	22.68
313A	10	2	25	0.94	14.96	0.063	0.0384	1.000	1.000	1.000	0.0000	5.68	1.06	10.29
331A	5	2	11	66.26	85.30	0.777	0.5529	0.748	0.494	1.002	0.3596	102.60	41.55	163.65
331F, 331G	6	1	13	0.32	9.03	0.035	0.0307	3.336	3.336	3.336	0.0000	0.66	0.66	0.66
331I	12	3	27	2.76	19.70	0.140	0.1339	0.791	0.372	1.000	0.3627	1.87	1.64	27.90
341B, 341C	17	4	39	3.13	21.29	0.147	0.1308	1.000	1.000	1.000	0.0000	5.81	3.31	262.40
342A, 342E, 342F, 342G	8	0	19	0.00	39.44	0.000	—	—	—	—	—	0.00	0.00	0.00
342B, 342C	17	8	37	16.65	51.98	0.320	0.1619	0.957	0.428	1.978	0.4465	46.08	2.26	89.75
342H, 342I	7	1	14	4.07	20.65	0.197	0.2115	1.049	1.049	1.049	0.0000	24.44	24.44	24.44
M212A	70	63	254	41.04	74.03	0.554	0.0875	0.974	0.221	2.699	0.5937	32.53	1.71	341.48
M212B	20	17	86	18.13	82.19	0.221	0.0596	0.724	0.197	2.233	0.4846	16.38	2.01	105.14
M212C	18	18	65	44.70	87.18	0.513	0.1716	1.056	0.191	2.704	0.6336	24.80	1.28	257.31
M221A	52	40	162	56.63	73.36	0.772	0.1945	0.837	0.247	2.546	0.5094	34.11	1.49	328.11
M221B	21	12	80	35.05	86.39	0.406	0.2060	0.761	0.220	1.525	0.4405	13.55	2.24	258.17
M221C	17	13	63	57.31	69.77	0.821	0.4322	0.554	0.231	1.392	0.3869	28.08	5.56	548.10
M221D	41	26	108	49.10	102.86	0.477	0.1806	1.038	0.197	2.773	0.6985	62.67	6.73	489.38
M242A	39	15	82	74.83	136.34	0.549	0.2884	0.840	0.131	3.371	0.7969	48.98	5.94	641.63
M242B	37	17	78	34.21	146.81	0.233	0.0792	0.694	0.053	1.788	0.4723	40.89	0.74	174.05
M242C	53	17	111	33.91	62.63	0.541	0.2103	0.705	0.250	1.319	0.3208	43.04	1.10	481.28
M261A	45	24	103	21.79	85.28	0.256	0.1382	0.979	0.300	3.181	0.6372	18.54	2.10	767.56
M261B	16	7	35	103.74	88.50	1.172	0.9635	1.704	0.243	7.017	2.4557	14.51	0.44	809.83

continued

Appendix table B.1—Summary of mortality statistics by ecoregion section (continued)

Ecoregion section code	Plots	Plots with mortality	Observations	Mortality	Growth	MRATIO	Std. error MRATIO	DDLD ratio Mean	DDLD ratio Minimum	DDLD ratio Maximum	DDLD ratio Std. error	Annual plot mortality volume[a] Median	Annual plot mortality volume[a] Minimum	Annual plot mortality volume[a] Maximum
	- - - number	- - -	- - -	*ft³ per acre per year*								- - - - *ft³ per acre per year*	- - - -	
M261C, M261F	27	10	62	3.13	33.40	0.094	0.0403	0.720	0.136	1.443	0.4494	10.71	0.55	30.80
M261D	17	8	36	7.85	99.89	0.079	0.0421	0.926	0.269	2.000	0.6438	12.38	0.37	386.58
M261E	53	18	126	28.09	74.14	0.379	0.1729	0.913	0.114	3.037	0.7370	20.14	1.07	672.23
M261G	21	3	46	3.68	21.82	0.169	0.1148	1.044	0.386	1.443	0.5743	22.32	12.58	34.51
M262A, 261A	11	2	24	0.63	43.60	0.014	0.0189	1.997	0.902	3.092	1.5487	16.92	0.49	33.35
M262B, 261B	6	1	13	1.14	23.81	0.048	0.0434	1.000	1.000	1.000	0.0000	6.88	6.88	6.88
M331A, M331J	15	3	35	43.42	34.76	1.249	1.0916	1.617	0.654	3.334	1.4907	33.91	10.26	329.85
M331D	26	7	58	3.34	48.80	0.068	0.0357	0.784	0.252	1.261	0.3902	11.55	2.45	43.04
M331F	10	4	27	3.66	29.17	0.125	0.0721	0.973	0.749	1.142	0.1633	4.19	2.90	17.77
M331G	32	20	82	12.90	31.20	0.413	0.1611	1.113	0.225	3.129	0.6512	6.23	0.30	74.24
M331H	33	20	84	16.61	48.19	0.345	0.0748	0.794	0.303	1.842	0.3475	18.14	1.53	68.20
M331I	32	18	77	8.07	33.84	0.238	0.0818	0.872	0.169	1.671	0.4632	7.03	0.61	42.52
M332A	49	19	109	63.75	51.43	1.240	0.4690	1.165	0.193	4.345	0.8572	45.78	0.68	330.33
M332E	7	2	16	1.04	33.40	0.031	0.0278	1.225	0.540	1.909	0.9679	8.45	0.77	16.13
M332F	11	5	26	11.67	16.33	0.715	0.3889	1.771	0.503	5.001	1.8461	13.68	2.45	63.83
M332G	32	12	67	28.50	34.29	0.831	0.3632	1.014	0.099	2.611	0.7347	44.83	3.06	1165.94
M333A	31	13	69	63.38	66.24	0.957	0.7503	1.059	0.422	1.802	0.4472	27.73	3.81	563.30
M333D	26	17	60	61.76	103.28	0.598	0.2355	1.003	0.287	2.898	0.7022	31.85	1.41	398.79
M341B	13	5	30	3.19	22.77	0.140	0.0842	0.973	0.557	1.379	0.3692	3.68	1.05	10.95

DDLD ratio = ratio of the average dead tree diameter to the average live tree diameter; MRATIO = ratio of annual morrtality volume to gross volume growth; — = no value calculated.
[a] Minimum, maximum, and median plot mortality values were determined using only those plots which had any recorded mortality.

Appendix table B.2—Supplemental crown and damage information

Ecoregion section code	Plots	Mean plot basal area	Plot basal area std. dev.	Average percent of plot basal area associated with: Unhealthy trees[a]	Trees with unhealthy crowns[b]	Severely damaged trees[c]	Average percent of trees on each plot classified as: Unhealthy[a]	Unhealthy crowns[b]	Severely damaged[c]
	number	*square feet per acre*		*percent*					
212A	11	12.61	8.96	28.74	16.68	19.12	25.75	17.28	15.14
212B	23	15.35	7.96	17.26	6.62	13.11	15.80	6.19	11.43
212C, 212D	23	15.71	7.27	26.12	15.17	14.30	26.00	15.74	14.39
212E	9	10.84	5.62	26.22	4.81	24.21	25.70	4.26	23.26
212F	48	16.07	5.19	17.54	2.37	15.72	16.26	3.19	13.76
212G	16	18.56	8.93	19.65	2.54	18.27	14.79	1.91	13.71
212H	78	14.99	6.74	17.68	5.60	14.24	15.19	5.52	11.50
212J	68	15.24	6.53	23.60	5.53	19.81	22.31	6.15	18.04
212K	28	11.88	6.05	25.78	7.71	21.28	20.24	6.16	15.85
212L	63	12.35	6.03	20.51	5.54	16.23	17.30	5.86	12.71
212M	31	12.65	6.50	19.39	2.73	17.82	16.25	2.91	14.31
212N	64	11.44	5.69	21.70	3.98	18.41	19.53	4.30	15.88
221A	45	15.90	6.67	23.01	8.48	16.16	19.98	7.54	14.09
221B	10	14.18	4.92	23.11	5.03	19.68	20.99	5.45	17.23
221C, 221D	23	11.94	4.83	13.34	3.46	10.28	13.16	2.59	10.90
221E, 221F	52	13.28	5.74	18.89	1.41	17.89	17.52	1.81	16.30
221H, 221I	30	13.93	5.51	32.97	7.43	28.30	33.15	7.67	29.01
221J	11	16.78	8.28	17.07	1.86	16.03	15.92	2.02	14.73
222A	77	12.03	4.72	15.78	1.39	14.82	12.85	1.47	12.01
222C	16	13.62	7.35	23.52	1.87	22.91	23.06	2.17	21.94
222D	8	13.56	3.77	28.86	2.57	27.48	25.38	2.67	24.02
222E, 222F	45	13.25	5.07	29.72	1.45	28.99	26.75	2.09	25.79
222G	6	15.58	10.54	27.43	1.66	26.90	25.06	2.78	23.21
222H	9	15.10	5.75	31.79	8.58	28.62	22.10	3.24	20.24
222I, 222J	30	12.91	7.66	17.99	3.63	16.08	14.15	4.19	11.76
222K	12	9.08	5.18	35.78	21.52	25.52	30.65	19.47	21.13
222L	15	14.49	7.06	33.71	8.39	28.06	26.11	4.63	23.79

continued

Appendix table B.2—Supplemental crown and damage information (continued)

Ecoregion section code	Plots	Mean plot basal area	Plot basal area std. dev.	Average percent of plot basal area associated with: Unhealthy trees[a]	Trees with unhealthy crowns[b]	Severely damaged trees[c]	Average percent of trees on each plot classified as: Unhealthy[a]	Unhealthy crowns[b]	Severely damaged[c]
	number	*square feet per acre*		*percent*					
222M, 222N	37	10.82	5.39	23.32	2.99	21.44	17.50	2.47	16.20
231A	181	13.88	6.66	11.71	1.62	10.64	11.98	2.21	10.55
231B	62	12.12	5.26	13.38	1.54	12.73	13.37	1.87	12.69
231C	18	13.13	4.45	14.48	2.99	11.85	11.42	3.38	8.49
231D	10	12.87	7.12	15.54	1.24	14.52	15.83	2.21	13.97
231E	15	11.76	6.67	11.74	1.98	11.06	13.92	3.92	11.74
231G	4	13.59	4.29	14.77	2.02	13.07	14.98	4.54	11.24
232A	50	16.84	7.29	19.84	1.43	18.76	18.14	1.70	17.07
232B	83	13.10	7.25	12.79	2.82	11.15	12.40	3.06	10.48
232C	53	14.77	8.35	13.97	2.55	12.18	13.48	2.91	11.09
232F	10	11.11	6.15	9.03	2.06	8.28	12.91	3.45	11.91
234A	7	15.65	6.60	20.63	6.37	14.78	15.26	6.13	10.92
242A	26	31.22	15.48	8.64	4.00	5.00	8.66	5.19	4.25
251A, 251B	5	10.18	6.90	26.44	0.25	26.19	22.11	0.74	21.37
251C, 251D	27	11.44	4.69	27.86	2.33	27.23	20.65	3.79	18.95
251E	1	5.09	—	0.00	0.00	0.00	0.00	0.00	0.00
261A, M262A	9	17.38	9.21	23.27	2.82	23.08	16.19	1.59	15.70
261B, M262B	2	35.04	32.57	16.43	3.15	16.43	28.33	2.78	28.33
263A	8	35.19	15.27	19.33	5.73	16.56	19.54	4.53	16.22
313A	4	19.37	12.01	38.98	25.73	25.76	31.47	23.24	18.12
331A	5	15.72	7.59	9.42	3.30	6.12	9.56	3.37	6.19
331F, 331G	2	8.44	2.90	2.14	0.00	2.14	3.85	0.00	3.85
331I	7	22.03	22.21	30.61	14.93	19.25	24.01	11.65	14.48
331J	2	11.25	3.87	14.86	0.00	14.86	17.74	0.00	17.74
341A	1	18.48	—	28.40	11.12	17.28	18.18	6.06	12.12
341B, 341C	8	14.08	7.74	27.75	8.24	21.47	23.26	8.90	15.44
341D, 341E	10	17.93	6.38	24.29	18.28	6.50	18.31	13.09	5.99

continued

Appendix table B.2—Supplemental crown and damage information (continued)

Ecoregion section code	Plots	Mean plot basal area	Plot basal area std. dev.	Average percent of plot basal area associated with: Unhealthy trees[a]	Trees with unhealthy crowns[b]	Severely damaged trees[c]	Average percent of trees on each plot classified as: Unhealthy[a]	Unhealthy crowns[b]	Severely damaged[c]
	number	*square feet per acre*		*percent*					
341F	11	14.06	6.46	30.64	28.06	11.59	24.03	20.05	9.48
341G	5	17.81	9.91	25.74	11.26	21.00	15.10	4.71	12.87
342A	9	19.69	8.68	43.25	21.18	29.20	35.19	17.35	24.64
342B, 342C	17	15.52	6.51	18.89	8.81	10.76	14.43	7.16	8.30
342D	2	14.56	2.30	12.90	1.94	11.84	28.23	4.90	26.67
342F, 342G	9	19.69	8.68	43.25	21.18	29.20	35.19	17.35	24.64
342H, 342I	7	12.22	4.39	9.77	4.42	5.35	6.57	3.48	3.09
M212A	57	14.14	7.70	25.46	5.30	21.39	21.34	5.73	16.83
M212B	21	19.33	8.19	26.99	5.29	24.06	26.42	7.13	22.96
M212C	17	16.36	7.23	32.86	7.23	28.02	29.33	7.14	24.38
M212D	35	17.09	7.45	29.67	5.30	26.65	27.53	5.27	24.07
M212E	10	15.53	5.51	30.94	4.99	29.53	28.87	3.55	27.70
M221A	76	14.91	5.54	16.58	3.36	14.62	15.00	3.52	12.89
M221B	25	15.58	6.02	21.79	0.87	20.97	20.30	1.00	19.46
M221C	16	13.57	5.41	36.02	3.22	33.46	34.52	3.10	32.58
M221D	63	16.27	6.17	17.12	3.51	14.93	16.59	3.85	13.76
M222A	3	13.23	4.35	10.58	5.87	7.65	15.93	11.45	11.86
M231A	8	15.89	4.75	27.92	13.94	14.96	27.58	18.51	12.21
M242A	46	25.07	15.81	15.60	3.57	13.81	12.25	2.96	10.00
M242B	49	34.44	19.17	13.23	3.48	10.10	10.14	3.98	6.68
M242C	52	20.76	11.91	14.57	6.64	9.55	15.41	7.26	10.09
M261A	50	24.17	12.49	12.21	4.00	9.18	10.55	3.26	8.36
M261B	15	18.65	10.49	30.22	3.73	28.78	21.44	2.19	20.50
M261C	21	12.56	7.96	25.97	9.61	22.90	22.38	6.64	18.13
M261D	17	24.55	19.57	5.99	0.84	5.64	8.90	2.31	7.84
M261E	48	23.31	13.29	14.14	5.75	8.49	9.89	3.28	6.84
M261F	21	12.56	7.96	25.97	9.61	22.90	22.38	6.64	18.13

continued

Appendix table B.2—Supplemental crown and damage information (continued)

Ecoregion section code	Plots	Mean plot basal area	Plot basal area std. dev.	Average percent of plot basal area associated with			Average percent of trees on each plot classified as		
				Unhealthy trees[a]	Trees with unhealthy crowns[b]	Severely damaged trees[c]	Unhealthy[a]	Unhealthy crowns[b]	Severely damaged[c]
	number	*square feet per acre*		- - - - - - - - - - - - - -	- - - - - - -	- - - - - - *percent*	- - - - - - -	- - - - - - -	- - - - - - -
M261G	18	18.86	8.07	8.86	4.59	5.57	10.06	5.02	6.20
M313A	1	5.80	—	4.10	0.00	4.10	4.76	0.00	4.76
M331A	14	16.62	4.54	22.73	14.10	13.14	19.76	10.69	12.37
M331B	5	24.44	6.63	24.35	19.09	10.62	21.41	16.14	10.42
M331D	20	17.48	9.62	14.18	5.91	10.88	14.66	5.32	11.99
M331F	9	15.28	8.62	13.40	6.61	11.68	12.63	4.70	10.31
M331G	23	16.89	9.33	15.93	7.96	11.37	15.47	6.54	11.73
M331H	28	20.51	10.83	12.67	2.76	10.42	12.46	2.55	10.38
M331I	31	17.99	7.52	19.92	13.69	7.79	18.93	12.90	7.86
M331J	14	16.62	4.54	22.73	14.10	13.14	19.76	10.69	12.37
M332A	46	18.81	9.37	14.69	7.03	10.29	11.53	4.86	7.74
M332E	5	18.86	7.49	14.99	9.78	10.53	11.61	6.95	6.32
M332F	8	12.34	7.30	22.27	5.23	19.05	19.39	4.47	17.00
M332G	33	15.46	6.03	15.17	7.69	9.87	13.88	7.71	7.94
M333A	31	16.22	8.35	9.91	2.66	7.50	8.57	3.40	5.44
M333B	1	29.92	—	22.03	19.88	2.15	21.43	14.29	7.14
M333D	25	21.19	10.63	12.59	4.56	8.98	10.55	6.19	5.23
M334A	2	16.00	10.86	1.99	1.43	1.99	5.41	4.55	5.41
M341A	24	16.77	9.00	26.16	13.60	13.85	19.06	10.10	10.26
M341B	9	17.54	14.30	32.33	4.94	29.78	22.21	4.85	19.83

— = no standard deviation because only one plot.
[a] Trees meeting the criteria for unhealthy crowns or severe damage.
[b] Adjusted ZB-index of 0.25 or higher (all species) or dieback of 10 percent or greater (softwoods only).
[c] Tree-Level Damage Severity Index of 45 or greater.

Coulston, John W.; Ambrose, Mark J.; Riitters, K. H.; Conkling, Barbara L. 2005. Forest health monitoring: 2002 national technical report. Gen. Tech. Rep. SRS–84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 97 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. This annual report focuses on "Criterion 3—Maintenance of Forest Ecosystem Health and Vitality" from the "Criteria and Indicators of Sustainable Forestry of the Santiago Declaration" as the reporting framework. The report is composed of five main data sections and two appendices. The "Introduction" provides background information about FHM, details about the conceptual approach to the report, and details about data used in the analyses. The next three sections each focus on a specific indicator from criterion 3. The first indicator section contains analyses of abiotic, biotic, and anthropogenic disturbances including drought, hurricanes, tornadoes, fire, insects and diseases, introduced species, and land development. The second indicator section contains analyses of air pollution data including nitrate and sulfate wet deposition data and ozone data. The third indicator section contains analyses of tree health data including tree mortality, crown condition, and damage. The final data section is a multivariate analysis, providing an integrated presentation of the data used in the report. Two appendices contain details about the analyses methods and summary data tables.

Keywords: Assessment, bioindicators, climate, criteria and indicators, forest health, mortality, ozone.

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