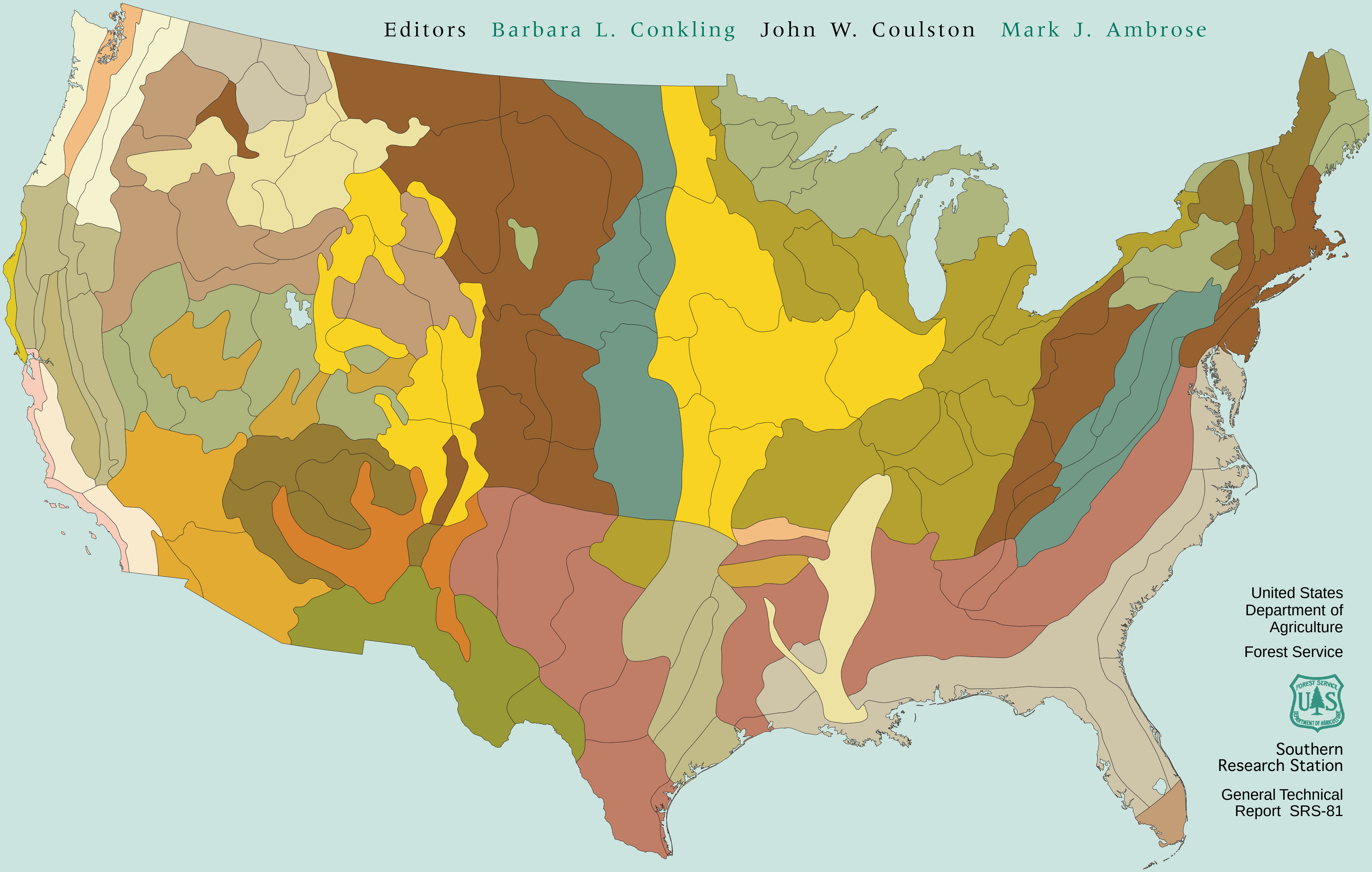
Forest Health Monitoring 2001 National Technical Report

Editors Barbara L. Conkling John W. Coulston Mark J. Ambrose



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Forest Health Monitoring 2001 National Technical Report

Editors

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Abstract

The Forest Health Monitoring (FHM) Program's annual national report uses FHM data, as well as data from a variety of other programs, to provide an overview of forest health based on the criteria and indicators of sustainable forestry framework of the Santiago Declaration. It presents information about the status of and trends in various forest health indicators nationwide and uses statistically valid analysis methods applicable to large-scale ecological assessments. Five main sections correspond to the Santiago criteria: Biological Diversity, Productive Capacity, Health and Vitality, Conservation of Soil, and Carbon Cycling. A variety of indicators contribute information about the status of each forest ecosystem considered. Many indicators use data collected from ground plots. Such indicators include species diversity (tree and lichens), bioindicator species (lichens and vascular plants sensitive to ozone), changes in trees (crown condition, damage, and mortality), physical and chemical soil characteristics, and aboveground and belowground carbon pools. Additional information about forest health status and change is derived from data that are used to measure forest extent; data about insects and pathogens; and remotely sensed and/or ground-based data about forest fragmentation, fire, and air pollution. A sixth section presents and discusses a multivariate analysis of the indicators. The technique provides a composite picture of forest health, based on statistically significant principal components.

Keywords: Assessment, bioindicators, carbon, criteria and indicators, diversity, fragmentation, mortality.

Table of Contents

continued

Contents, cont.

List of Figures

Figures, cont.

Figures, cont.

List of Tables

Introduction

Barbara L. Conkling

John W. Coulston

Mark J. Ambrose

The Forest Health Monitoring (FHM) Program has begun the task of producing an annual technical summary report, presenting the data from a national perspective. The report's primary clients are national forest managers, although regional and State managers also are expected to be interested in the data. The report's purpose is to use FHM Program data and other appropriate data to determine the status of and changes in indicators described in the "Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests" (Anon. 1995b). It includes the most recent FHM plot data available, as well as analyses that demonstrate how statistical methods can be used to contribute supplemental information.

The FHM Program

The FHM Program is a multiagency cooperative effort to determine on an annual basis the status of, and changes and trends in, all forest ecosystems in the United States. The U.S. Department of Agriculture (USDA) Forest Service cooperates with State forestry and agricultural agencies to conduct FHM activities. Universities and other Federal agencies also participate. From 1990 through the 1999 field season, the FHM Program was comprised of four interrelated components:

- Detection Monitoring—field plot and aerial survey activities for national and regional monitoring
- Evaluation Monitoring—intensified monitoring or analysis in problem areas
- Intensive Site Ecosystem Monitoring—monitoring to understand processes and improve predictive capabilities
- Research on Monitoring Techniques—research to improve monitoring

Using FHM ground plots, Detection Monitoring covered all forested lands except in cities and riparian forests < 100 feet wide. A hexagonal network of permanent fixed-area plots located approximately 17 miles apart constitutes 4,600 potentially forested plots nationwide. Each year crews measure a systematic sample, or panel, of one-fourth of the total plots as well as one-third of the plots from the previous year's panel, called the overlap. This 4-year rotating panel design results in measurement of one-third of the permanent plots each year.

In addition to FHM's national reports, the five FHM regions produce region- or State-specific reports; e.g., Atkins and others 1999; Burkman and others 1998; Campbell and others 2000; Dale and others 2000; Gatch and others 1999; Rogers and others 2001, 1998. Each region also works with the State agencies to produce "State Highlights" fact sheets (available on the FHM Web site: http://www.fhm.fs.fed.us) and other State reports.

Details about the Report

The USDA Forest Service has adopted the Santiago Declaration and accompanying criteria and indicators framework (Anon. 1995a, 1995b) to assess and disseminate information on forest sustainability (Smith and others 2001; U.S. Department of Agriculture, Forest Service 2001). This report addresses the first five criteria as extensively as possible. It is not an exhaustive analysis of each criterion, but demonstrates the use of data from FHM, Forest Inventory and Analysis (FIA), Forest Health Protection (FHP), and other agencies to describe forest health status and changes.

The report contains six data analysis sections. The first five correspond to the first five criteria and include the relevant indicators used to examine each criterion. In the sixth section, entitled "A Multivariate Analysis of Forest Indicators," individual indicators are combined to produce additional information. The first of three appendices provides details about the analyses and assumptions used. The second appendix contains supplemental data tables that may be of interest to the reader, and the third is the summary from the 1999 quality assurance report about the FHM plot data.[1]

USDA Forest Service data sources were FHM (1990 through 1999), FIA annual survey (U.S. Department of Agriculture, Forest Service 2001), FHP (1998 through 1999), and Fire Sciences Laboratory (Fire Sciences Laboratory 1999a, 1999b). Other data sources were National Oceanic and Atmospheric Administration (1895 through 1999), National Atmospheric Deposition Program (NADP) (1979 through 1995), Clean Air Status and Trends Network

[1] 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, Forest Health Monitoring Program. [Number of pages unknown]. Vol. 1. On file with: James Pollard, FIA Quality Assurance Coordinator and Program Director-Fisheries and Aquatic Sciences at the University of Las Vegas-HRC, 4505 S. Maryland Parkway, Las Vegas, NV 89154–4009.

(CASTNET) (1979 through 1995), and Canadian Air and Precipitation Monitoring Network (CAPMON) (1979 through 1996). Specific data collection methods for FHM ground plots are described in the 1998 and 1999 FHM field methods guides.[2] [3]

Where possible, data were analyzed using a national hierarchical system of ecological units (Bailey 1995), which classifies the United States into ecoregion domains, divisions, provinces, sections, subsections, land-type associations, and land types (McNab and Avers 1994). We used the ecoregion section scale, which typically describes thousands of square miles. Areas within an individual ecoregion section typically have similar geologic origins and lithology, regional climate, soils (examined to the levels of orders, suborders, or great groups), potential natural vegetation, and/or potential natural communities (Cleland and others 1997) (fig. 1).

Analyses of FHM Plot Data

For FHM plot data analyses, the data were stratified spatially by Bailey's ecoregion section (Bailey 1995, Freeouf 1997, McNab and Avers 1994, Miles and Goudy 1997). The minimum level of analysis was the mean plot value of each variable and/or indicator by ecoregion section.[4] If an ecoregion section contained an insufficient number of plots for a specific analysis, it was combined with an adjacent section in the same ecoregion province.

Table 1 displays the States and years in which FHM plot data were collected. Indicators using FHM plot data and the years they were collected are presented in table 2. Estimations of indicator change by ecoregion section were made using data from all States that included repeated measurements. Change values are reported for all ecoregion sections that are, at least in part, in States where two or more panels, i.e., one-half of the plots, had been remeasured. Change values also are reported for ecoregion sections in Pennsylvania, where data were available from a single panel; i.e., one-fourth of the plots, which had been remeasured twice over a 5-year period.

[2] U.S. Department of Agriculture, Forest Service. 1998. Forest health monitoring 1998 field methods guide. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, National Forest Health Monitoring Program. 473 p. On file with: The Forest Health Monitoring Program National Office, 3041 Cornwallis Road, Research Triangle Park, NC 27709.

[3] 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.

[4] 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.

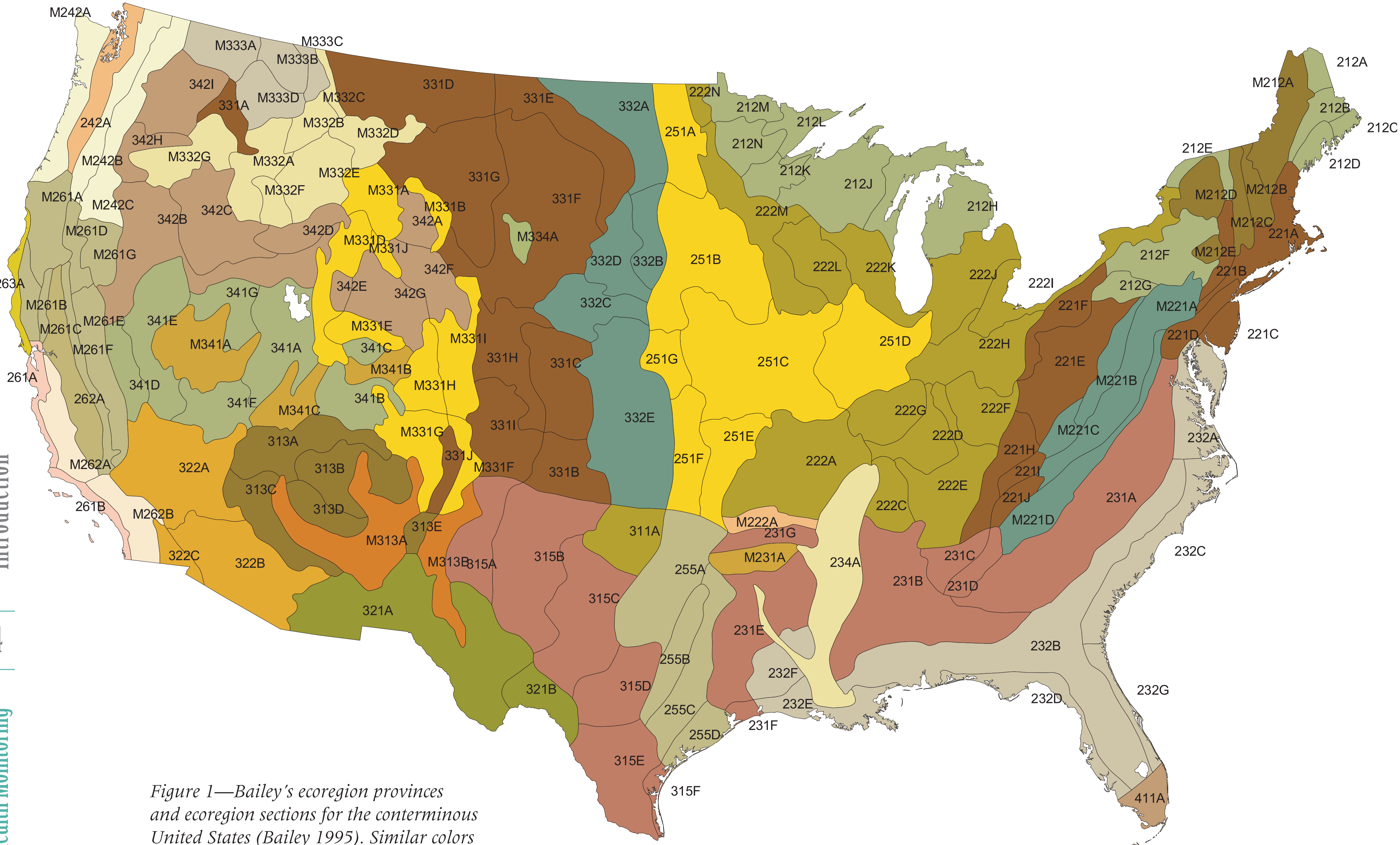

Figure 1—Bailey's ecoregion provinces and ecoregion sections for the conterminous United States (Bailey 1995). Similar colors in groups are the ecoregion sections within the ecoregion provinces.

Eastern ecoregion provinces

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

Western ecoregion provinces

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

Table 1—Years in which plot data were collected in each State through 1999

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

Table 2—Indicators using plot data and years of plot data used in this report

Indicator	Years in which data collected
Tree species richness	Most recent measurement of each plot 1990–99
Lichen diversity	Most recent measurement of each plot 1994–98
Growth (tree)	1990–99
Ozone bioindicator plants	1994–99
Lichen bioindicator	1992–98
Crown condition	1991–99
Tree damage	Most recent measurement of each plot 1994–99
Tree mortality	1990–99
All soil chemistry and carbon	1998–99
Soil erosion and compaction	1999
Tree carbon	1990–99

Monitoring Data and Making Cause-and-Effect Inferences

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 USDA Forest Service FIA data as an example. They stated that although establishing correlation is easy, establishing cause and effect is difficult. To highlight this, Schreuder and Thomas (1991) presented three criteria from Mosteller and Tukey (1977) with the note that two of the three criteria need to be met to infer cause-and-effect relationships:

1. Consistency—implies the presence and magnitude of the effect (y) are always associated with a minimal level of the suspected causal agent (x)
2. Responsiveness—established by experimentally exposing the population under study to the suspected causal agent and by reproducing the symptoms
3. Mechanism—established by demonstrating a cause-and-effect linkage in a step-by-step approach

Monitoring data or observational data, such as FIA phase 2 (FIA annual inventory plots) and phase 3 (or FHM Detection Monitoring data), most clearly address the consistency criterion (Olsen and Schreuder 1997). Feinstein (1988) used examples from epidemiology in his discussion of a scientific approach to use observation data; e.g., monitoring data, to help determine cause-and-effect relationships. Olsen and Schreuder (1997) said that two kinds of field plots, in addition to monitoring plots, are important when testing and establishing cause-and-effect relationships. The number of one kind of plot should be fewer than the number of monitoring plots and measured more frequently, with the option of destructive sampling. The other kind of supplemental plot should be long-term ecological research sites from which data will be used to study responsiveness and mechanisms. These kinds of additional plots correspond well to FHM Evaluation Monitoring studies and Intensive Site Ecosystem 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?

Rowe and Sheard (1981) stated that maps produced as part of the process 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). Different assessment clients are interested in various spatial scales, such as counties, States, regions [USDA Forest Service, FHM, Resource Planning Act (RPA), etc.], as well as ecological units such as provinces, divisions, and ecoregions. The choice to use a particular scale or unit usually will be based on data applicability and client needs. 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, the analyst should refer to the criteria used in formulating the unit. In this report we use Bailey's ecoregion sections (Bailey 1995), which are based on climate, vegetation, and soil factors such as erosion, chemical properties, and compaction. Although any single spatial scale may not be the best for every indicator to be analyzed, it will provide a starting point or common framework for an ecologically based assessment.

FHM and the Enhanced FIA Program

In 1999, the ground plot activities of FHM's Detection Monitoring component were integrated with FIA plot activities to maximize the strengths of both programs. An enhanced FIA systematic grid was established that includes some but not all former FIA plots. The grid includes annual survey plots (phase 2) to be measured on a 5-year rotation, such that one-fifth of the plots are measured each year. FIA field crews collect a core set of mensuration measurements on these plots. In 2000, the established FHM Detection Monitoring plots became phase 3 plots in the enhanced FIA program. Phase 3 plots are a subset of phase 2 plots, and the same basic plot and sampling design are used on all of them. An additional set of tree and nontree indicators is measured on phase 3 plots, and includes crown condition, lichen communities, soils (both physical and chemical characteristics), vegetation structure, and down woody debris. The ozone bioindicator plants indicator remains a phase 3 indicator, although it may no longer have to be measured near a ground plot. Detection Monitoring remains a component of FHM and includes aerial and ground surveys. The other three components of FHM—Evaluation Monitoring, Intensive Site Ecosystem Monitoring, and Research on Monitoring Techniques—remain the same. More information about the enhanced FIA Program can be found on the FIA national Web site: http://www.fia.fs.fed.us.

The Santiago Declaration and Accompanying Criteria and Indicators

In 1995, 12 countries including the United States, representing 90 percent of the World's temperate forests and 60 percent of all forests worldwide, endorsed the Santiago Declaration and its accompanying criteria and indicators.

The criteria and indicators provide a framework for measuring and assessing the sustainability of forest resources. They also promote a common understanding of the important components and processes in a sustainable forest ecosystem. The text of the Santiago Declaration and the accompanying criteria and indicators can be found at: http://www.fs.fed.us/land/sustain_dev/sd/sfmsd.htm. 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

The first six criteria address forest conditions, attributes, or functions, and the values associated with environmental and socioeconomic goods and services provided by forests (Anon. 1995b). The seventh criterion addresses broader issues that are often external to the forests, but that support sustainable forest management. In this context, each criterion is "a category of conditions or processes by which sustainable forest management may be assessed" (Anon. 1995b), and each is then characterized by related indicators—"a quantitative or qualitative variable which can be measured or described and which when observed periodically demonstrates trends" (Anon. 1995b).

Maps in this Report

Maps included in this report both 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 for all ecoregion sections or plot values. 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 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 in this report, 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 landcover maps derived from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery and is not very detailed (fig. 3). In addition, several maps portray State or regional boundaries to help orient readers geographically. On maps showing data by plot, plot locations are approximate. Figure captions contain a brief title, the years of data used (where applicable), and a reference to the text or appendix if needed.

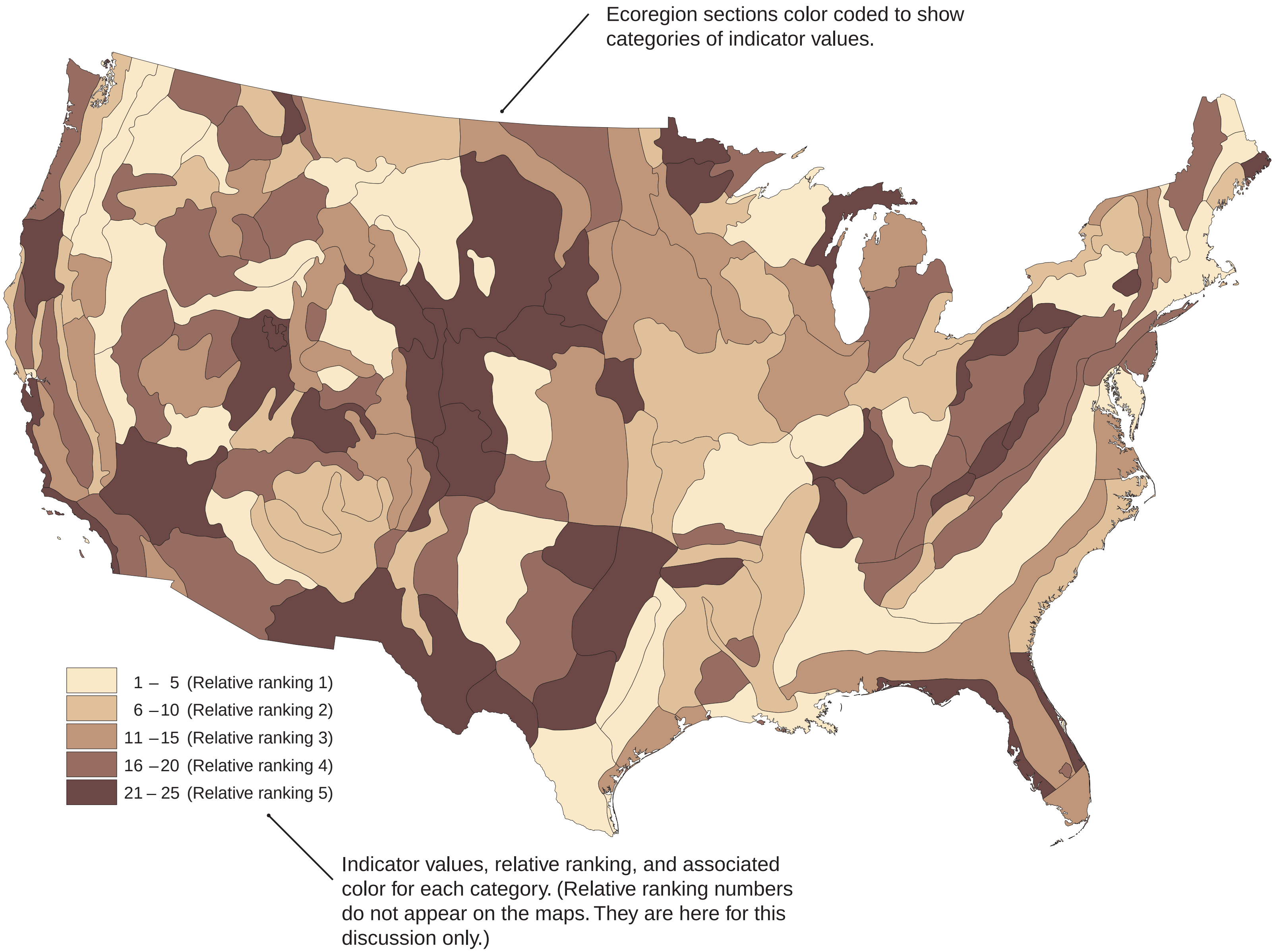

Figure 2—How to read a map in this report.

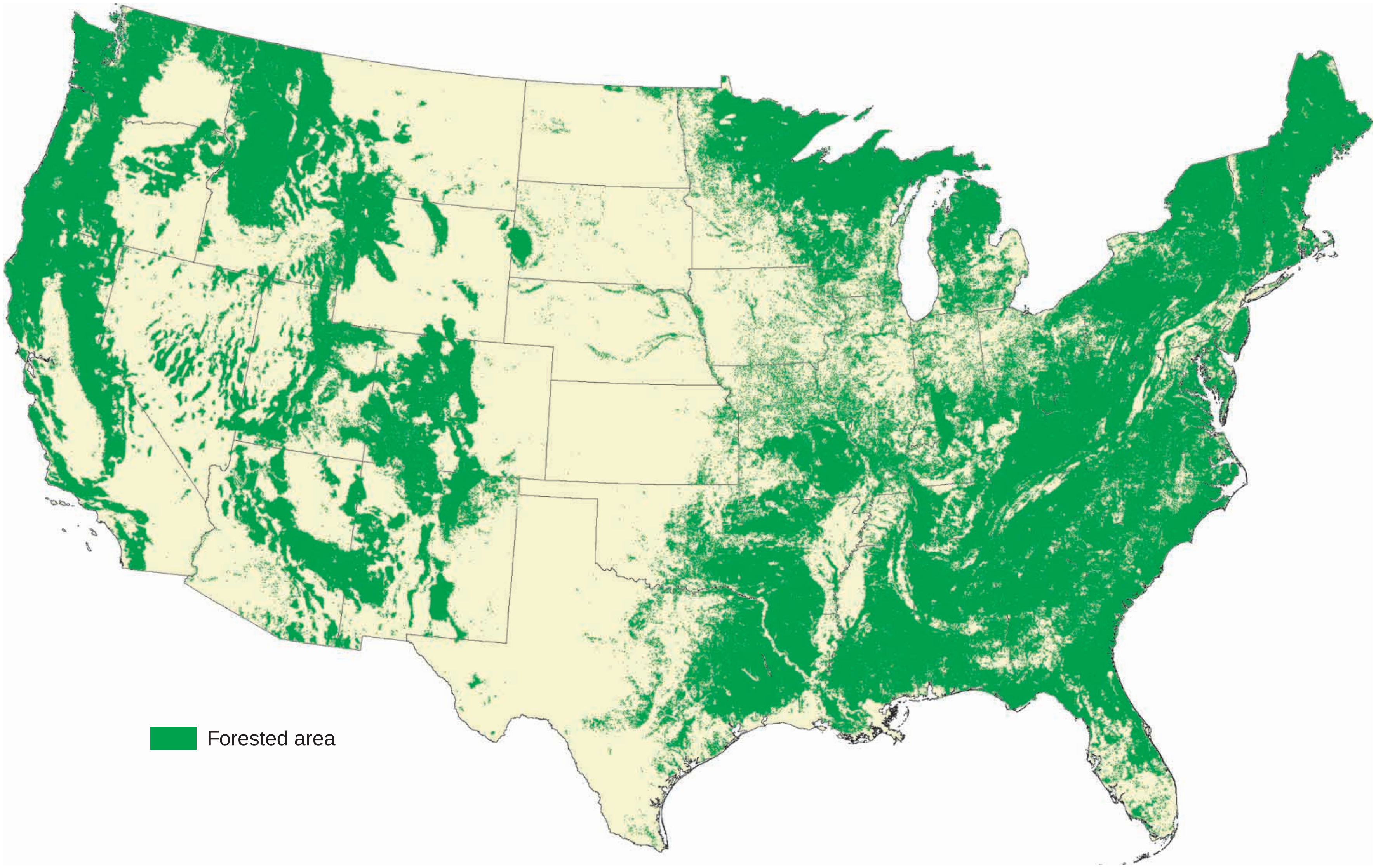

Figure 3—Forest land backdrop for maps from landcover maps derived from Advanced Very High Resolution Radiometer satellite imagery.

CRITERION 1— Biological Diversity

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Biological diversity, described as "the variety and variability among living organisms and the ecological complexes in which they occur" (Office of Technology Assessment 1987), is an important aspect of any sustainable forest ecosystem. Maintenance of biological diversity is important to ecosystem health because it enables the system to "respond to external influences, to recover from disturbance, and to maintain the organisms essential for its ecological processes" (Roundtable on Sustainable Forests 2000). Diversity also sustains production of the many goods and services that forests provide. It is the source of many of the economic, aesthetic, or spiritual values that humans assign to forests (Noss and Cooperrider 1994, Roundtable on Sustainable Forests 2000).

Biological diversity exists at a variety of scales—from the genetic diversity present within a population of a species, to the diversity of species within a community, to the diversity of plant and animal communities across the landscape (Noss 1990). At any scale there are many aspects to biodiversity, including the three primary attributes of composition, structure, and function (Noss 1990). Following the Santiago criteria, this report addresses the conservation of diversity at several of those spatial scales using data from a variety of sources, including remotely sensed and FHM plot data.

Extent of Timberland by Forest Type, Stand-Age Class, or Successional Stage

Many plants and animals have habitat in forests of a particular type, age, and/or successional stage. Maintaining forest cover representing the range of forest types, ages, and successional stages sustains the habitat for a variety of forest-dependent species. It also provides for the sustainable yield of a variety of forest products.

Data about forest extent in the United States are collected by the USDA Forest Service and reported in the RPA reports. The most recent RPA report and summary were used as source information for this section (Smith and others 2001; U.S. Department of Agriculture, Forest Service 2001). Figures 4 and 5 show the amount of forest land[5] in the East and West (including Alaska) by forest type and land class[6] for 1997.

[5] Forest land is land at least 10-percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10-percent stocked with forest trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper (*Pinus edulis-Juniperus communis*) and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads, trails, streams, and clearings in forest areas are classified as forest if < 120 feet wide (Smith and others 2001).

[6] Timberland is forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included (Smith and others 2001). Reserved forest land is forest land withdrawn from timber utilization through statute, administrative regulation, or designation without regard to productive status (Smith and others 2001). Other forest land is forest land other than timberland and productive reserved forest land. It includes available and reserved forest land which is incapable of producing annually 20 cubic feet per acre of industrial wood under natural conditions because of adverse site conditions such as sterile soils, dry climate, poor drainage, high elevation, steepness, or rockiness. Urban forest land is also included (Smith and others 2001).

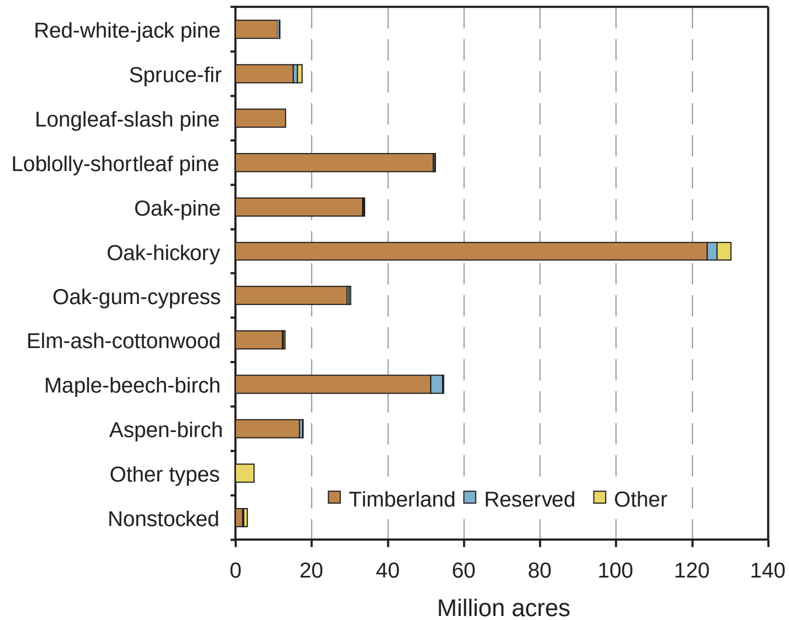


Figure 4—Forest land in the East by forest type and land class, 1997 (Smith and others 2001).

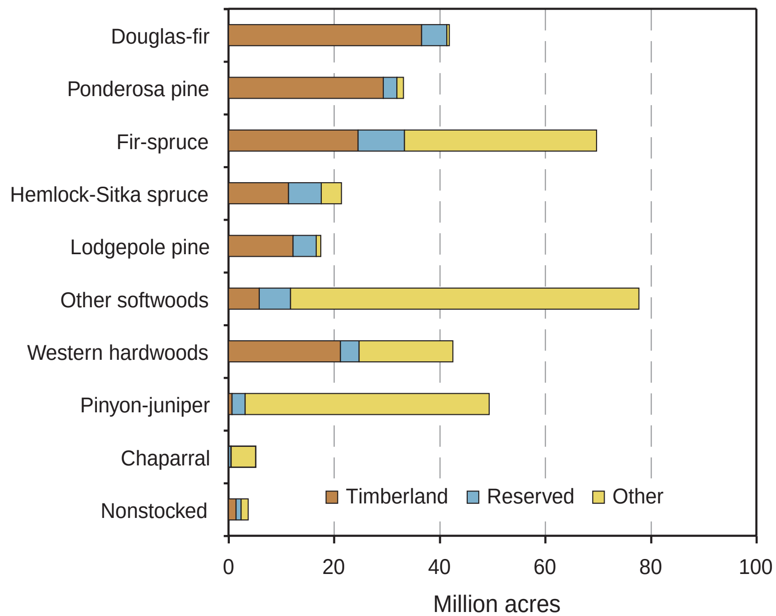


Figure 5—Forest land in the West by forest type and land class, 1997 (Smith and others 2001).

Stand-size class is one measure of forest structure and age. Four classes were used in the RPA report (Smith and others 2001): (1) nonstocked—timberland < 10-percent stocked with live trees; (2) seedling-sapling—live trees < 1.0-inch diameter at breast height (d.b.h.) and at least 1 foot in height through live trees 4.9 inches d.b.h.; (3) poletimber—live trees at least 5.0 inches d.b.h., but smaller than sawtimber trees; and (4) sawtimber—live trees containing at least one 12-foot saw log or two noncontiguous 8-foot saw logs, meeting regional specifications for freedom from defect, and at least 9.0 inches d.b.h. if softwood and at least 11.0 inches d.b.h. if hardwood. The trends in size class distribution over about the last 30 years are shown in figures 6 and 7 (Smith and others 2001).

Timberland area by stand-age class in the East and West is presented in figure 8. About 71 percent of all timberland in the East is classified as having an average stand age of > 40 years (including uneven-aged stands). In the West, about 80 percent of all timberland is so classified. One factor contributing to the difference in average stand age is that more areas in the West have never been harvested (U.S. Department of Agriculture, Forest Service 2001).

Figure 6—Trends in area of timberland in the East by stand-size class, 1953–97 (Smith and others 2001).

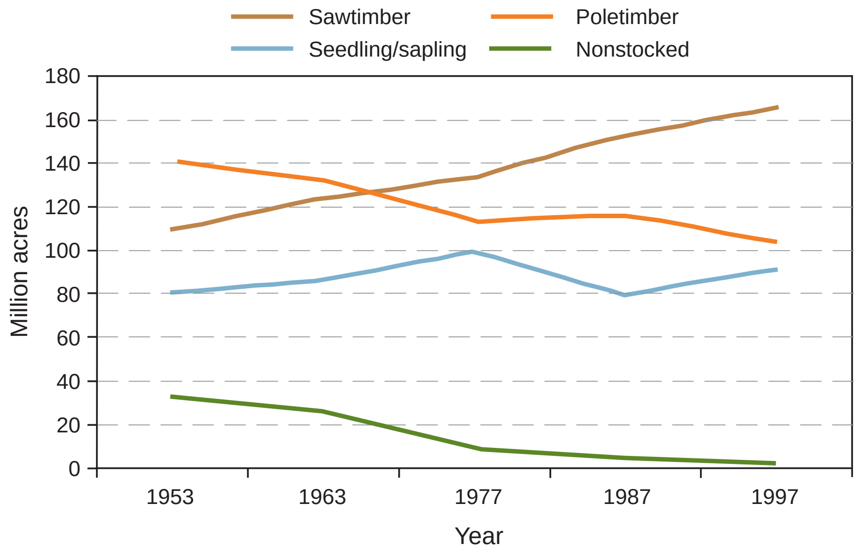
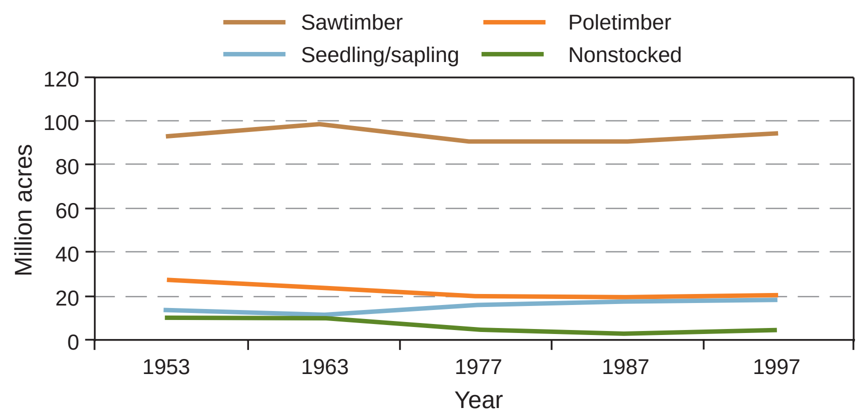


Figure 7—Trends in area of timberland in the West by stand-size class, 1953–97 (Smith and others 2001).



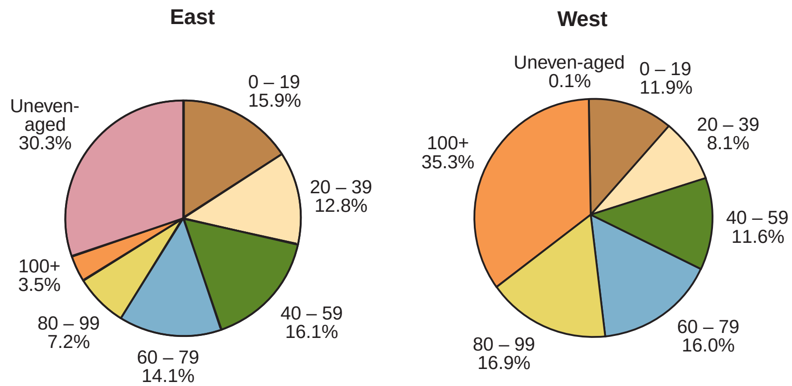


Figure 8—Timberland area by stand-age class (U.S. Department of Agriculture, Forest Service 2001).

When forest-type groups on unreserved forest land[7] in the conterminous United States were evaluated for change between 1977 and 1997, the area of loblolly-shortleaf pine, oak-gum-cypress, oak-hickory, and maple-beech-birch increased in the East while Douglas-fir, hemlock-Sitka spruce, redwood, other softwoods, pinyon-juniper, and western hardwoods increased in the West (U.S. Department of Agriculture, Forest Service 2001). It was observed that overall, hardwood forests are getting older in the East, demonstrated by an increase in area of forest types more representative of later successional stages and a decrease in area of forest types more representative of earlier successional stages (U.S. Department of Agriculture, Forest Service 2001).

Protected Areas

The total area under protection is a direct measure of the importance that society places on conservation (Anon. 1995b). Some consider protected areas to be the most effective way to conserve biological diversity (Leader-Williams and others 1990, MacKinnon and others 1986, McNeely and Miller 1984). Such areas also help conserve natural ecosystem processes at or below the spatial scale of a given area.

The International Union for Conservation of Nature (IUCN) uses six categories to define protected areas (International Union for Conservation of Nature 1994). This report considers only class I and class II areas.

[7] Unreserved forest land is forest land that is not withdrawn from harvest by statute or administrative regulation. It includes forest lands that are not capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands (Smith and others 2001).

A description of each category follows:

I. Strict nature reserve/wilderness area—protected area managed mainly for science of wilderness protection
II. National park—protected area managed mainly for ecosystem protection and recreation
III. Natural monument—protected area managed mainly for conservation of specific natural features
IV. Habitat/species management area—protected area managed mainly for conservation through management intervention
V. Protected landscape/seascape—protected area managed mainly for landscape/seascape protection and recreation
VI. Managed resource protected area—protected area managed mainly for the sustainable use of natural ecosystems

This classification system is based on protection by legal statute and covers only public lands. Management objectives on private ownership may change, for example, when a property is sold (U.S. Department of Agriculture, Forest Service 2001).

In 1997 there were approximately 747 million acres of forested land in the United States. Fifty-two million forested acres were classified as reserved under IUCN class I and class II (Smith and others 2001). This estimate included Federal and State land, but not privately owned lands. In the East, 3 percent of forested area was classified as reserved, and in the West 11.1 percent was classified as reserved (U.S. Department of Agriculture, Forest Service 2001).

In the East, forest types with the smallest percentage of class I or class II areas were longleaf-slash pine and loblolly-shortleaf pine forest types (0.7 percent). Such areas account for roughly 1.8 and 7.0 percent of the total forested area in the United States, respectively (fig. 9). The eastern forest type with the greatest percentage of area in protected status was maple-beech-birch (5.7 percent). In the West, the forest type with lowest percentage of area in protected status was pinyon-juniper (5.0 percent) (fig. 9). Conversely, 50.9 percent of the western white pine forest type was in IUCN class I or class II, although it accounted for < 1 percent of the total forested area in the United States.

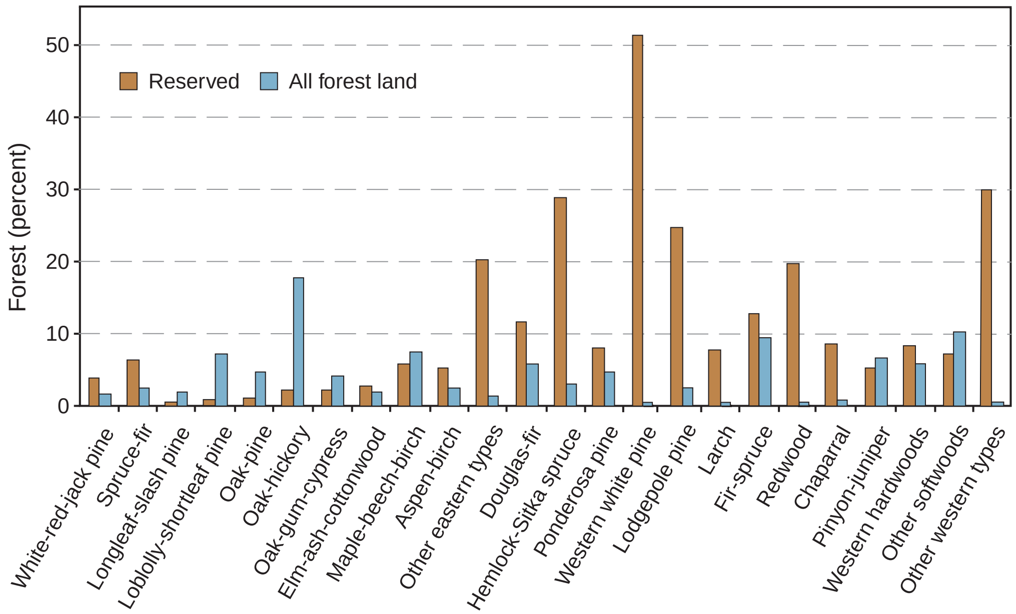


Figure 9—Percent of forest type area in the United States which is classified as International Union for Conservation of Nature Class I or Class II.

Forest Fragmentation

This section provides national summaries of selected indicators of forest fragmentation by ecoregion section and generally discusses observed patterns at a national scale. Biological interpretation of the observations is beyond the scope of this report.

Generally, forest fragmentation refers to the loss of forest land and division of the remaining forest acreage into smaller individual parcels (Wilcove and others 1986). Early concerns about forest fragmentation arose because of impacts on wildlife habitat. While many species thrive in highly fragmented landscapes, many do not (Burgess and Sharpe 1981, Harris 1984, Wilcove and others 1986). The persistence of regional populations of all species clearly is linked to the spatial arrangement of available habitat at multiple scales (Hanski 1999, Wiens 1989). As a result of historical land use patterns, habitat fragmentation now is considered to be one of the greatest threats to biodiversity worldwide (Noss and Cooperrider 1994). In addition, forest fragmentation affects other ecosystem values such as water quality (Jones and others 2001), as well as ecosystem processes such as pollution deposition (Weathers and others 2000) and the duration of insect outbreaks (Roland 1993).

In response to scientific evidence that forest fragmentation is important to ecosystem function, the International Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Montreal Process 1995) identified and endorsed “fragmentation of forest types” as a key indicator for assessing the conservation of biodiversity (Federal Geographic Data Committee 2001). There is no single accepted methodology to measure or calculate fragmentation (Federal Geographic Data Committee 2001). Degree of fragmentation depends on the definition of forest, the scale at which forests are mapped, the scale at which fragmentation is measured, and other features of the analysis. In addition, interpretation of the available metrics depends on an assessment’s focus. For example, the effect of a given degree of fragmentation is different for interior- and edge-forest wildlife species. No single set of fragmentation metrics can provide unambiguous answers for all questions regarding fragmentation and its impacts.

Despite the difficulties, as a point of departure for a national-level assessment, expert workshops conducted by the Roundtable on Sustainable Forests (2000) identified four aspects of forest fragmentation: (1) average forest patch size, (2) amount of forest edge, (3) distance between forest patches, and (4) patch contrast (referring to the degree of difference between forest and adjacent nonforest patches). The rationale for the recommended measures, a scientific critique, and an analysis of their likely utility are provided in the workshop report (Roundtable on Sustainable Forests 2000). The measures’ focus is on forest spatial structure and associated processes at regional landscape scales (Noss 1990). The available data do not permit very detailed assessments, and the best available national-level data are landcover maps derived from satellite imagery (Roundtable on Sustainable Forests 2000).

Seven fragmentation indicators were derived from a national landcover map produced by the Multi-Resolution Land Characteristics (MRLC) Consortium (Loveland and Shaw 1996). They are average forest patch size, area-weighted average forest patch size, amount of forest edge, forest connectivity, number of forest patches, percent forest area, and landcover texture. The seven are likely candidates (Riitters 2001) for addressing three of the four aspects of fragmentation recommended in the workshop report (Roundtable on Sustainable Forests 2000).

About the Fragmentation Analysis

This analysis is based on the Multi-Resolution Land Characteristics (MRLC) landcover maps for the conterminous 48 States (Vogelmann and others 1998a, 1998b). The primary source of data for those maps is Thematic Mapper (satellite) data circa 1992. Other sources of spatial data included land elevation, human population, soils, and landcover information derived by other programs. Each pixel on a map represents the landcover for an area of 0.09 ha—about the size of a baseball diamond infield—and there are about 9 billion pixels for the conterminous 48 States in the MRLC database. Of the 21 landcover types labeled, 3 are upland forest types and 1 is a wetland forest type (see tabulation).

For all but one of the fragmentation indicators, the four forest landcover types were combined into one forest type (tabulation). As a result, the indicator values reflect forest versus nonforest landcover, and not the fragmentation of individual forest types or the fragmentation of age classes within individual forest types. No distinction was made between natural and anthropogenic causes of fragmentation, because all nonforest landcover types were combined. The spatial resolution of the MRLC database is such that relatively small (< 30 m) breaks in the forest canopy are not detected and, as a result, some fragmenting agents such as small roads do not enter into the analysis. Accuracy of analysis depends largely on the accuracy of the underlying landcover map (Zhu and others 2000), but the per-pixel classification accuracy is not a good estimate of per-patch classification accuracy, which is probably higher (Wickham and others 1997).

The seven fragmentation indicators were calculated within analysis units defined as square landscapes of size 7.5 km by 7.5 km (56.25 km^2). A grid of about 140,000 such landscapes was placed over a map of the 48 States, and landscapes that were not completely contained within the States were excluded to ensure comparability of measurements among equal-size landscapes. Ecoregion section average landscape values were then obtained for each of the measures by averaging the measurements for all landscapes whose center points fell within the boundary of a given ecoregion section. A total of 138,340 landscapes met these criteria, and individual ecoregion sections typically contained 1,000 or more landscapes.

Definition of 8 landcover types from the 21-class MRLC legend

Combined category	*MRLC category*
Water	11 Open water
	12 Perennial ice/snow
Developed/urban	21 Low-intensity residential
	22 High-intensity residential
	23 Commercial/industrial /transportation
Barren/disturbed	31 Bare rock/sand/clay
	32 Quarries/strip mines/gravel pits
	33 Transitional
Forest	41 Deciduous forest
	42 Evergreen forest
	43 Mixed forest
Shrubland	51 Shrubland
Agriculture	61 Orchards/vineyards/other
Grassland	71 Grasslands/herbaceous
Agriculture	81 Pasture/hay
	82 Row crops
	83 Small grains
	84 Fallow
Developed/urban	85 Urban/recreational grasses
Forest	91 Woody wetlands
Wetland	92 Emergent herbaceous wetlands

The combined categories were used in this report.
Source: MRLC Readme file for National Land Cover Data (Arizona, Version 09-06-2000), NLCD Land Cover Classification System Key, revised July 20, 1999.

Percent forest area—Percent forest is the percentage of pixels in a landscape that have forest landcover. The national picture (fig. 10) reinforces what generally is known about the gross distribution of forest land. The average landscape in most ecoregion sections of the Eastern United States is typically more than one-half forested. In the West, landscapes in ecoregion sections west of the Cascade Mountains and in the northern Rocky Mountains contain relatively more forest than do landscapes in the Intermountain and Plains regions. In the East, landscapes in some ecoregion sections in the Ohio and Mississippi River watersheds have relatively little forest, and this reflects the predominant agricultural land use. Even the most highly developed ecoregion sections in the Mid-Atlantic and Southeastern United States contain landscapes that are on average more than about one-third forested.

Forest connectivity—Figure 11 portrays by ecoregion the connectivity of forest in an average landscape. Forest connectivity measures the likelihood that land in a pixel next to a forest pixel is also forest, for whatever amount of forest is actually present (Riitters and others 2000). Values range from 0.0 in a completely fragmented (checkerboard) forest pattern, to 1.0 in a completely forested landscape. Starting in a completely forested landscape, the index decreases monotonically as fragmentation increases and connectivity decreases. Values closer to 1.0 indicate that forest pixels in a landscape are more likely to appear adjacent to one another; i.e., in patches of forest.

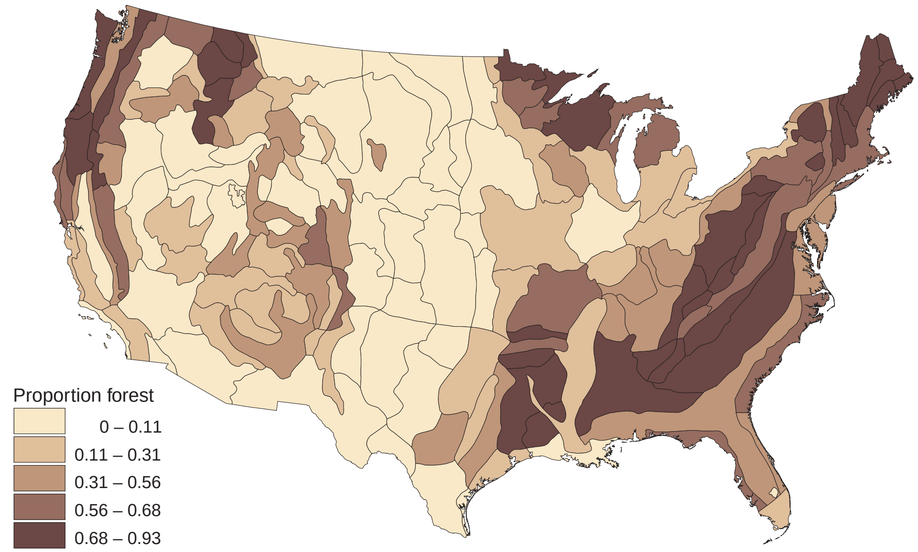


Figure 10—Percent forest shown by ecoregion section. Percent forest is the percentage of pixels in a landscape that have forest landcover.

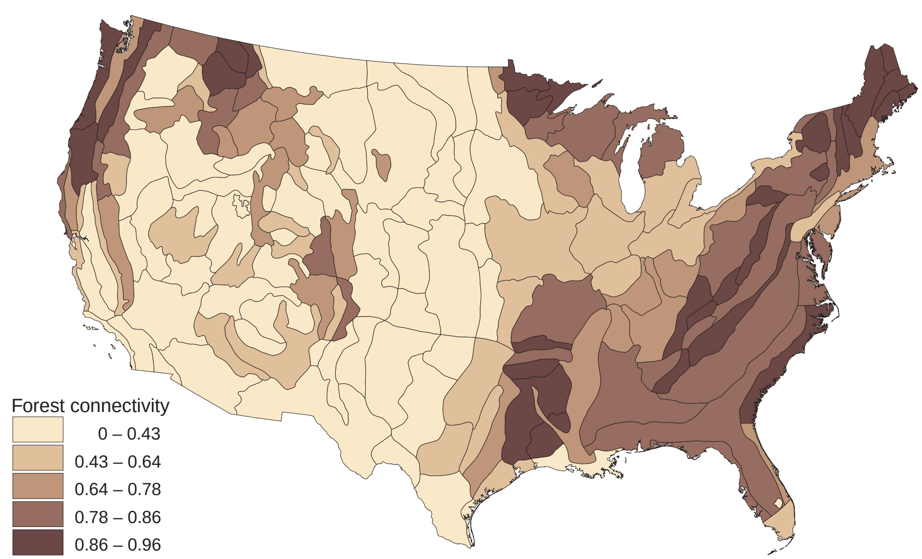


Figure 11—The connectivity of forest in an average landscape, for the amount of forest actually present. Forest connectivity measures the likelihood that a pixel next to a forest pixel is also forest.

Amount of forest edge—Forest edge (fig. 12) is expressed as the number of forest-to-nonforest edges in a landscape, where an edge is the imaginary line that separates two adjacent pixels on the landcover map. Generally, landscapes with more forest have more edge, and landscapes that are more fragmented have more edge. The total length (in kilometers) of forest edge in a landscape can be obtained by multiplying the reported value by 0.03, because the nominal length of a pixel side is 30 m.

Figure 12 also should be viewed in combination with the map of percent forest (fig. 10), because the amount of forest edge depends both on the amount of forest and its spatial arrangement across a landscape. Naturally, there is little forest edge when there is not much forest; e.g., ecoregion sections over most of the Western United States. Conversely, there also is little forest edge when most of an ecoregion section is forested; e.g., ecoregion sections containing the Adirondack Mountains in upstate New York, and the northern Cumberland Plateau. Regional differences (not shown) in the dominant nonforest landcover type produce different kinds of forest edge; e.g., in the Northeastern urban metroplex (forest/urban edge), south Florida (forest/wetland edge), the Central United States (forest/agriculture edge), and the West (forest/grassland and forest/shrubland edge).

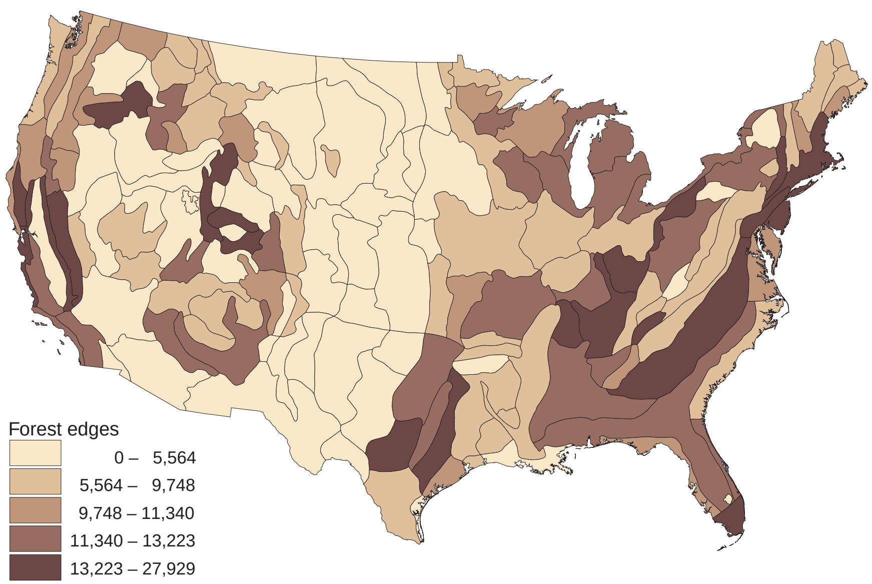


Figure 12—The number of forest-nonforest edges by ecoregion section, where an edge is the imaginary line that separates two adjacent pixels.

Number of forest patches—Forest patches are defined as distinct clumps of forest pixels in a landscape. The forest patches in each landscape were counted (fig. 13). Mostly forested regions that contain relatively few forest patches include several in the Eastern United States (New England, New York, Tennessee, West Virginia, Arkansas, and Minnesota) and several in the West (Oregon, Washington, and Idaho) (fig. 13). These are likely locations for interior-forest habitat over large areas. Ecoregion sections with moderate amounts of forest and many forest patches include several in the southern Great Lakes region, where forests typically exist as woodlots or riparian forest in urban and agricultural settings. In the Western United States, forest patches are often delineated by natural cover types such as grassland and shrubland (including, in this analysis, most of the pinyon-juniper landcover type), and this is reflected in ecoregion sections with moderate amounts of forest and many patches; e.g., California, Washington, Oregon, and the northern Rocky Mountains.

Average forest patch size—Average forest patch size is the arithmetic average number of pixels in a forest patch within a landscape. The measurement can be converted to hectares by multiplying the reported value by 0.09 ha/pixel.

Average forest patch size (fig. 14) appears small almost everywhere because most landscapes contain a large number of very small patches. Exceptions are ecoregion sections where nearly all of the forest is contained in relatively large patches. Such ecoregion sections probably are composed of large tracts or reserves of interior-forest habitat. In the East, several such ecoregion sections are found in northern New England, New York, and Pennsylvania, as well as on the Cumberland Plateau and in the central chain of the Appalachian Mountains. In the West, they exist in the mountain regions of the Pacific Northwest and the Front Range of Colorado.

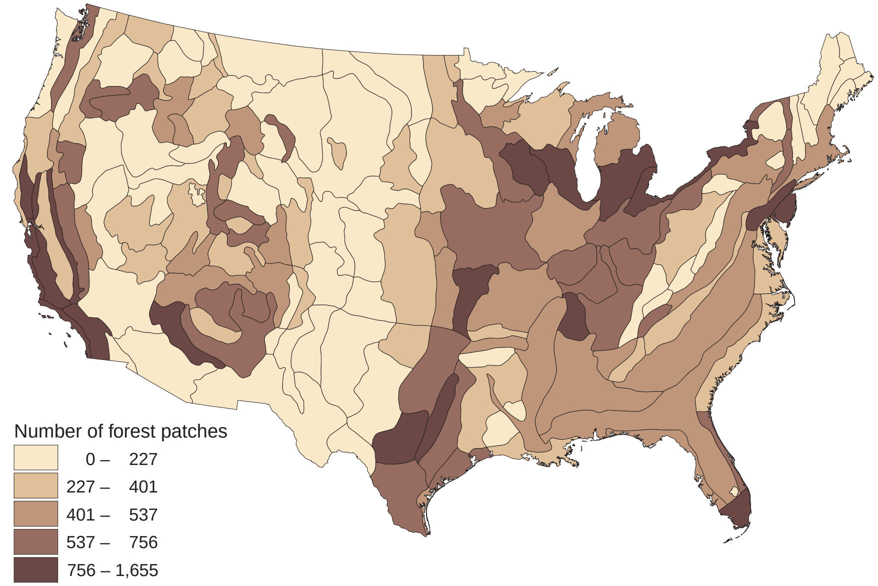


Figure 13—The number of distinct clumps of forest pixels in a landscape, by ecoregion section, where the four-neighbor rule was used to group adjacent forest pixels into patches.

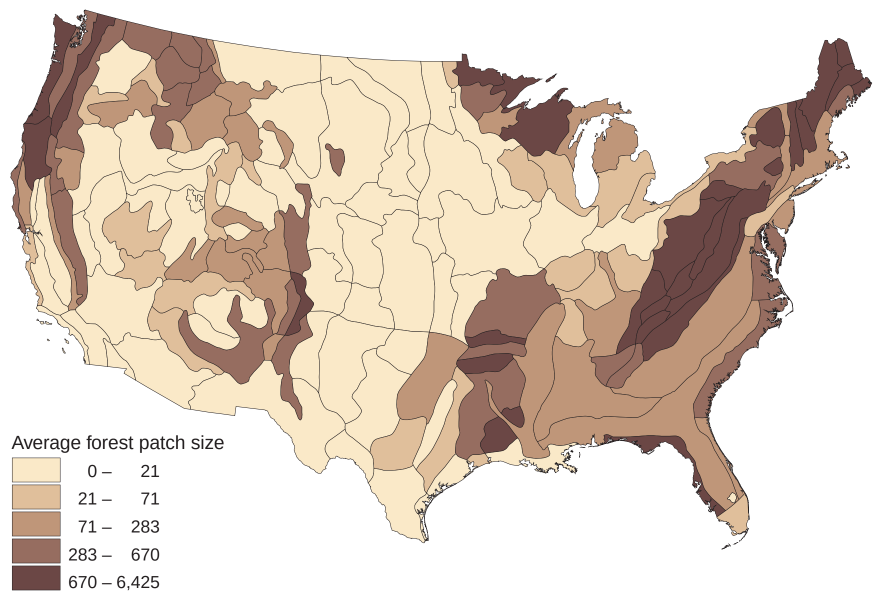


Figure 14—Average forest patch size, as the average number of pixels contained in a forest patch in a landscape, presented by ecoregion section.

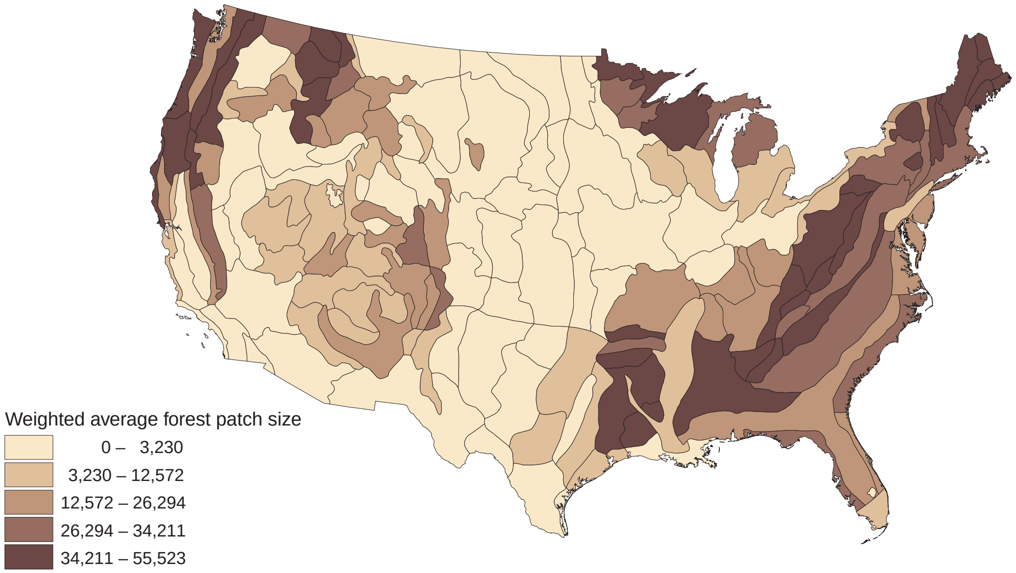


Figure 15—Average forest patch size by ecoregion section, weighted by its relative size, emphasizing forest area that is contained in large patches.

Area-weighted average forest patch size— Weighting is used to reduce the influence of many small forest patches and to emphasize forest area within large patches. In comparison to unweighted average patch size, area-weighted average patch size (fig. 15) identifies likely reserves of interior-forest habitat after adjusting for large numbers of small forest patches. Weighting has helped identify several additional ecoregion sections that probably contain large tracts of interior-forest habitat, including some in northern California and the southern Mississippi River basin.

Landcover texture—Landcover texture is a measure of overall landscape contrast. It is obtained by summing the diagonal elements of the attribute adjacency matrix within each landscape (Riitters and others 2000). Conceptually and computationally similar to the forest connectivity measure, this measure considers all landcover types, not just forest. Note that the tabulation (p. 20) identifies the eight landcover types considered. Values range from zero to 1, and higher values indicate landscapes where all landcover types, not just forest, are more likely to be contained in a clump of a given landcover type. A value of zero indicates a landscape where no pixel is adjacent to another pixel of the same landcover class. With increasing fragmentation (for a fixed number of landcover types), the index decreases monotonically.

Figure 16 illustrates where landcover of any type (not just forest) is more or less well connected; i.e., not as fragmented as other places. In addition to those ecoregion sections already shown to have well-connected forest landcover, some ecoregion sections in the Central United States and the Central Valley of California appear to have well-connected nonforest (agricultural) landcover, and observed values for ecoregion sections in the Intermountain region of the Western United States reflect well-connected shrubland (including pinyon-juniper) distribution patterns.

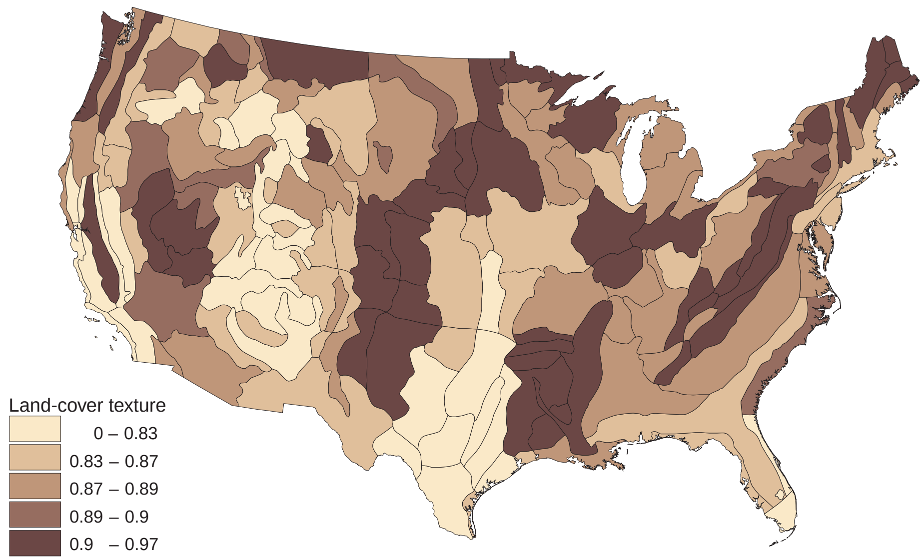


Figure 16—Landcover texture by ecoregion section, a measure of overall landscape contrast considering all landcover types.

Species Diversity

Plant biological diversity may be characterized by number of species (richness) and relative abundance of species (evenness). A variety of indices of diversity; e.g., Shannon-Wiener, incorporate one or both of these aspects of diversity. Plant diversity, like many other ecosystem attributes, is dynamic both in time and space. Species composition changes over time with stand development and stand disturbances, both natural and anthropogenic. Species composition also varies across the landscape based on a variety of environmental gradients.

Species diversity can be considered at various scales. At the smallest scale, it characterizes particular plant communities. At larger scales it can characterize an ecosystem or a landscape. Analysis of species diversity at multiple scales can provide information both on the total species diversity of a region and on how that diversity is sorted into plant communities varying across a landscape.

A single analytical approach from ecology is used to examine both tree and lichen species richness, and three aspects of diversity are considered. First, diversity at the local level, such as the diversity of a particular stand or community, is referred to as alpha (α) diversity (Whittaker 1960). In this report, α diversity is defined as the species richness of each sample plot. Second, the total species richness of a region, gamma (γ) diversity, is defined as the total species richness of an ecoregion section. Third, the diversity across communities within a region is termed beta (β) diversity. Beta diversity is a measure of the amount of heterogeneity in species distribution across a region; i.e., how different the species compositions are at various locations in a region. Ecologists sometimes think of this as the rate at which species composition changes as one moves along environmental gradients (species turnover). Alternatively, β diversity may be thought of as a representation of the number of distinct communities present within a region (Whittaker 1972, Wilson and Shmida 1984). Ecologists have proposed a number of measures of β diversity (Gray 2000, Wilson and Shmida 1984); the formula used in this report is shown in "Appendix A: Supplemental Methods, Species Diversity."

Tree species richness—Tree species richness was analyzed at both plot and ecoregion section scales using the most recent measurements from each plot. Figure 17 shows tree species richness by plot (α); figure 18 shows overall tree species richness (γ) by ecoregion section (numeric labels on the map indicate the total number of plots sampled in each ecoregion section). Together these two figures illustrate the importance of spatial scale in analyzing species diversity.

In most of the West, α values were low, with most plots containing four species or fewer. In most of the West, γ was low as well, although in some areas, such as western Washington and Oregon, γ values (ecoregion section tree species richness) were relatively high (20 to 49 species). One of the highest levels of diversity across plots (β = 11.67) was found in Section M242C—Eastern Cascades, where the typical plot contained only 3 tree species but the ecoregion section contained 35 tree species (appendix table B.1). These results agree with characterizations of many western forests as being nondiverse at the stand level but quite varied on larger scales, because forest composition varies greatly based on site characteristics such as slope and aspect, or stand characteristics such as age and successional status (Brockway 1998, Noss and Cooperrider 1994).

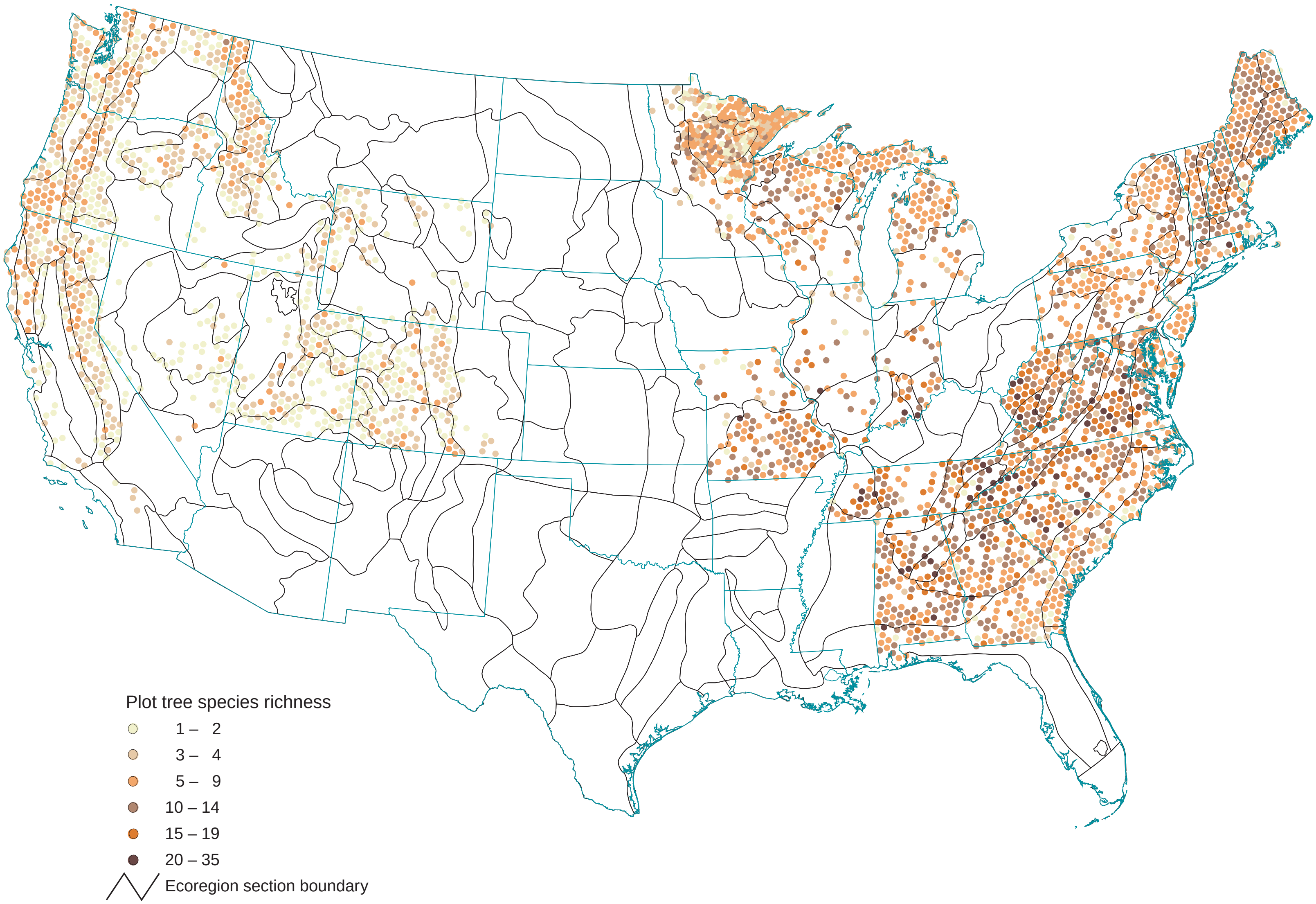


Figure 17—Plot tree species richness (α diversity); the number of tree species (including seedlings, saplings, and canopy trees) found on the most recent visit to each Forest Health Monitoring plot (1990 through 1999).

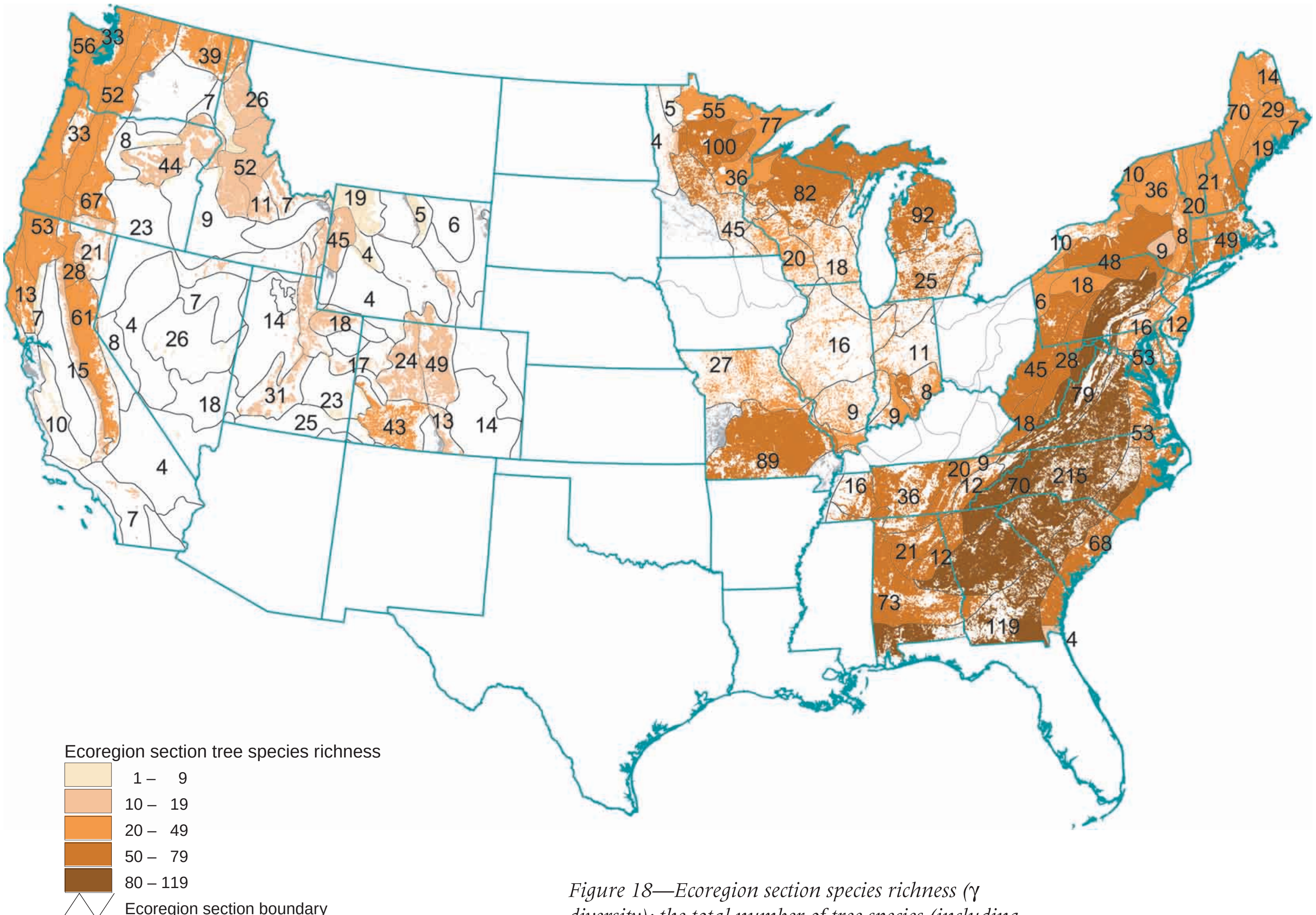


Figure 18—Ecoregion section species richness (γ diversity); the total number of tree species (including seedlings, saplings, and canopy trees) found in each ecoregion section based on the most recent visit to each Forest Health Monitoring (FHM) plot (1990 through 1999). Labels indicate the number of FHM plots in each ecoregion section.

In the Eastern United States, the highest γ values were found in Section 231A—Southern Appalachian Piedmont; Section 232B—Coastal Plains and Flatwoods, Lower; and the Appalachian Mountains (Sections M221A and M221D), with 84 to 119 tree species occurring in each ecoregion section. Those regions also had quite high plot-level species richness (α), especially in the mountains where individual stands usually contain a diverse mix of tree species. The Southern Coastal Plain (Sections 232B and 232C) and Section 231A had the highest β values (> 10), indicating that a number of different forest types occur in each section.

Appendix table B.1 shows species richness (γ) by ecoregion section as well as the mean, median, maximum, and minimum α values (plot-level richness) and the β diversity value for the ecoregion section. The percentage of richness on the median plot, also presented in the appendix table, gives an indication of the portion of the total ecoregion species richness that may be found on a so-called typical plot.

Together with the maps, appendix table B.1 can be used to further interpret the patterns of tree species diversity found in a particular ecoregion section. For example, a typical plot in highly diverse ecoregion sections in the Southeast (Sections 231A, 232B, M221A, and M221D) contained only 8 to 13 percent of all tree species present, indicating significant site-to-site variation in species composition.

By itself, tree species diversity is not a meaningful measure of forest health because natural diversity varies due to climate, elevation, etc., and some healthy ecosystems are just naturally low in tree species. However, conserving species diversity is important for maintaining forest health, and understanding patterns of species diversity can enable more effective management to conserve species diversity. Tree species richness alone also provides an incomplete view of overall species richness and diversity. Several forest types containing few tree species are extremely rich in herbaceous and shrub species. FIA has begun implementing a protocol for sampling understory vegetation as well as trees. Once this component is fully implemented, a more complete assessment of plant biodiversity will be possible.

Lichen diversity—Lichens are a group of nonvascular plantlike organisms that grow on a variety of substrates including soil, rocks, and trees. Lichens are symbiotic combinations of fungi and algae. The fungi absorb mineral nutrients (primarily from the air, but also in small amounts from the substrate) and supply structural support; the algae conduct photosynthesis. Because lichens lack epidermis, cuticle, and stomata, they cannot control gas exchange with the atmosphere and are, therefore, especially sensitive to air pollution (Stolte and others 1993).

FHM field crews collect a time-constrained sample of macrolichen species growing on woody plants (live stems and branches as well as woody debris) in the sample plot. They rate the relative abundance of lichen species on the plot and collect samples of each. These samples are later identified by lichen specialists. Plot-level lichen species richness scores, evenness, and overall diversity can then be calculated. Lichen species richness is often correlated with several variables that can affect the forest ecosystem, including air quality, climate, forest type, forest successional status, and land management status. Generally, higher numbers of lichen species are found in cooler, moister areas and in areas with good air quality. Within similar forest types; i.e., at smaller spatial scales such as ecoregion sections, higher lichen diversity tends to be strongly associated with later successional status and greater structural diversity (McCune 1993, Neitlich and McCune 1997).

Figure 19 shows lichen species richness scores at the plot level (α diversity), and figure 20 shows total lichen species recorded by ecoregion section (γ diversity). Diversity values were calculated using FHM data from 1994 through 1999. Forest cover is only shown within the States where FHM plots had been established as of 1999. The two figures together show how characterization of species richness depends on scale. In such areas as western Oregon, the Southern Appalachian Mountains of Virginia and West Virginia, and northern Maine, individual plots contained a large number of lichen species (α). However, in areas such as Section 231A—Southern Appalachian Piedmont, a large number of lichen species were found in the section overall (γ), although many individual plots manifested rather low species richness scores (α). This phenomenon illustrates the importance of local or subregional conditions in determining the composition of the lichen community. High heterogeneity among plots (β diversity) usually indicates that several distinct community types are present in an ecoregion section.

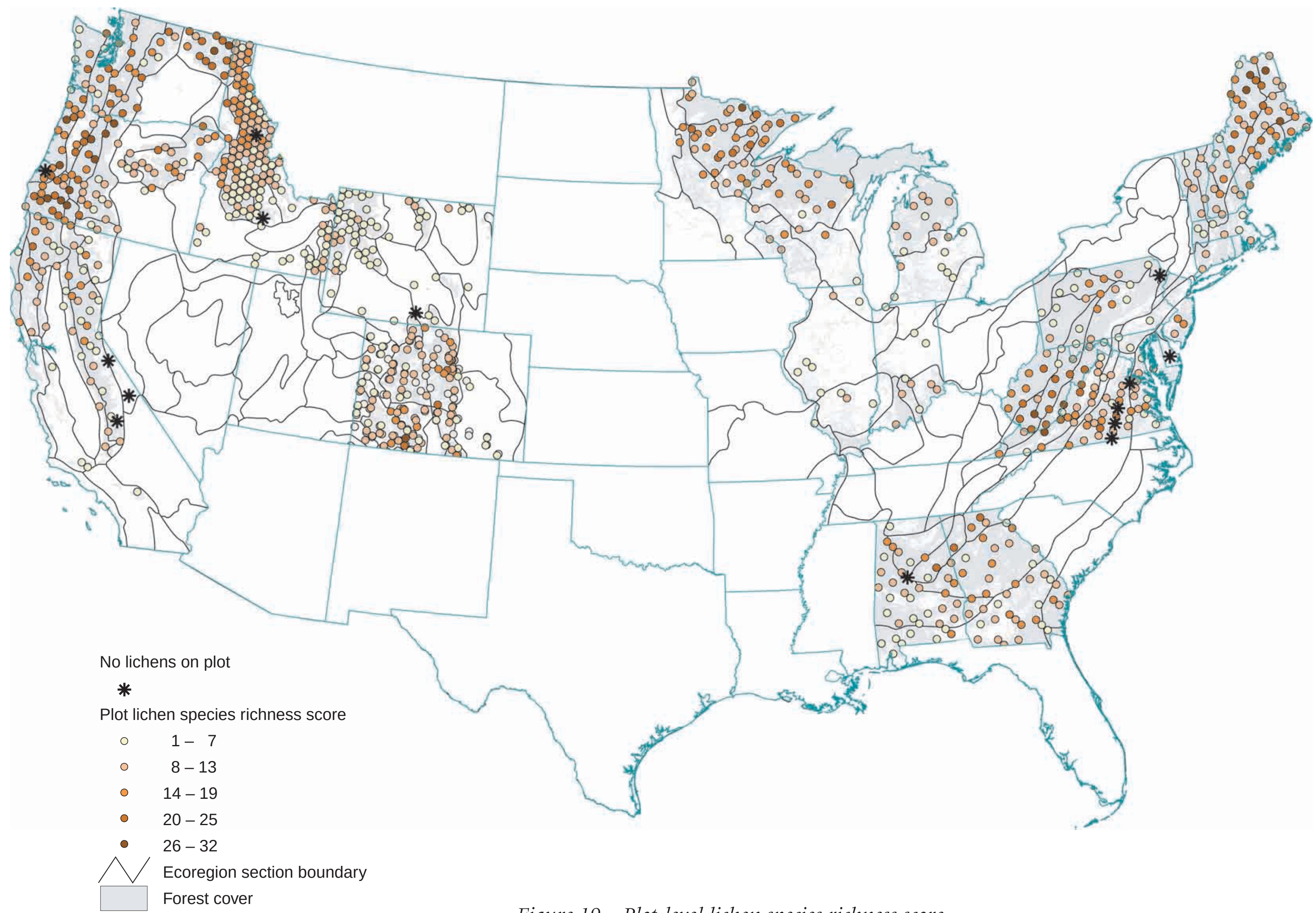


Figure 19—Plot-level lichen species richness score (α diversity) as of the most recent visit to each Forest Health Monitoring plot (1992 through 1998).

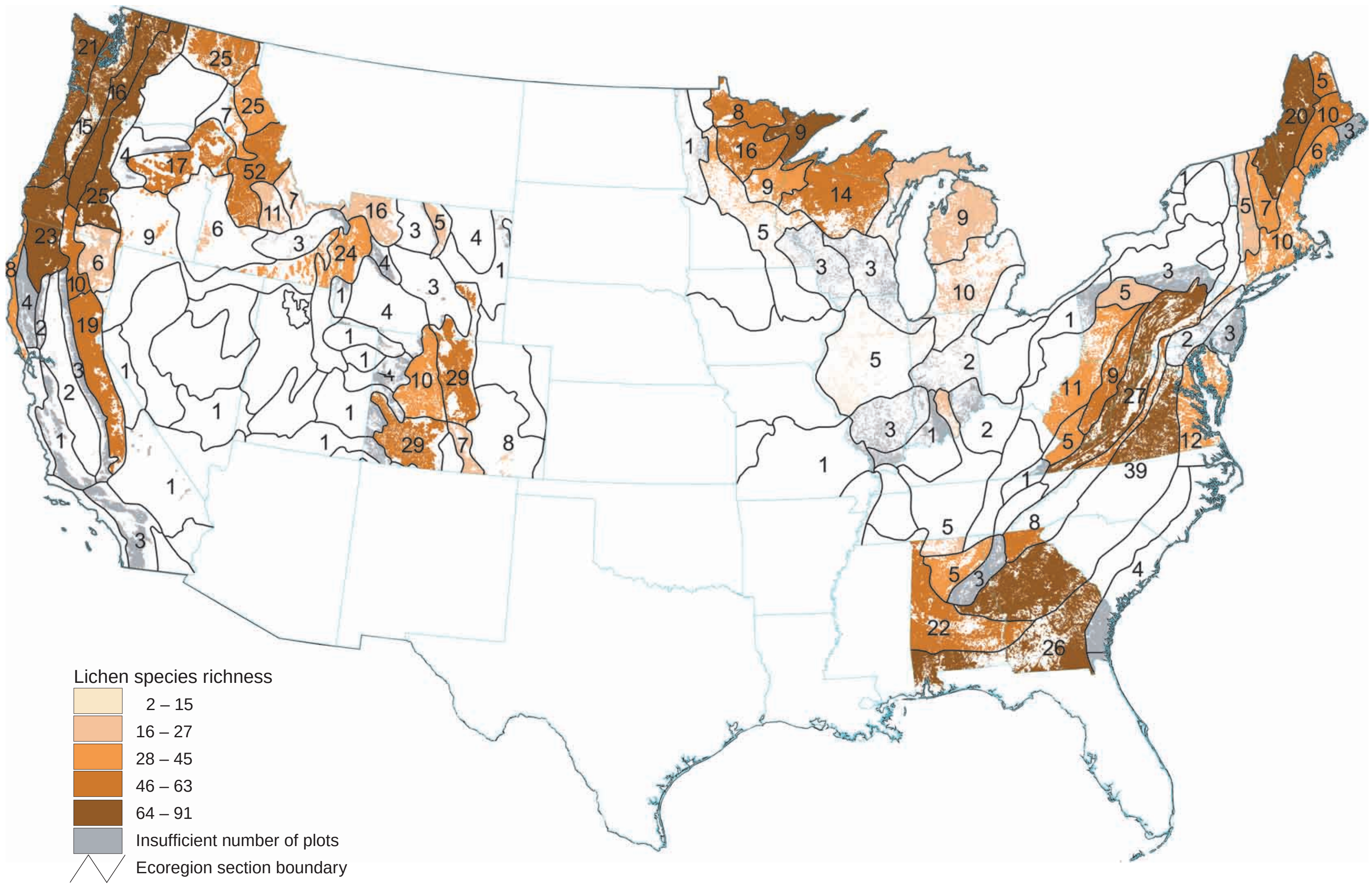


Figure 20—Ecoregion section lichen species richness (γ diversity); the total number of lichen species recorded in each ecoregion section based on the most recent visit to each Forest Health Monitoring (FHM) plot (1994 through 1998). Labels indicate the number of FHM lichen plots in each ecoregion section. γ diversity not calculated for sections with fewer than 5 lichen plots; γ diversity may be underestimated for sections with fewer than 10 lichen plots. The number of plots indicated for each ecoregion section does not always exactly match the number of lichen plots shown in the previous figure, because the data from several plots shown in Colorado were not available in the format needed for the ecoregion level analysis.

In estimating total lichen species based on the number recorded (γ), an adequate number of sample plots is essential. In a number of ecoregion sections, the number of lichen plots sampled through 1999 was less than optimal for this calculation. For this reason, in figure 20 γ diversity is presented only for those ecoregion sections having at least five lichen plots. In addition, for those ecoregion sections having fewer than 10 lichen plots, lichen species richness (γ) may well be underestimated. The numeric labels on the map in figure 20 give the number of lichen plots in each ecoregion section.

Appendix table B.2 shows the lichen species recorded (γ) by ecoregion section, as well as the mean, median, maximum, and minimum α species richness score (plot level) and the β diversity values for the ecoregion section. The percentage of species on the median plot, also presented in the appendix table and calculated using the formula presented in "Appendix A: Supplemental Methods, Percentage of Richness on the Median Plot," gives an indication of the portion of the total ecoregion section species richness (γ) that may be found on a so-called typical plot.

The fact that plot-to-plot variation in species composition led to high total species recorded in ecoregion sections in which individual plots had low numbers of species reinforces the idea that total lichen species richness may be underestimated in those ecoregion sections where relatively few plots were sampled. Also, in extremely arid zones much of the lichen community often is found growing on rocky substrates, rather than as epiphytes. In such areas FHM may only be sampling a small fraction of the total lichen community.

Preliminary analysis of the lichen data together with other environmental data indicated that there are several issues of concern with respect to lichen community conservation. Primary among these are blackout zones (areas lacking in lichen species that one would expect to find given forest stand and climate conditions) for cyanolichens and other pollution-sensitive taxa, community degradation due to excess nitrogen deposition, and depressed species richness over large areas of the Northeast. Blackout zones for the otherwise conspicuous cyanolichen flora of the Pacific Northwest have been observed in the vicinity of large urban areas such as Seattle and Portland and throughout the Columbia River Gorge, a national scenic area (Neitlich, no date; Neitlich and others 1999). A gradient model under development relates lichen occurrence to air quality in this region (see “Criterion 3—Health and Vitality: Effects by Air Pollutants, Lichen Bioindicator”) and should provide information about the size of the blackout zone. Nitrification, primarily due to agricultural inputs, has created a bloom of nitrophilous taxa (primarily the orange *Xanthoria* genus) in and near the Central Valley of California (Neitlich, no date; Neitlich and others 1999). This bloom apparently has suppressed the growth of other native taxa.

Lastly, throughout large sections of the Northeast—from the Ohio Valley eastward to New York, Pennsylvania, and southern New England—lichen species richness is lower than might be expected under clean air conditions. Preliminary analyses of FHM data and comparisons with historical records of lichen distribution have indicated reduced lichen species richness in this region. Presumably this is a long-term, regional pollution effect. However, the correlation of background air pollution levels with regional climate variables makes it difficult to extract a regional gradient of air pollution response independent of climate response. This has necessitated the development of a relatively complex air pollution gradient model (still being refined) to explain the observed differences in lichen community composition (see “Criterion 3—Health and Vitality: Effects by Air Pollutants, Lichen Bioindicator”).[8]

[8] Personal communication. 2001. Susan Will-Wolf, Department of Botany, University of Wisconsin, 430 Lincoln Drive, Madison, WI 53706.

CRITERION 2—
Productive Capacity

Mark J. Ambrose

Productive forest ecosystems provide many benefits, including marketable commodities such as wood products. Maintenance of forest productivity is essential to ensuring sustainable supplies of wood and nonwood forest products. The productive capacity of a forest ecosystem directly relates to environmental factors such as soil fertility, climate, and air quality. To sustain forest production, adequate land area must be kept under forest cover; the health of forest ecosystems; i.e., the inherent productive capacity of the systems, must be maintained, and certain forest areas must be managed appropriately to optimize production of useable forest products.

Actual forest production and the portion of that production that is harvestable as forest products are functions of both the productive capacity of the ecosystem and factors connected to forest management. Natural factors such as insects, diseases, and year-to-year variation in weather also can have a major impact on production at any one time, although they do not affect the inherent productivity (productive capacity) of the ecosystem. Most of the standard indicators associated with the productive capacity criterion address actual production and removal of forest products and the land area managed for timber production (Anon. 1995b). This report focuses more directly on the underlying issue of ecosystem productive capacity, which is directly related to forest health.

Gross growth, the total wood production before subtracting losses due to mortality, is a reasonably good indicator of productive capacity. Gross growth rates will be high in systems that are productive in terms of woody biomass, even when net production is low. For example, an old-growth forest will have a net growth rate near zero, because mortality losses almost equal or sometimes exceed growth. However, in a productive old-growth forest, the gross growth rate will be quite high.

Of course, wood volume growth is not a perfect indicator. Because more than just wood is produced, gross wood volume growth underestimates an ecosystem's productive capacity. In some cases gross wood volume growth rates may significantly underestimate an ecosystem's productivity, because production of nonwoody biomass (in the form of tree foliage and fruits, shrubs, or herbaceous plants) is an important component of total productivity. In fact, for some open woodland systems, the production of forage for grazing may be the most economically important element of forest production.

For each ecoregion section, average gross growth rates of wood volume (cubic feet per acre per year) since initial FHM plot establishment were estimated using a generalized least squares regression modeling procedure (see "Appendix A: Supplemental Methods, Productive Capacity"). Average gross growth rates are shown in figure 21. Ecoregion sections were classified by growth rates corresponding to FIA site productivity classes, ranging from class 2 to class 7. No ecoregion section had an average growth rate corresponding to class 1 (225+ cubic feet per acre per year). This was not surprising, because no large geographic area would be expected to contain only very highly productive sites.

Tree growth rates generally followed climate gradients, with the highest productivity being found in those areas experiencing long growing seasons and abundant rainfall favorable to tree growth. Forest productivity was lower in colder and drier regions. Gross productivity was highest (120 to 177.4 cubic feet per acre per year) in western Washington and Oregon, on the northern California coast, in the Bitterroot Mountains of northern Idaho, on the middle and lower Atlantic Coastal Plain of the Southeast, and parts of southern Indiana and Illinois.

The lowest productivity (0 to 19.9 cubic feet per acre per year) was found in desert and semidesert regions of the West. There, low rainfall limits tree growth, tree cover is sparse, and desert vegetation is dominant.

One region that stands in contrast to the general pattern of productivity following climate gradients is the Upper Atlantic Coastal Plain and Northern Appalachian Piedmont of eastern Maryland, eastern Pennsylvania, and New Jersey. Growth rates there were low (20 to 49.9 cubic feet per acre per year), although the soils and climate are generally favorable for good tree growth. The region's low productivity probably is due to the fact that much of the most productive forest land has been converted to agriculture uses or urban and suburban development. Many of the sites that remain in forest cover, such as the New Jersey Pine Barrens, have relatively low productivity.

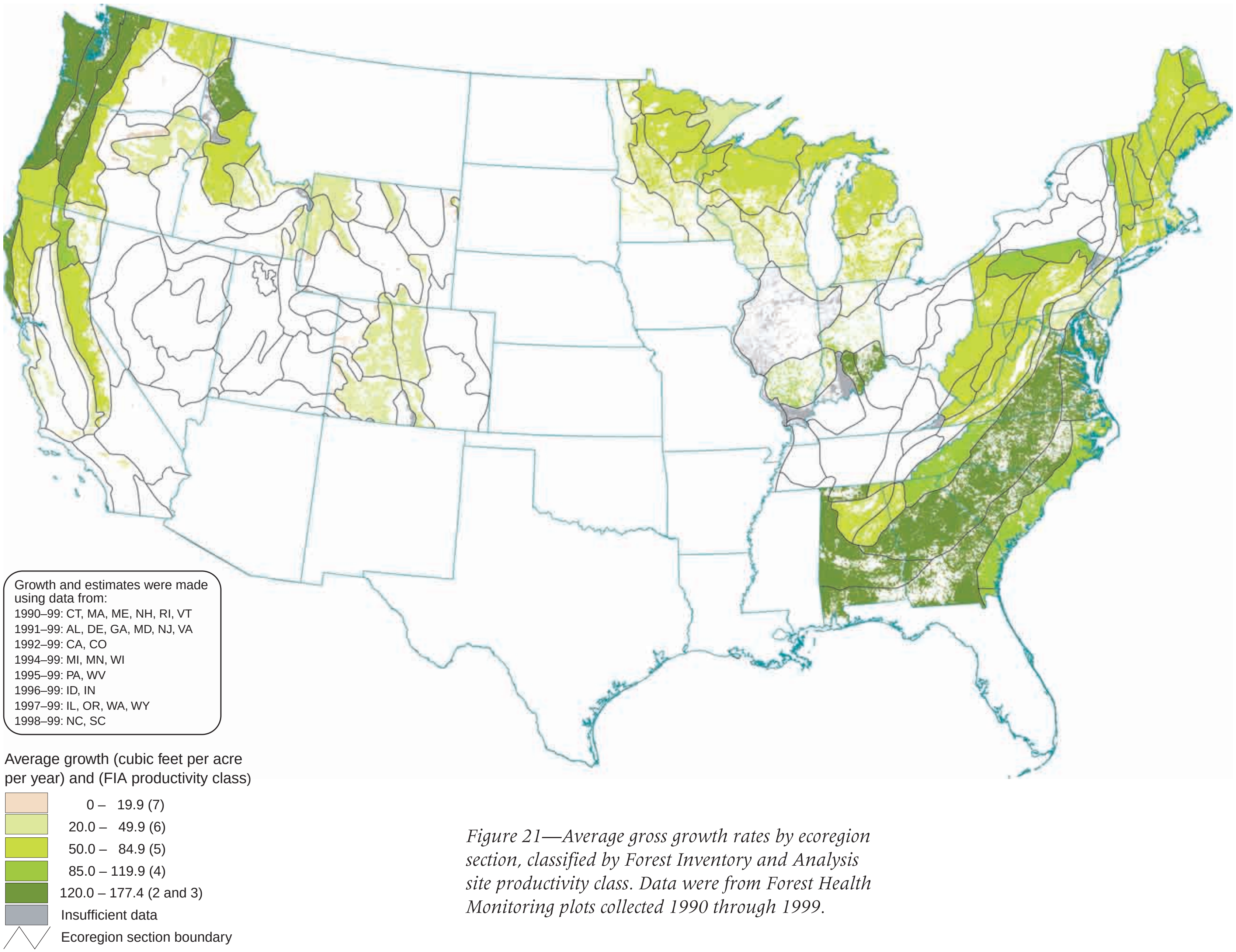


Figure 21—Average gross growth rates by ecoregion section, classified by Forest Inventory and Analysis site productivity class. Data were from Forest Health Monitoring plots collected 1990 through 1999.

CRITERION 3—

Health and Vitality

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Forest ecosystems not only contain floral and faunal communities adapted to local conditions, but also are sites of a variety of fundamental ecological processes. They produce a complex, interrelated system of communities and processes. Indicators are chosen to provide information about pieces of the complex system. The challenge of assessment is to analyze the pieces to give a picture of the system's status and change as products of its component parts. This section considers forest ecosystem health and vitality by presenting information about effects by processes or agents, effects by air pollutants, and potentially diminished or changed biological components. Later in this report a multivariate analysis illustrates an approach to analyzing the components in relation to each other.

Effects by Processes or Agents

Insects and pathogens—Insects and pathogens are a natural part of ecosystems and are essential to ecological balance in natural forests (Castello and others 1995). Population dynamics of insects and pathogens are influenced by climate, management activities, natural tree defenses, and natural enemies. Non-native 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 processes of forested landscapes mostly through tree mortality and/or reduced tree vigor. These effects may occur at small scales (gap phase) or large scales (forest development) and at any seral stage (Castello and others 1995).

The FHP Program conducts annual aerial surveys to identify damage to forested areas. The surveys use sketch-mapping to record damage from a number of stressors such as insects, pathogens, and climatic events. Sketch-mapping is a remote sensing technique of observing forest change events from an aircraft and documenting them manually onto a map (McConnell and others 2000); it organizes information based on characteristics of the overstory trees. Ground surveys are also used to assess insect and pathogen damage in many parts of the country. For this assessment, both aerial and ground survey data were compiled nationally on an annual basis starting in 1998.

Examining trends of individual insect or pathogen populations is useful in understanding their dynamic nature. The FHP Program summarizes insect and pathogen activity by agent and year.[9] For large-scale analysis, however, examining the cumulative affects of insects and pathogens gives a representation of ecosystem stress. In this report, the exposure of forests to insects and pathogens is addressed in terms of status and short-term spatial trends, not the impacts of specific agents.

Using nationally compiled FHP survey data from 1998 and 1999, reported insect and pathogen activity was summarized for this report by Bailey's ecoregion sections (Bailey 1995), and the most active agent was identified. Percent of

[9] These summaries are available online http://www.fs.fed.us/foresthealth/annual_i_d_conditions/index.html.

forested area with reported insect or pathogen presence by ecoregion section was calculated using aerial survey data and forest cover data derived from AVHRR satellite imagery provided by the National Fire Sciences Laboratory.[10]

In 1999, approximately 78 percent of the forested area in Section 222K—Southwestern Great Lakes Morainal reported insect and pathogen presence; Section 222L—North-Central U.S. Driftless and Escarpment had approximately 38 percent (fig. 22). Most reported damage was classified as general defoliators. In Section 222L, oak wilt also was present and had caused the most widely reported mortality in that section. Section 313A—Grand Canyon Lands had approximately 24 percent of forested land with reported activity (fig. 22), most of which was aspen defoliation. Large aspen tortrix was the most widely reported defoliation agent in Sections 212J and 212L—Southern and Northern Superior Uplands, respectively. Approximately 7 percent of forested area in Section 232E—Louisiana Coast Prairies and Marshes were reported as having fruit tree leafroller (fig. 22). The forested area of Section M331F—Southern Parks and Rocky Mountain Ranges in Colorado and New Mexico had approximately 6 percent insect and pathogen presence (fig. 22). The two main agents responsible were the western spruce budworm and mountain pine beetle.

The above discussion focused on ecoregion sections with 6 percent or more of the forested area having insect or pathogen presence. It is important to note, however, that most sections reported insect or disease presence on < 6 percent of the forested area.

Each agent in the database was classified by FHP as mortality- or defoliation-causing. Short-term spatial trends (1998–99) in exposure to mortality- and defoliation-causing agents were assessed on a county basis within each FHM region. Counties were used because they constituted the finest consistent spatial resolution. Exposure was defined as the area in acres with mortality- or defoliation-causing agents present. The short-term spatial trend analysis was based on relative exposure (observed versus expected) on a county basis and was used to identify hot spots of activity during the time period.

[10] Fire Science Laboratory. 1999. Current cover types. Version 2000. 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. www.fs.fw.us/fire/fuelman/. [Date accessed: January 8, 2004].

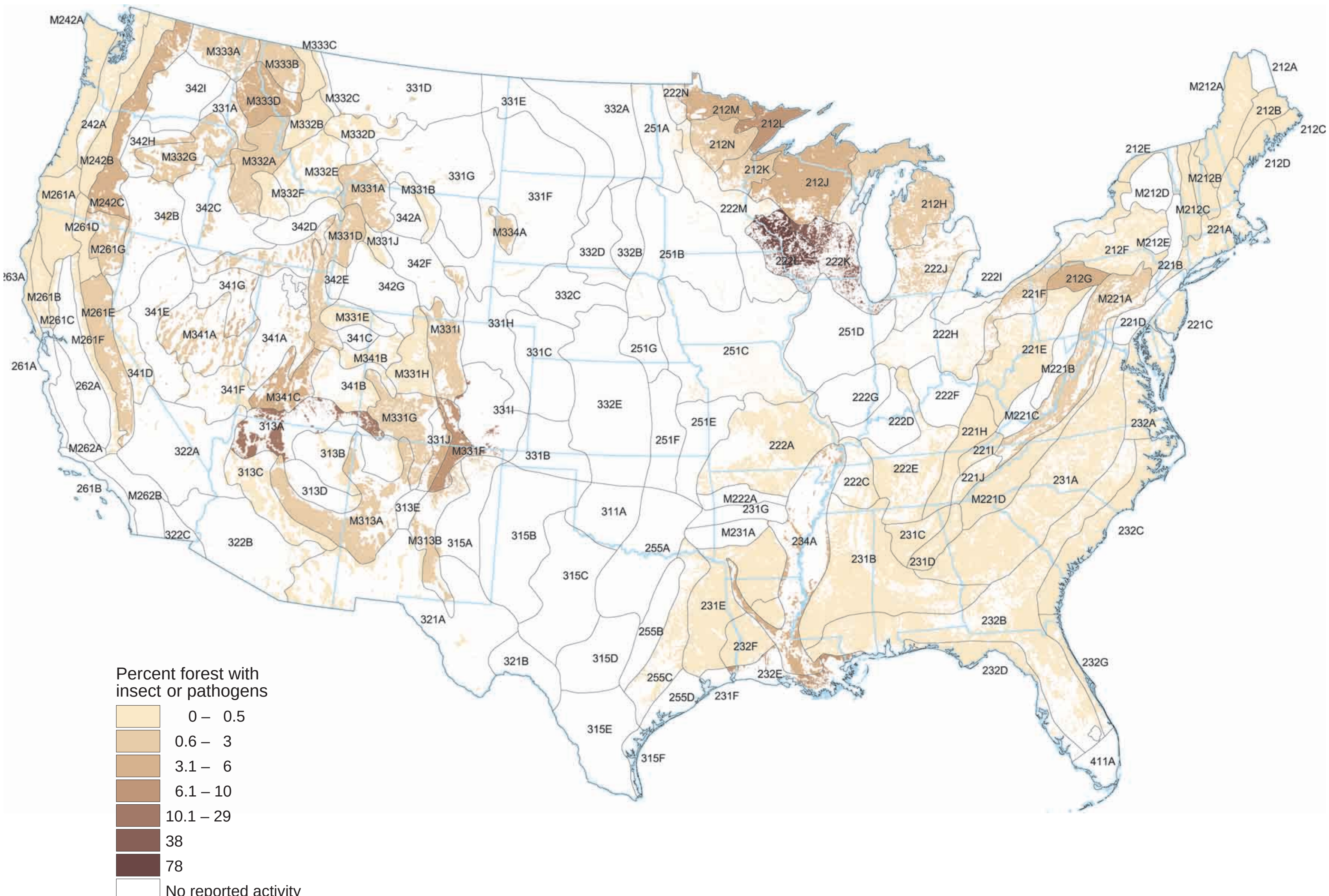

Figure 22—Insect and pathogen activity reported in 1999 expressed as percent forest in each ecoregion section with activity.

Short-Term Spatial Trend Analysis

Expected amounts of exposure were based on a Poisson model (see "Appendix A: Supplemental Methods, Insects and Pathogens" for details). The measure is referred to as relative exposure and is the ratio of observed to expected exposure. Relative exposure was calculated for mortality- and defoliation-causing agents and was used to identify forested areas within FHM regions that were hot spots as compared to the rest of the region (Coulston and Riitters 2003). The actual value calculated ranged from zero to infinity, where < 1 represented low relative exposure and less than expected defoliation or mortality within the region. A value of > 1 represented more than the expected exposure to defoliation- or mortality-causing agents within the FHM region of interest. The measure is linear, so a relative exposure value of 2 indicates an area has experienced twice the exposure expected for the region.

Generally, forests in the North FHM region had relative exposures to mortality-causing agents of < 1. There were only a few hot spots in this region (fig. 23). Areas with more than twice the expected exposure to mortality-causing agents were found in Section 212D—Central Maine Coastal and Interior; Section 212C—Fundy Coastal and Interior; Section 221A—Lower New England; Section M212C—Green, Taconic, Berkshire Mountains; and Section M221D—Blue Ridge Mountains.

Generally, in the South FHM region southern pine beetle was the only mortality agent reported. Hot spots of more than twice the expected exposure rates to mortality-causing agents were found in Section 231B—Coastal Plains, Middle (fig. 23). Other areas of interest in the Southern region include portions of Section 221H—Northern Cumberland Plateau and Section 231A—Southern Appalachian Piedmont.

In the North Central FHM region, the most obvious hot spot of mortality-causing agent activity from 1998 through 1999 was in Section M334A—Black Hills (fig. 23). Other areas where relative exposure rates to mortality-causing

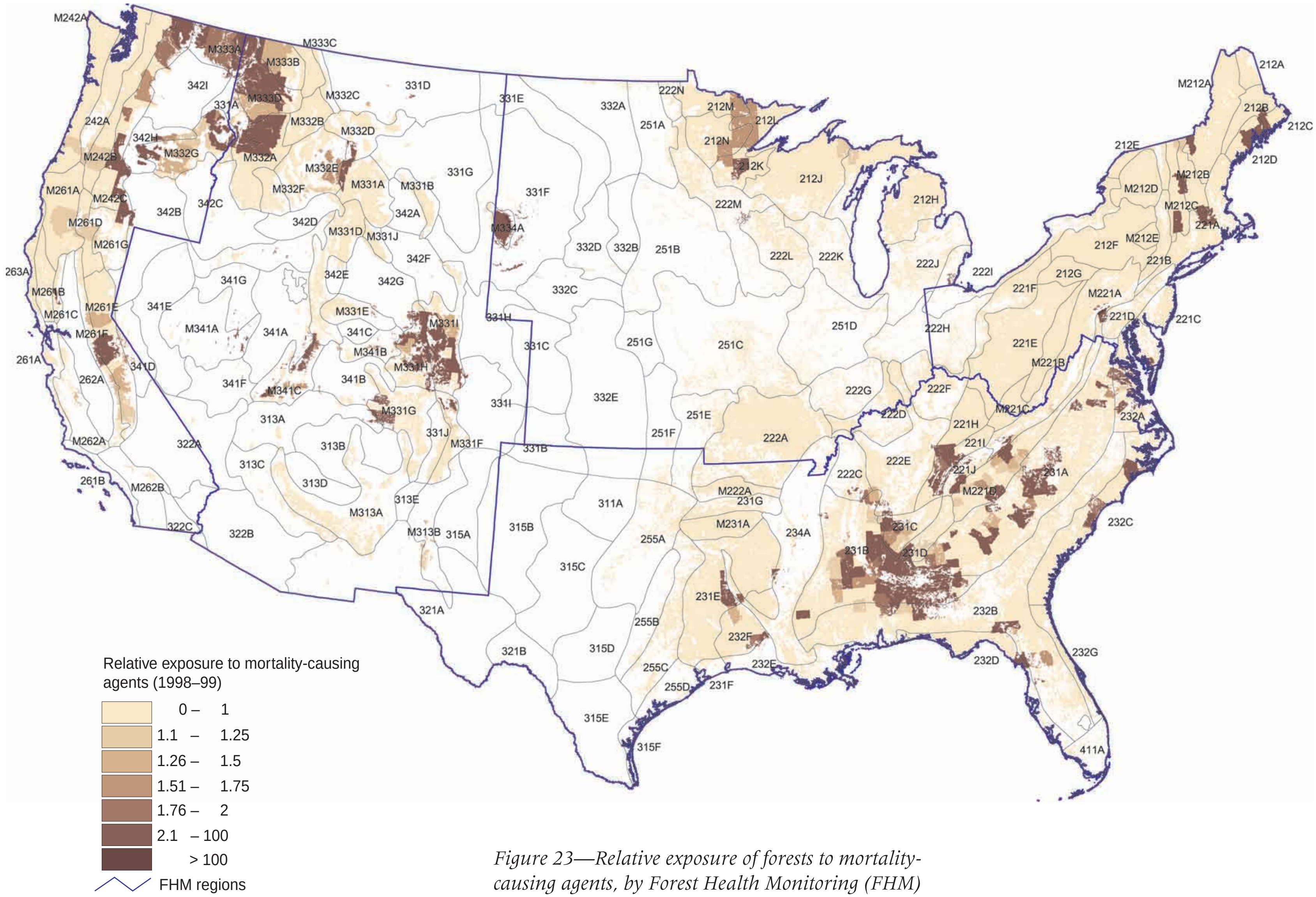

Figure 23—Relative exposure of forests to mortality-causing agents, by Forest Health Monitoring (FHM) region, from 1998 through 1999 (see text and appendix A—Supplemental Methods, "Insects and Pathogens," for more information).

agents were of interest were found in Section 212K—Western Superior, Section 212L—Northern Superior Uplands, Section 212M—Northern Minnesota and Ontario, and Section 212N—Northern Minnesota Draft and Lake Plains (fig. 23).

Several hot spots of exposure to mortality-causing agents were in the Interior West FHM region. In Colorado, much of the forests in Section M331H—North-Central Highlands and Rocky Mountain and Section M331I—Northern Parks and Ranges had exposure more than twice the expected rate (fig. 23). This was also true in forested areas in northern Idaho and western Montana. These areas were in Section M332A—Idaho Batholith, Section M333D—Bitterroot Mountains, and Section M333A—Okanogan Highlands ecoregion sections (fig. 23).

In the West Coast FHM region, two ecoregion sections had a large portion of forested area with more than the expected exposures to mortality-causing agents. They were Section M242C—Eastern Cascades and Section M333A—Okanogan Highlands of Washington and Oregon. Other forest areas of interest in the West Coast region were in Section M332G—Blue Mountains and Section M261E—Sierra Nevada (fig. 23).

Figure 24 shows short-term spatial trends in exposure of forests to defoliation-causing agents for each FHM region. In the North region, several ecoregion sections had hot spots with twice the expected exposure rate to defoliation-causing agents for the time period. These areas were in Section M212C—Green, Taconic, Berkshire Mountains; Sections 212G and 221E—Northern and Southern Unglaciated Allegheny Plateau; Section M221A—Northern Ridge and Valley; and Section 221C—Upper Atlantic Coastal Plain. Most reported defoliation in the South FHM region was in Section 232E—Louisiana Coast Prairies and Marshes and Section 234A—Mississippi Alluvial Basin.

In the North Central FHM region, there were higher exposure rates to defoliation-causing agents than expected in the scattered forest area of Section 222L—North-Central U.S. Driftless and Escarpment and Section 222K—Southwestern Great Lakes Morainal. Section

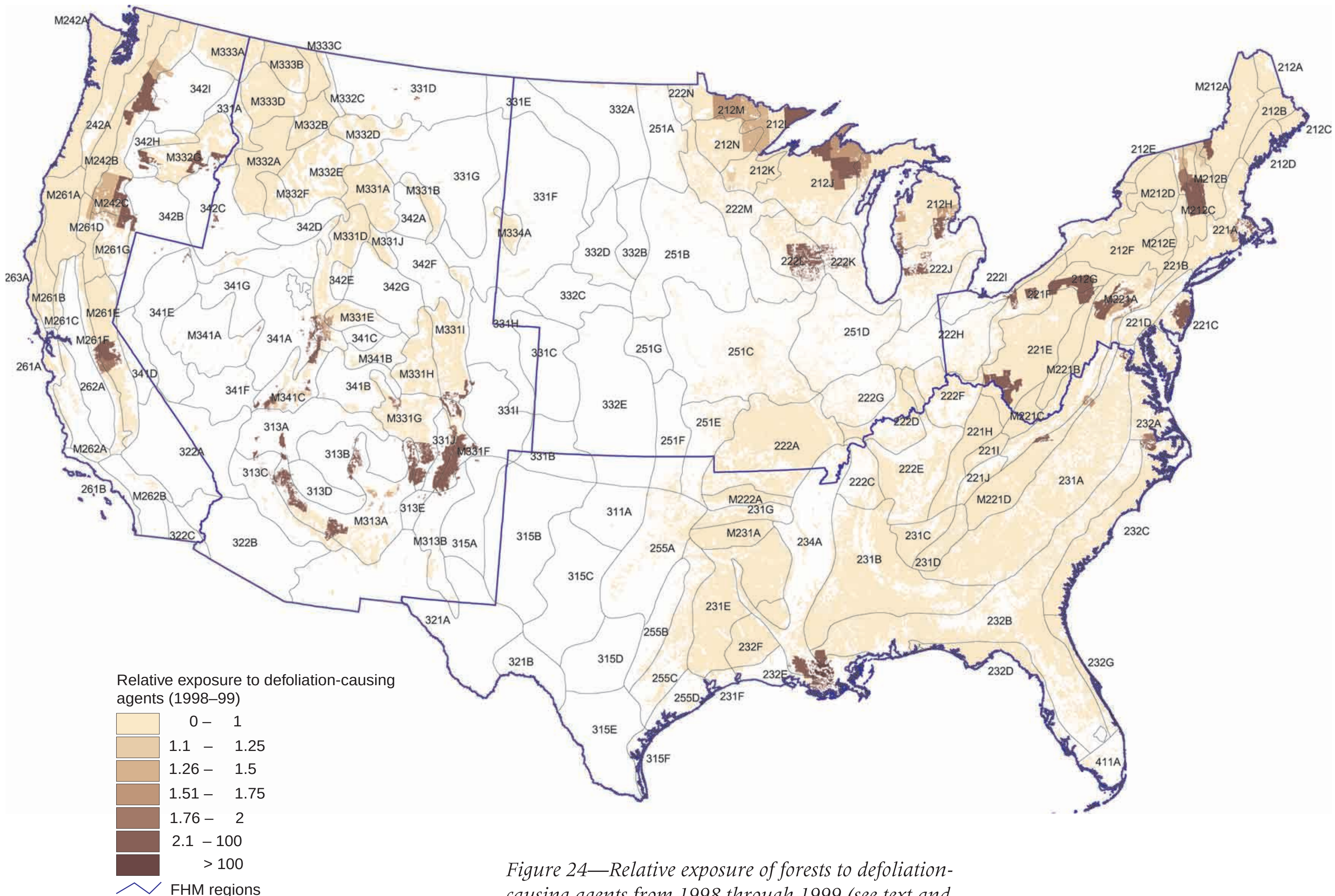

Figure 24—Relative exposure of forests to defoliation-causing agents from 1998 through 1999 (see text and appendix A—Supplemental Methods, "Insects and Pathogens," for more information).

212J—Southern Superior Uplands also had a large hot spot of defoliation-causing agent activity (fig. 24).

Most defoliation in the Interior West FHM region occurred in Colorado, Utah, Arizona, and New Mexico. Areas in Section M331F—Southern Parks and Rocky Mountain Ranges had more than twice the expected exposure to defoliation-causing agents. Some hot spots in Section M331G—South-Central Highlands and Section M313A—White Mountain—San Francisco Peaks—Mogollon Rim also were identified. In the West Coast FHM region, Section M332G—Blue Mountains, Section M242C—Eastern Cascades, and Section M261E—Sierra Nevada had large areas of forest with greater than expected exposure rates to defoliation-causing agents (fig. 24).

In summary, several ecoregion sections had insect and/or pathogen activity in > 6 percent of their forested area in 1999. It is not yet clear whether those areas are exceeding historical variation. The short-term spatial trend analysis identified several hot spots for each FHM region from 1998 through 1999. As more data become available, this type of analysis will identify areas that are continuously exposed to insects and/or pathogens and identify the relative importance of the exposure to the corresponding FHM region.

Fire—Fire is a powerful, selective, regulatory mechanism in forest ecosystems. It is a natural part of the environment, and fire-affected ecosystems depend on a particular frequency and intensity of fire. Such 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 depends on fuel buildup, weather conditions, and the occurrence of ignition. Historically, most fires were started by lightning strikes. Humans have altered historic fire regimes through fire suppression, tree harvesting, and prescribed burning. Influencing either fire frequency or intensity can possibly change the species composition and age structure of a fire-adapted community, as well as soil characteristics (Kimmins 1987).

Current condition classes categorize departure from historic fire regimes based on five ecosystem attributes (fig. 25).[11] They are

[11] Fire Science Laboratory. 1999. 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. www.fs.fw.us/fire/fuelman/. [Date accessed: January 8, 2004].

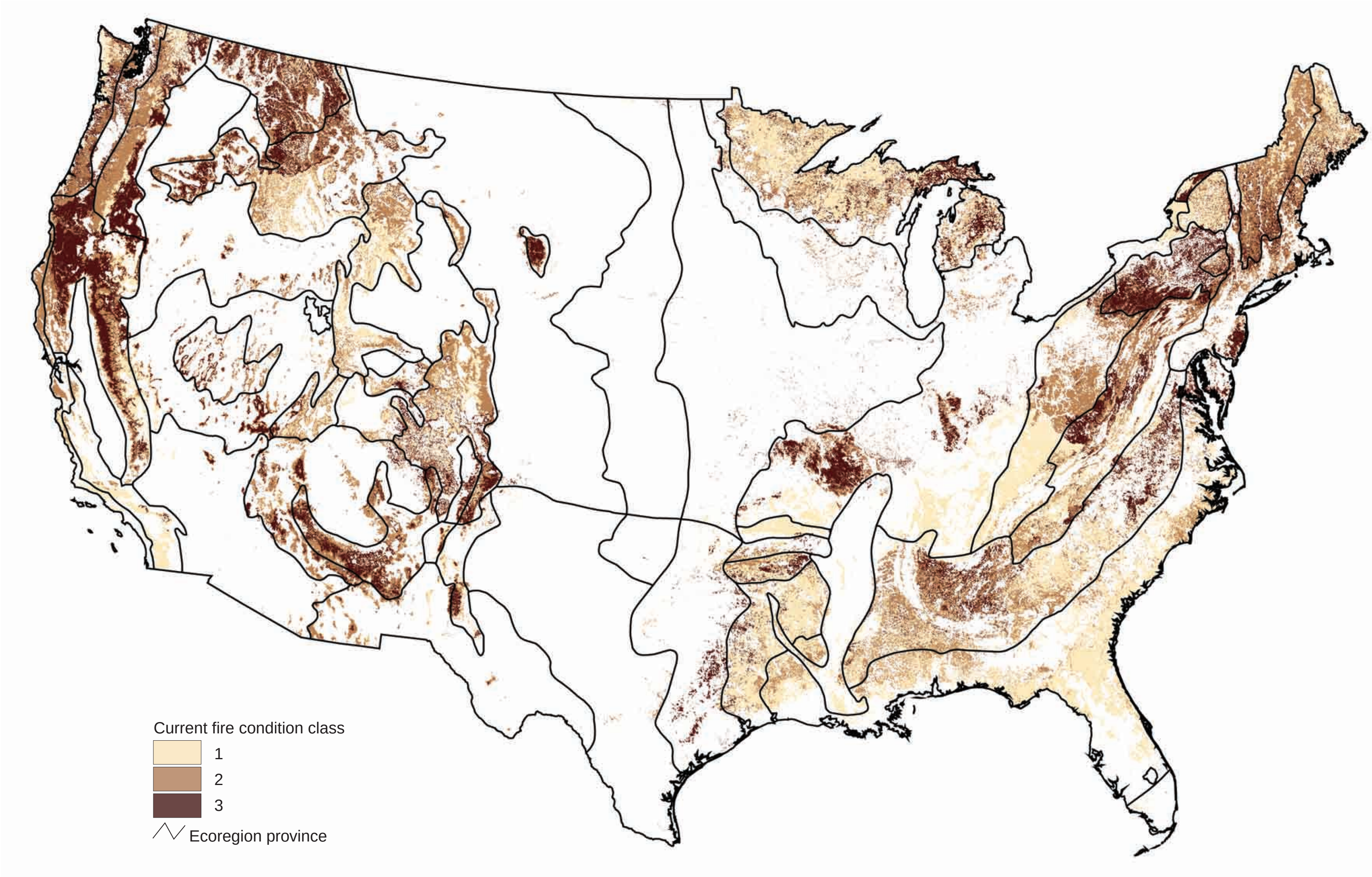

Figure 25—Deviation from ecological conditions compatible with historical fire regimes.

disturbance regimes, disturbance agents, smoke production, hydrologic function, and vegetative attributes. Current condition class 1 represents a minor deviation from ecological conditions compatible with historic fire regimes, and condition class 2 represents a moderate deviation. Restoration of historic fire regimes in areas in condition class 2 may require some silvicultural treatment. For example, ponderosa pine stands in the Southwest historically were adapted to low-severity frequent fire to maintain understory diversity and an open-canopy structure. Without frequent low-severity fire, such stands may become extremely dense. Covington and others (1997) suggest thinning ponderosa stands to historically similar densities and establishing a 2- to 7-year low-intensity fire cycle.

Current condition class 3 represents a major deviation from ecological conditions compatible with historic fire regimes. Restoration may require management activities such as harvesting and replanting. For example, lodgepole pine in the Northern Rockies is adapted to severe-but-infrequent fire with periodic low-severity fires. In the absence of this fire regime, shade-tolerant species such as Douglas-fir and subalpine fir eventually replace lodgepole pine. To restore lodgepole pine to areas that have been replaced by shade-tolerant species, the shade-tolerant species can be harvested and the area replanted in lodgepole pine. Restoration of the historic fire regime is integral to successfully maintaining lodgepole pine stands (Monnig and Byler 1992). Examples of management activities that may be used to restore historic fire regimes in the various current condition classes are simply used in this report to give the reader an idea of what current condition classes mean. No site-specific management activities should be inferred. Figure 25 displays the deviation from historic fire regimes for forested areas. Further discussion of fire regimes can be found in Stolte and others (in press). The percentage of each ecoregion province in condition class 3 also was used in the multivariate analysis presented in the section "A Multivariate Analysis of Forest Indicators."

Drought—Drought is a naturally occurring abiotic stressor to forest communities. It is a function of the amount of precipitation in the form of rain, snow, ice, and fog drip, as well as soil characteristics such as water-holding capacity. Moderate drought stress tends to slow plant growth, while severe drought stress reduces photosynthesis and 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 have reached outbreak status following drought episodes. Berryman (1973, 1982) identified drought as a cause of outbreak for both fir engraver beetle and mountain pine beetle. There also is evidence that drought stress influences plants' uptake of ozone (see "Criterion 3—Health and Vitality: Effects by Air Pollutants, Ozone Bioindicator Plants"). Ozone exposure levels can be relatively high as measured by active monitors, but if plant physiological activity is reduced due to drought stress, ozone uptake and subsequent impact will be reduced.

The National Climate Data Center (NCDC) calculates the Palmer Drought Severity Index (PDSI) monthly by climate division for the conterminous United States (National Climate Data Center 1994). The PDSI is an empirically derived index based on total rainfall, the rainfall periodicity, and soil characteristics. 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).

Growing season PDSI was calculated for each climate division for each year from 1895 through 1999 using the NCDC data. For each year (1895 through 1999), the proportion of the conterminous United States under moderate, severe, or extreme drought was calculated.

A spectral analysis was performed to assess whether there was some underlying frequency in growing season drought using Brocklebank and Dickey's (1986) procedure. Details of this analysis procedure are presented in "Appendix A: Supplemental Methods, Drought." The procedure revealed two significant cycles, 26 and 13 years. The 26-year cycle of growing season drought corresponds to large-scale episodes, typically 40 percent or more of the total land area of the conterminous United States. The 13-year cycle of growing season drought corresponds to smaller-scale episodes of roughly 20 to 30 percent of the land area.

The frequencies of moderate, severe, and extreme drought based on the number of years of growing season droughts from 1895 through 1999 and 1990 through 1999, were calculated for each ecoregion section using a weighted average (see "Appendix A: Supplemental Methods, Drought").

The frequency of growing season drought from 1895 through 1999 served as an historical account or reference point for each ecoregion section. For example, 28 years of growing season drought were recorded for Section 212G—Northern Unglaciated Allegheny Plateau in western Pennsylvania from 1895 through 1999. Conversely, Section 212C—Fundy Coastal and Interior of northeastern Maine had only 6 years of growing season drought for the same time period. These historical accounts were then put on a 10-year basis and compared to the frequency of growing season drought from 1990 through 1999 to assess deviation from historical growing season drought by ecoregion section. For example, Section 212G—Northern Unglaciated Allegheny Plateau had 27 years of growing season drought over a 105-year period. This corresponds to about 3 years of growing season drought over a 10-year period. From 1990 through 1999 only 1 year of growing season drought was recorded for this ecoregion section. This implies that Section 212G was not as droughty from 1990 through 1999 as expected based on historic records. This is represented by a -2 PDSI in figure 26.

Overall, forests in the Eastern United States had either the expected or less than the expected number of growing season droughts from 1990 through 1999 based on historical records (fig. 26). Forests in the Western United States had either the expected or more than the expected number of growing season droughts for the time period. In the Western United States, Section 342E—Bear Lake in southwest Wyoming, Section M262B—Southern California Mountains and Valleys, and Section 342B—Northwestern Basin and Range ecoregion sections had a 2-year deviation in growing season drought occurrence and consist of scattered forested areas (fig. 26).

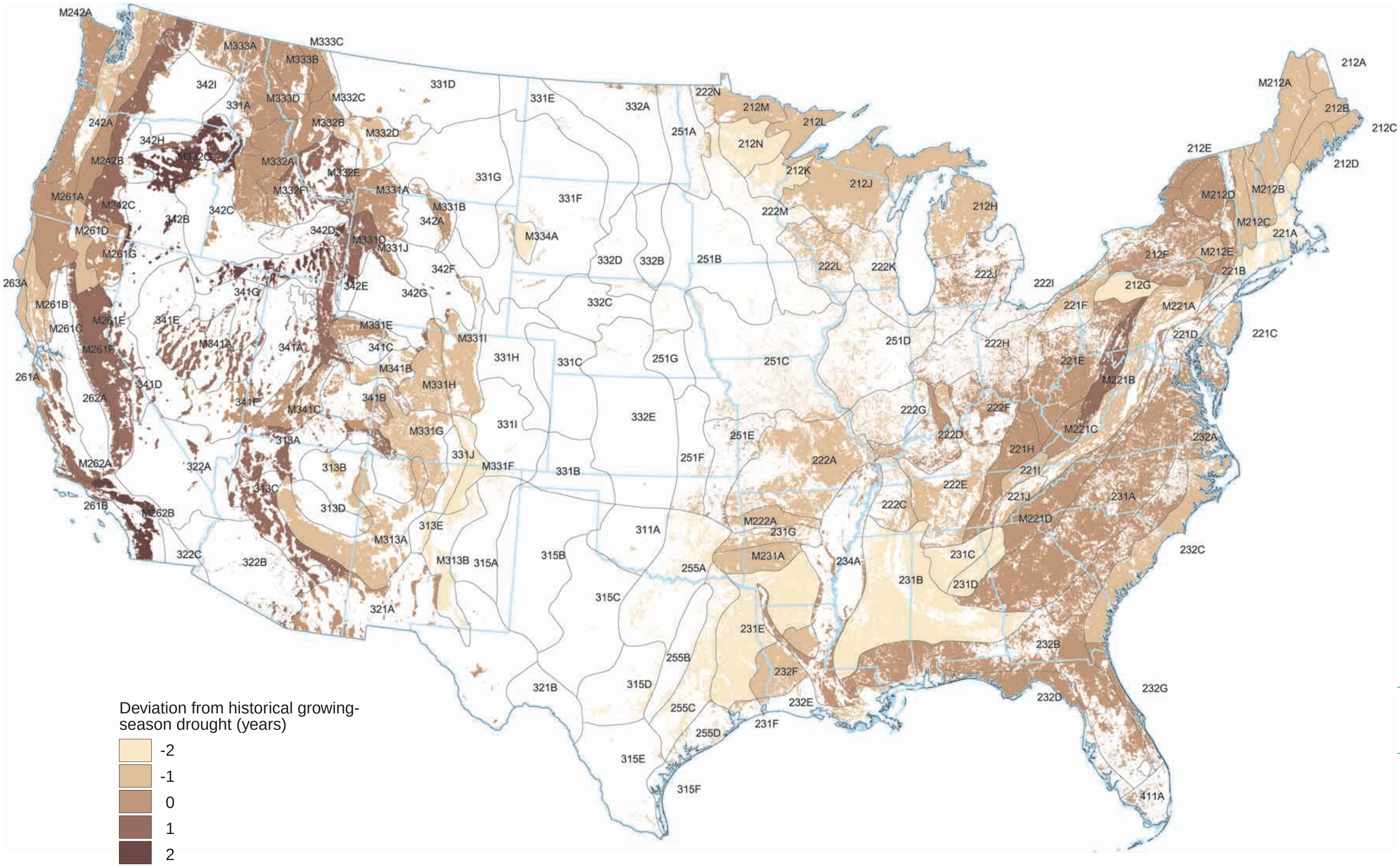

Figure 26—Deviation from historical growing-season drought in years by Bailey's ecoregion section. The frequency of growing-season drought from 1895 through 1999 was the historical reference, and the frequency of growing-season drought from 1990 through 1999 was compared to it.

Section M332G—Blue Mountains was the only section with a high proportion of forested area and +2-year deviation from historic drought.

The number of months of drought in 1999 as indicated by the PDSI is shown in figure 27 by ecoregion section. The most months of drought occurred in the Eastern United States, particularly in Sections 221E, M221B, M221C, and 232G, with 8 to 10 months of drought. Much of the Southeastern United States experienced 6 to 7 months of drought.

Drought stress plays a major role in ecosystem dynamics, including influencing insect populations and uptake of ozone by plants. The conterminous United States generally experiences large-scale drought episodes on a 26-year cycle and smaller-scale episodes on a 13-year cycle. Twenty-four ecoregion sections in the West had more than the expected years of growing season drought from 1990 to 1999 (1- or +2-year drought deviation). By contrast, the East had only one ecoregion section with more years of growing season drought than expected from 1990 to 1999. In 1999, the East had more months of drought than the West.

Effects by Air Pollutants

Ozone bioindicator plants—Air pollutants, such as ground-level ozone, are known to interact with forest ecosystems. Long-range transport of air masses contaminated by urban centers contributes to high ozone concentrations at remote forested sites. Pollutants such as ozone are dispersed over wide areas as regional-scale pollutants (Skelly and others 1987). Ozone is the only regional gaseous air pollutant that is frequently measured at known phytotoxic levels (Cleveland and Graedel 1979, Lefohn and Pinkerton 1988). Ozone pollution has been shown to have an adverse effect on tree growth and to alter tree succession, species composition, and pest interactions (Forest Health and Ozone 1987, Miller and Millecan 1971, Smith 1974). In addition, ozone causes direct foliar injury to many species (Skelly and others 1987, Treshow and Stewart 1973). FHM uses visible injury response to detect and monitor ozone stress in the forest environment. This approach is known as biomonitoring, and the plant species used are known as bioindicators (Manning and Feder 1980).

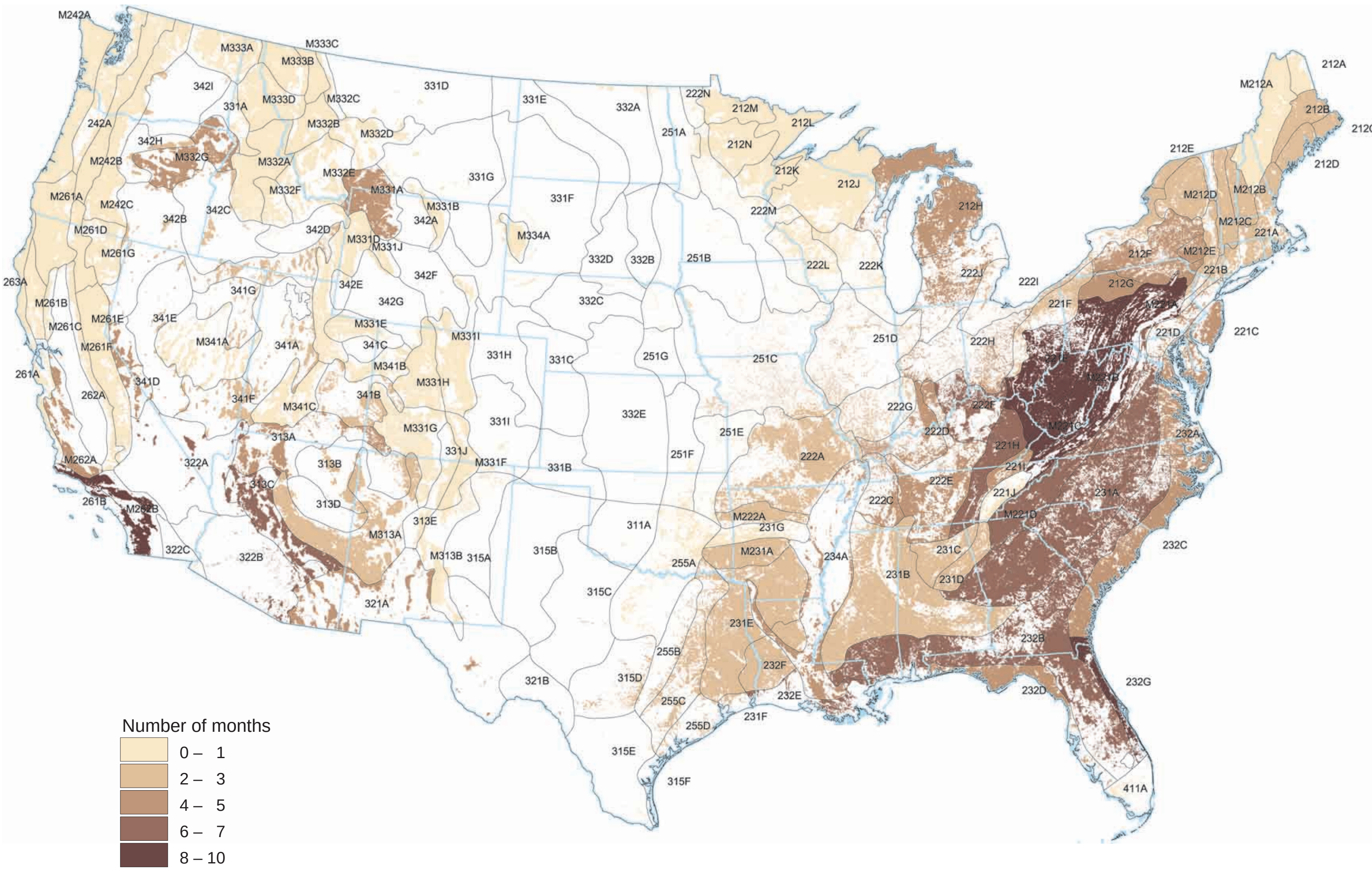

Figure 27—Number of months of moderate, extreme, or severe drought in 1999 as indicated by the Palmer drought severity index.

Useful bioindicator plants may be trees, woody shrubs, or nonwoody herb species. Essentially, these plants respond to ambient levels of ozone pollution with distinct visible foliar symptoms that are easy to diagnose. Field studies and/or fumigation experiments have identified ozone-sensitive species and characterized the ozone-specific foliar response for both eastern bioindicators (Davis and Umbach 1981, Duchelle and Skelly 1981, Krupa and Manning 1988) and western bioindicators[12] (Brace 1996, Richards and others 1968). Foliar injury symptoms include distinct patterns of coloration often associated with accelerated senescence. In the East, species such as blackberry, black cherry, common milkweed, yellow-poplar, and white ash are used as bioindicators; in the West they are ponderosa pine, quaking aspen, Scouler's willow, California black oak, and red alder.

Ozone biomonitoring plots are located close to or at some distance from the FHM Detection Monitoring ground plots, depending on the availability of open areas containing ozone-sensitive species. A plot-level index was calculated based on the amount of injury and severity rating for each plant and the number of species evaluated at each site (see "Appendix A: Supplemental Methods, Ozone Bioindicator Plants"). Plot ozone index values between zero and 4.9 reflect little or no foliar injury, values between 5 and 24.9 reflect low-to-moderate foliar injury, and values > 25 reflect severe foliar injury. Plot index values were averaged for each plot for as many years as data were available from 1994 through 1999.

In the East, up to 6 years of data were available, depending on how long the FHM Program had been implemented in each State. In the West, only 2 years of data were available (fig. 28). Ecoregion section values were the average of all plot values across all years. As with the plot-level index, the ecoregion ozone index was divided into three categories representing low, moderate, and severe foliar response to ambient ozone concentrations. At the ecoregion level, these three categories may be associated with increasing risk to the forest from ozone pollution. Indices are based on both wet and dry years, as well as variable ozone levels, providing a more representative indication of ozone stress.

[12] Mavity, E.; Stratton, D.; Barrang, P. 1995. Effects of ozone on several species of plants which are native to the Western United States. Unpublished report. Dry Branch, GA: U.S. Department of Agriculture, Forest Service, Center for Forest Environmental Studies. 12 p. On file with: U.S. Department of Agriculture, Forest Service, Region 8, 1755 Cleveland Highway, Gainesville, GA 30501.

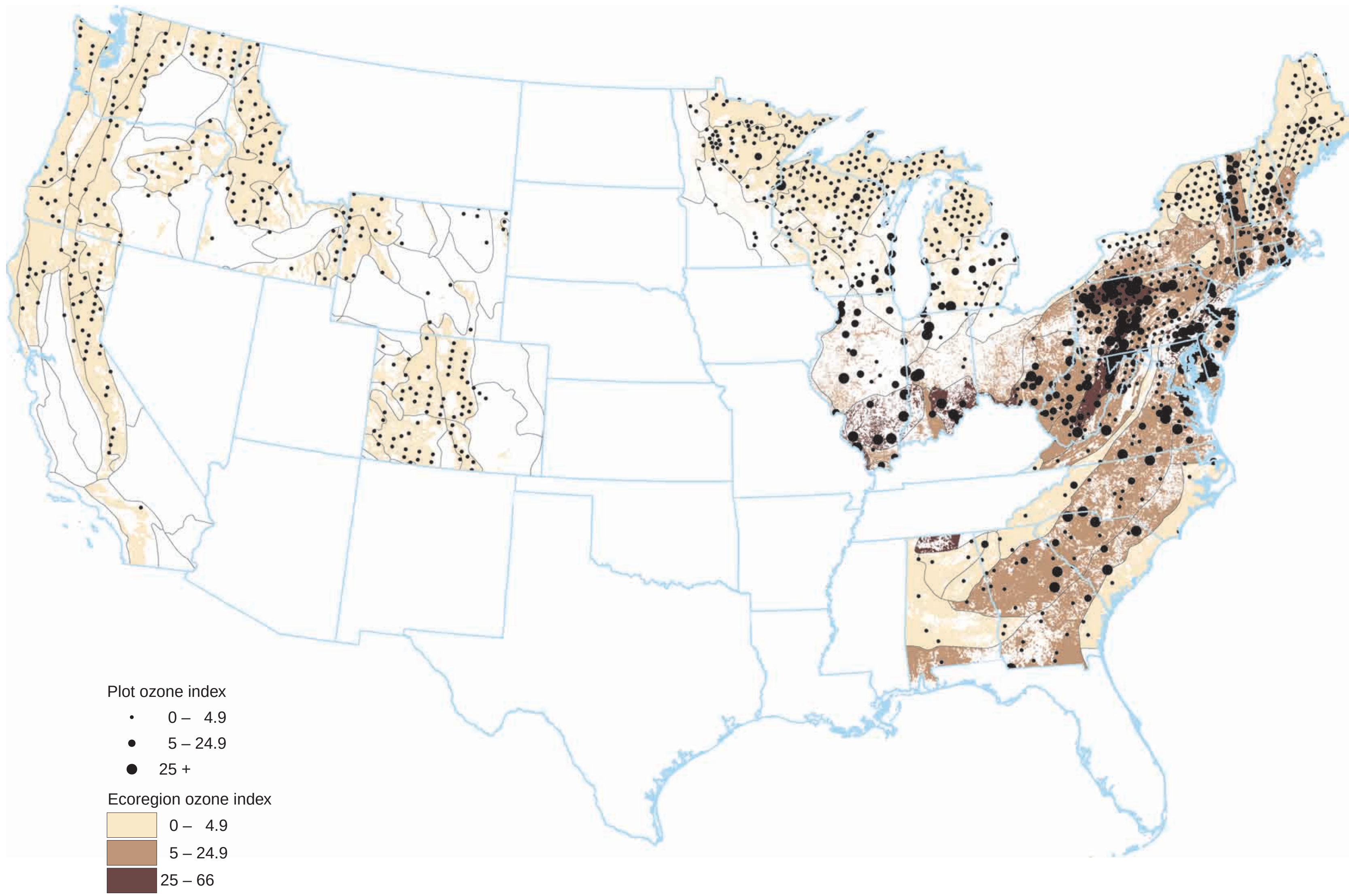

Figure 28—Ozone bioindicator plot-level values and average ecoregion section values using data collected from 1994 through 1999, depending on the years each plot was measured.

The national network of biomonitoring plots showed more ecoregions and a greater percentage of forest area in the higher injury index categories in the Eastern United States than in the sampled ecoregions of the six Western States (fig. 28). Relatively high injury index values are clustered in airsheds surrounding the more industrialized portions of Illinois, Indiana, and Ohio, and all along the eastern corridor from Georgia, north through Virginia, and up into southern New England. The mid-Atlantic ecoregions, where ambient ozone levels often exceed the National Ambient Air Quality Standards (U.S. Environmental Protection Agency 2001) during the growing season, showed the highest proportion of plots with injury.

In contrast to the East, the western ecoregions all fell into the lowest injury index category, representing little or no foliar response to ozone. This supported the hypothesis that large areas of the West are relatively ozone free, with only occasional intrusions of above-background concentrations in the ambient air. Note that bioindicator sites are lacking from the ponderosa pine forests of southern California, where high ambient ozone has had a significant negative impact on forest health (Miller and others 1996). Increased numbers of ozone biomonitoring sites will be established in the southern Sierra ecoregions soon. Many of the western bioindicator species on FHM plots do not have a long historical record in the field, and specific ozone symptoms are less well described. Fumigation studies are underway to improve the diagnostic capabilities of the ozone bioindicator for the western regions.

An initial step in assessing the interpretive value of ozone biomonitoring data is to examine the relationship between plot-level injury index data and the more traditional measurements of ozone air quality, such as SUM06, derived from data from active monitoring stations. SUM06 is the sum of hourly ozone concentrations > 0.06 parts per million (ppm). Twelve-hour (8:00 a.m. to 8:00 p.m.) SUM06 values (ppm-hrs) across the northern ecoregion sections were estimated from the Aerometric Information Retrieval System database of the U.S. Environmental Protection Agency (EPA) and compared to corresponding biomonitoring data for the years 1996 through 1999. Findings from these preliminary analyses are presented in tables 3 and 4. As ozone exposures increased, the

Table 3—Relationships among ambient air quality data, percent of ozone biomonitoring plots with injury, and mean injury index values for biomonitoring sites in eastern forests

Ozone exposure SUM06	Plots evaluated	Injured plots[a]	Mean injury index[b]
ppm-hrs	*number*	*percent*	
0–5	225	20	1.01
5–10	199	27	1.87
10–15	133	43	2.11
15–20	113	50	2.36
20–25	83	60	3.55
> 25	206	62	5.08

SUM06 = sum of all average hourly ozone concentrations (8:00 a.m. to 8:00 p.m.) > 0.06 parts per million for a 3-month growing season (June, July, and August); values averaged over 1996–99 time period.
[a] Total number of plots with injury divided by total number of plots in the corresponding ozone exposure category.
[b] The injury index is derived from the incidence and severity of ozone-induced foliar injury at each biomonitoring plot (see "Appendix A: Supplemental Methods, Ozone Bioindicator Plants").
Source: Personal Communication. 2000. Teague Prichard, Wisconsin Department of Natural Resources, Bureau of Air Management, 101 South Webster Street, Madison, WI 53703.

Table 4—Relationships among ambient air quality data, percent of ozone biomonitoring plots with injury, and mean injury index values for biomonitoring sites in eastern forests

Ozone exposure categories	Injured[a]		Mean injury index[b]	
	1996–98[c]	1999[d]	1996–98	1999
	- - - percent - - -			
Low ozone exposure				
SUM06 < 10 ppm-hrs	23	14	1.48	0.24
Moderate ozone exposure				
SUM06 10 to 25.5 ppm-hrs	50	38	2.76	0.63
High ozone exposure				
SUM06 > 25.5 ppm-hrs	62	25	5.05	2.25

SUM06 = sum of all average hourly ozone concentrations (8:00 a.m. to 8:00 p.m.) > 0.06 parts per million for a 3-month growing season (June, July, and August); values averaged over 1996–99 time period.
[a] Total number of plots with injury divided by total number of plots in the corresponding ozone exposure category.
[b] The injury index is derived from the incidence and severity of ozone-induced foliar injury at each biomonitoring plot (see "Appendix A: Supplemental Methods, Ozone Bioindicator Plants").
[c] Ozone levels and rainfall amounts variable but not extreme for 1996, 1997, and 1998.
[d] Ozone levels relatively high and rainfall amounts relatively low for 1999.
Source: Personal Communication. 2000. Teague Prichard, Wisconsin Department of Natural Resources, Bureau of Air Management, 101 South Webster Street, Madison, WI 53703.

percent of plots showing injury also increased, as did the mean injury index value for injured plots (table 3). In very dry years; e.g., 1999, the numbers of injured plots and the severity of injury are both sharply reduced (table 4). This suggests that biological monitoring data provide important interpretive value to ozone-stress assessment in the forest environment. Ozone exposure levels can be relatively high as measured by active monitors, but if plant stomata are closed due to drought stress, ozone uptake and its subsequent impact will be reduced.

There is no evidence now linking FHM ozone bioindicator response data to a specific tree health problem or a regional decline. Nevertheless, the mapped data demonstrate that plant-damaging concentrations of ozone air pollution are widespread across the landscape. Continued monitoring and analysis are important when determining probable or significant ozone impact.

Lichen bioindicator—Composition of the lichen community often is correlated with several ecological variables, including air quality, climate, forest type, successional status, and management status. Because lichens lack epidermis, cuticle, and stomata, they cannot control gas exchange with the atmosphere, and therefore are especially sensitive to air pollution (Stolte and others 1993). Sulfur and nitrogen oxides, hydrogen fluoride, and metal and organic toxins are particularly harmful. Lichens also are susceptible to and good indicators of wet and dry deposition of sulfates, nitrates, other sources of acidification, and ammonium. They are sensitive to long-term changes in temperature and moisture, and therefore are also good indicators of changing climatic and forest stand conditions.

Unlike most fungi, lichens are always directly exposed to the atmosphere. Soil fungi are generally well buffered by the soil system from the effects of air pollution and extremes of temperature. Because lichens are exposed directly to the atmosphere, they may serve as an early warning signal of changes that may later occur in the soil fungal community as a result of air pollution or climate change.

Using macrolichens (leafy, stalked, tufted, or hanging growth forms) as an environmental indicator requires a model that relates lichen species composition to environmental variables; e.g., air quality. Such a gradient model produces a score for the environmental variable based on the lichen community on each plot. To date, gradient models for the lichen bioindicator have been developed for Colorado and the Southeastern United States (McCune and others 1997, 1998). Gradient models are being developed for the Northeast, the Pacific Northwest, and California. Because the models for different areas were derived independently, additional calibration studies must be conducted before comparing gradient scores across regions.

The gradient model for Colorado assigns an air quality score to each plot based on the relative abundance of pollution-tolerant and pollution-intolerant lichen species, adjusted for the effects of elevation, which is closely tied to moisture and temperature (McCune and others 1998). Plot values of the Colorado air quality scores are shown in figure 29. The plots with the lowest air quality scores generally were located in or downwind from urban or industrialized areas.

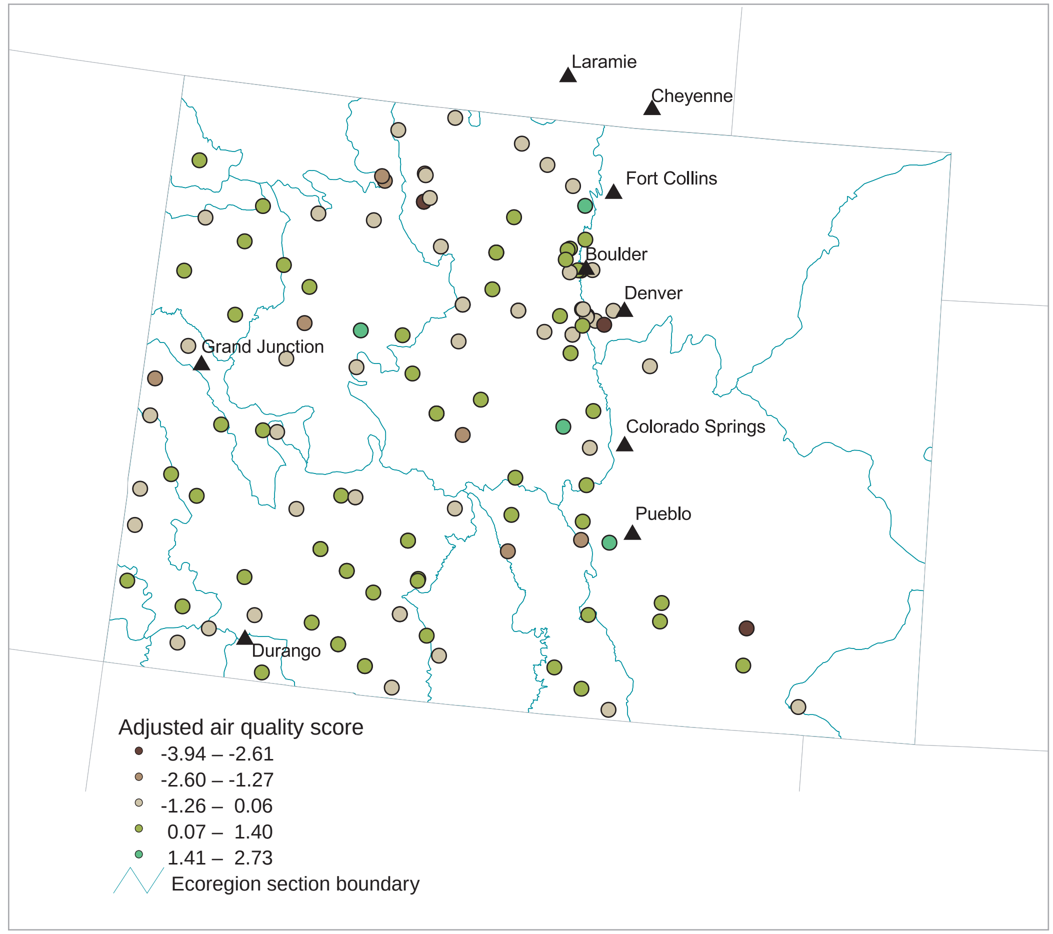

Figure 29—Lichen air quality scores for Colorado (high values = better air quality). Data are shown from both regular Forest Health Monitoring plots and off-frame plots located near urban or industrialized areas. This map uses the 1997 remapping of Bailey's ecoregion sections (Freeouf 1997).

The Southeast gradient model was developed using ordination techniques and gradient analysis of lichen species data. Two major gradients were found to explain the variation in species composition; one corresponds to macroclimate (warm and dry to cool and wet), the other to air quality (McCune and others 1997). Plot values on the two gradients are shown in figures 30A and 30B. Figure 30A shows the climate gradient reflected in lichen species occurrence; low values (indicating hotter conditions) are found to the south, and high values (indicating cooler conditions) are found to the north or at higher elevations. In figure 30B, the poorer air quality scores generally were located in northwestern Virginia and in the more urbanized northern and central parts of Virginia, Georgia, and Alabama.

Data now available provide a baseline for monitoring long-term changes in climate and air quality. Given what is known about lichen growth rates and species sensitivity to the environment, changes in lichen communities might provide evidence of any deterioration in air quality over a period of several years. Because lichens are not always good colonizers, any indication of improving air quality would take longer to manifest itself, and indication of global climate change might take even longer.

Research is ongoing to develop gradient models for lichen communities in other parts of the country and to refine the existing models (Neitlich and others 1999). Elemental analysis of lichen tissue offers a reliable way to measure elemental deposition in forested ecosystems. The FIA Phase 3 Lichen Indicator Team is examining the possibility of adding tissue analysis to the lichen indicator protocols, and will be working with the USDA Forest Service, Pacific Northwest Air Program to include tissue data as a component of the Pacific Northwest gradient model.[13] Tissue analysis data, as well as atmospheric deposition data, also may be used to refine current models.[14]

Ion deposition—Ionic compounds generated from industrial, transportation, and agricultural activities are transported in the atmosphere, deposited in precipitation (rain, snow, fog), and may cause forest health problems in areas where soils are limited in buffering capacity. The primary concerns are that sulfates (SO_4^{-2}),

[13] Personal communication. 2001. Peter Neitlich, National Park Service, P.O. Box 220, Nome, AK 99762.

[14] U.S. Department of Agriculture Forest Service. [N.d.]. U.S. Department of Agriculture Forest Service, Pacific Northwest Region, Lichens and Air Quality Home Page http://www.NACSE.ORG/lichenair/ .

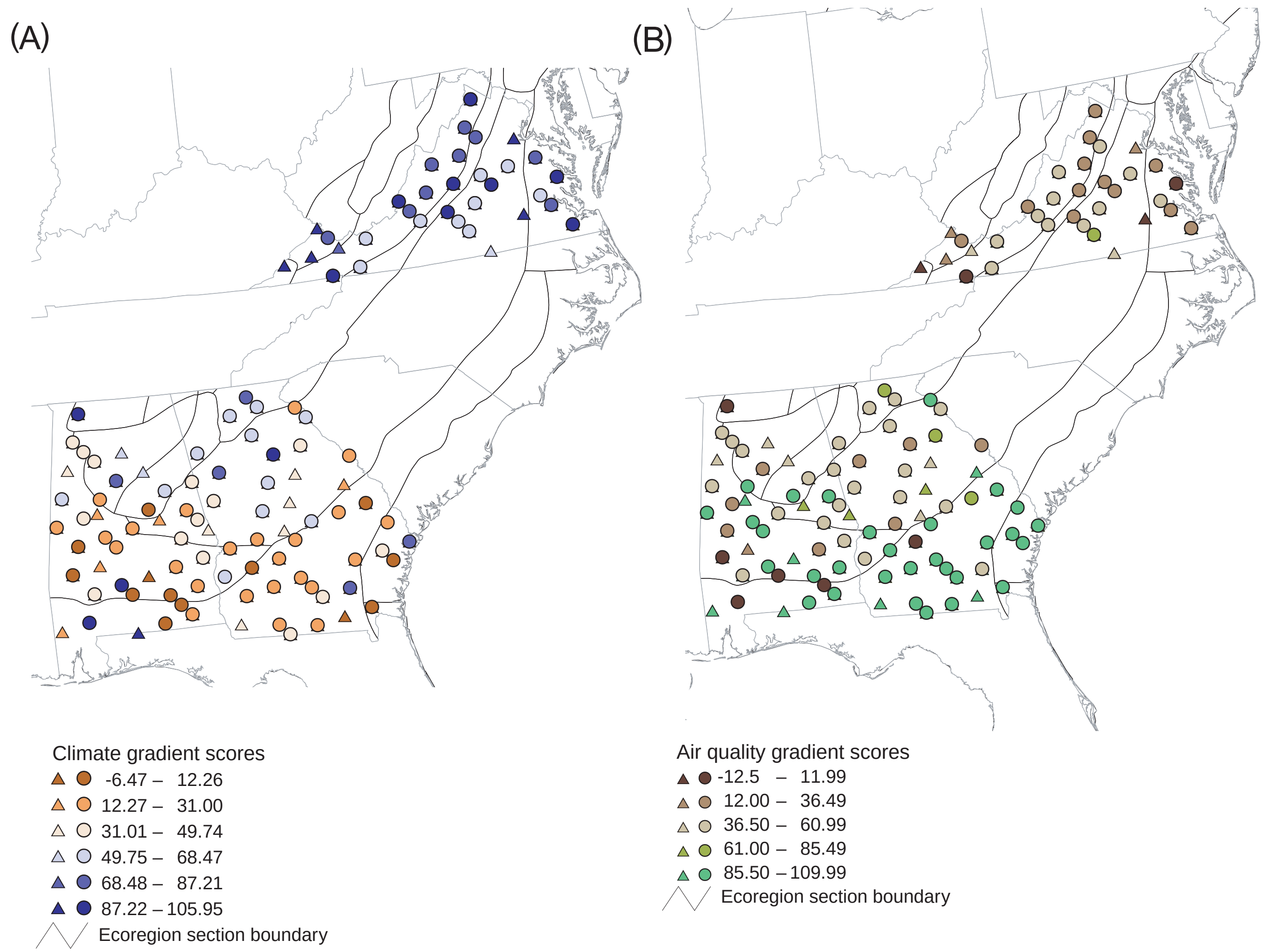

Figure 30—Lichen gradient model scores for Forest Health Monitoring plots in the Southeastern United States. Map A shows macroclimate gradient scores (high values = cooler and wetter). Map B shows air quality gradient scores (high values = better air quality). Circles = 1998 data; triangles = 1994 data.

nitrates (NO_3^-), and ammonium (NH_4^+) may leach nutrient cations from foliage, and acidify and fertilize soils. Acidified forest soils (pH < 5.0) release aluminum and manganese, reduce the number of fine roots, and reduce uptake of nutrient cations. These mobilized nutrient and toxic cations from soils are often transported to aquatic ecosystems where they affect water quality and biological diversity (Stolte and others, in press). Fertilization of natural forest stands with nitrogen can also differentially select for nitrophilous plant and microbial species and, if soils become nitrogen-saturated, lead to further acidification (Fenn and others 1998).

The spatial patterns of average annual wet deposition of sulfate, nitrate, ammonium, inorganic nitrogen, and precipitation pH from 1979 through 1995 were interpolated from NADP, CASTNET, and CAPMON data for the conterminous United States (Stolte and others, in press). Ozone monitoring sites established by the EPA were used to interpolate an average annual ozone concentration (1993 through 1996), excluding sites classified as urban because ozone levels in urban areas are often not representative of exposure levels found in forests (Stolte and others, in press). More details about the interpolation procedure are presented in "Appendix A: Supplemental Methods, Ion Deposition."

Interpolated maps for the ion depositions listed in the previous paragraph were presented in an earlier FHM national technical report (Stolte and others, in press). Because no additional data have been added, those maps are not included in this report. However, to allow the ion deposition data to be included in a multivariate analysis (see "A Multivariate Analysis of Forest Indicators"), an additional manipulation was done. For each ion, the average ion deposition for the forested area in each ecoregion section was calculated using the interpolated data. As an example, the reader can compare the interpolated data map from the previous report for precipitation pH (fig. 31) with the map showing the average rainfall pH in the forested area of each ecoregion section (fig. 32). Average ion deposition in the forested area of each ecoregion section for the ions listed previously was used in the multivariate analysis (see "A Multivariate Analysis of Forest Indicators").

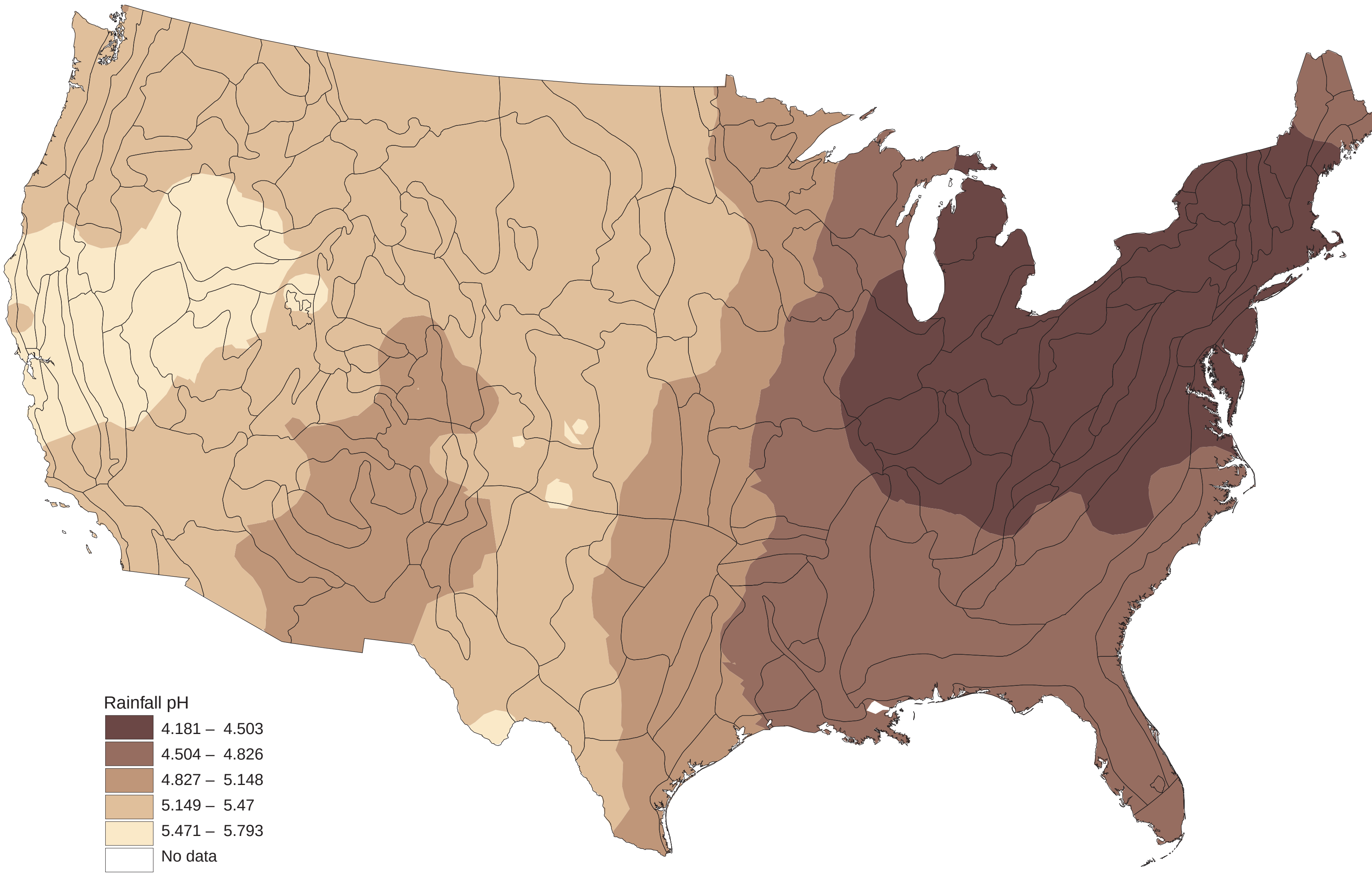

Figure 31—Average annual acidity of precipitation (pH) from 1979 through 1995, interpolated from monitoring station data.

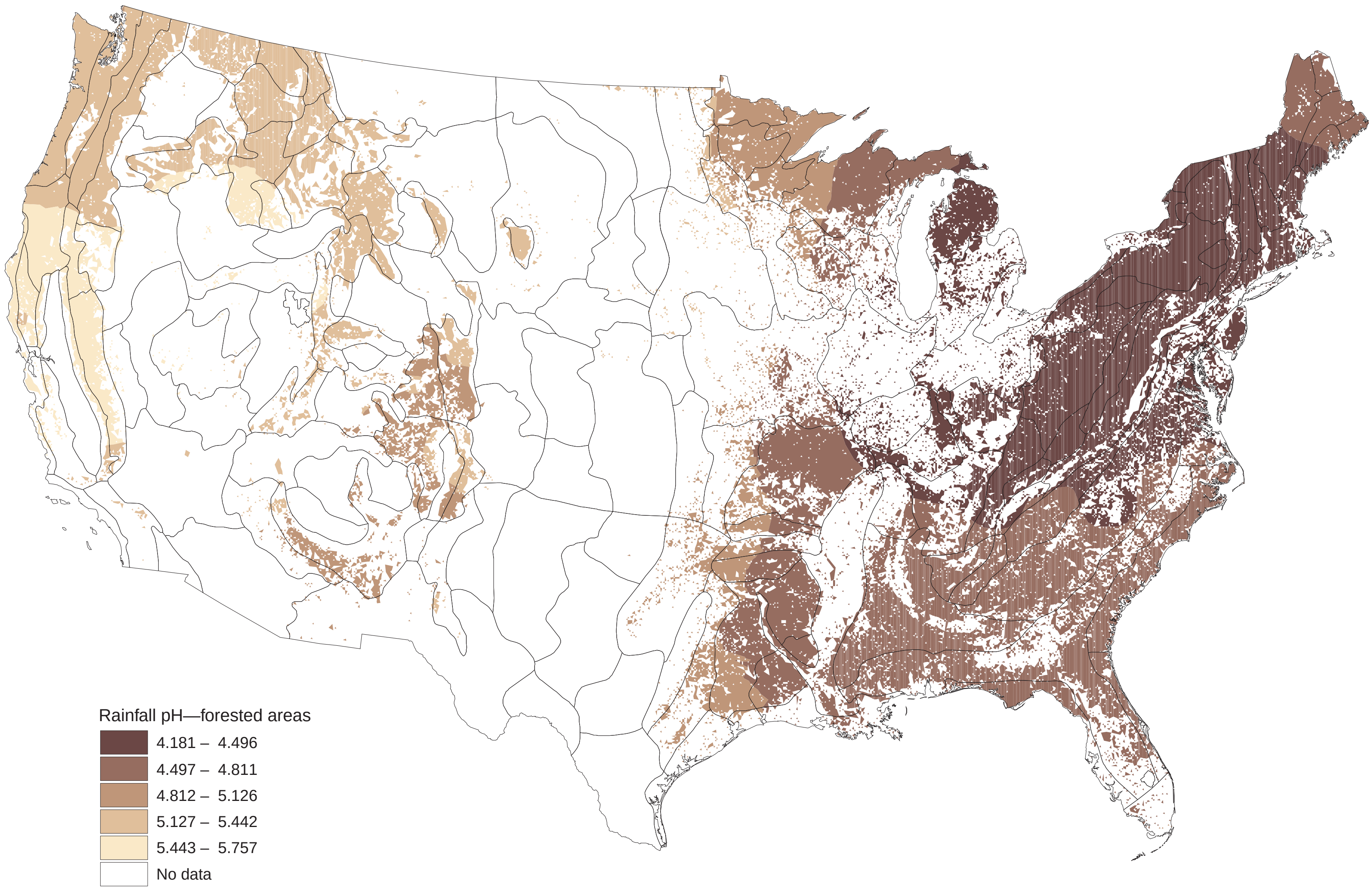

Figure 32—Average annual acidity of precipitation (pH) shown for the forested area of each ecoregion section from 1979 through 1995.

Diminished or Changed Biological Components

Crown condition—Tree 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 during a growing season (Stolte 1997).

The relationship between crown condition and tree health is complex. Because crown condition directly reflects a tree's current photosynthetic ability, it gives an indication of current growth and potential future growth. Large, healthy crowns reflect a potential for high productivity. Conversely, poor crown condition may indicate reduced forest productivity. Extremely poor crown condition may mean that trees have insufficient photosynthetic ability to meet their basic maintenance respiration costs, and that tree mortality may soon occur. Poor crown condition is not a direct indicator of the stress that a tree may be experiencing; rather, it indicates a tree's response to one or more stressors.

FHM field crews measure several variables that relate to amount and fullness of foliage and the vigor of the crown's apical growing points. Two such variables are mortality of terminal twigs in sun-exposed portions of tree crowns (dieback) and transparency of foliage in the whole tree crown to sunlight; i.e., sparseness of crown foliage. Crown dieback is recorded as percent mortality of the terminal portion of branches > 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 to the nearest 5 percent via ocular estimates.

Crown dieback and increased transparency may occur in response to a number of stressors, both biotic and abiotic, both natural and anthropogenic. Abiotic stressors that can affect crown condition include air pollution and extreme weather; e.g., drought or harsh winters. Biotic stressors include native and introduced insects and pathogens (BFH 2000). Generally, high or increasing transparency or dieback values indicate that trees are under stress, and that there may be a potential forest health problem. However, crown response to stressors may vary depending on the particular stressors and tree species, complicating efforts to determine causal relationships or crown variable thresholds indicative of significant ecological impacts.

Average crown indicator values are determined by ecoregion section for hardwoods and softwoods. The hardwood indicator analyses used data from all plots except those having fewer than three hardwood trees > 5 inches d.b.h. and < 10 percent of the basal area in hardwoods. Similarly, the softwood analyses excluded data from plots having fewer than three softwood trees > 5 inches d.b.h. and < 10 percent of the basal area in softwoods.

For each ecoregion section an average crown indicator value for the section was estimated using a generalized least squares mixed modeling procedure (Smith and Conkling 2005). With this procedure, current and all prior plot measurements could be used to estimate simultaneously the current status as well as the periodic annual change in the crown indicator. Periodic annual change is defined as the total change observed from plot establishment to the most recent measurement expressed on an annual basis.

Because not all plots are measured every year in the FHM sampling design, for each plot that was not measured in 1999, dieback and transparency values were estimated from past measurements of that plot and past and current measurements of other plots using the mixed modeling procedure (see "Appendix A: Supplemental Methods, Analysis Using Generalized Least Squares Models," "Estimating Current Status and Change for a Region," and "Crown Condition"). Plot values shown on all maps are actual values if the plot was measured in 1999; the values are estimates for plots not measured in 1999. All maps in this section show plot values for 1999 status (in percent) and estimates by ecoregion section of either average 1999 status (in percent) or periodic annual change (in percentage points per year). Summary tables in "Appendix B: Supplemental Tables, Appendix tables B.3 through B.10", contain status and change estimates by ecoregion section, as well as associated statistical information. Only ecoregion section values are discussed in the remainder of this section.

***Hardwood crown condition*—**The periodic annual change in hardwood foliar transparency is shown in figure 33. Hardwood transparency has been increasing throughout most of the eastern half of the United States since FHM began data collection. Throughout most of the East, 1999 transparency values were relatively low, so the observed increase may not be of major concern. However, in the upper Midwest, especially Section 212K—Western Superior and Section 222L—North-Central U.S. Driftless and Escarpment, transparency values were quite high, indicating possible forest health concerns.

In the West, hardwood transparency has been increasing most in northern Idaho and eastern Washington (Section M333D—Bitterroot Mountains and Section M333A—Okanogan Highlands). This was also an area where 1999 hardwood transparency values were very high. However, forests in the region were mostly softwoods with a very small hardwood component. In this context, it is difficult to interpret the significance of increasing hardwood transparency. Hardwood transparency also was high in 1999 in Section 242A—Willamette Valley and Puget Trough and Section M242C—Eastern Cascades, although there were too few repeated measurements of plots with a hardwood component to estimate change.

Hardwood dieback is shown in figure 34 (status) and figure 35 (change). In the West, 1999 dieback levels were highest in Idaho's Section M333D—Bitterroot Mountains, Section M332E—Beaverhead Mountains, and Section M332F—Challis Volcanics (shown in figure 34 as status). In the Bitterroot Mountains, dieback levels also were found to be increasing (shown in figure 35 as change). Increases in both hardwood transparency and dieback suggest the need for further investigation of hardwood health. In the East, 1999 hardwood dieback was highest in Section 212A—Aroostook Hills and Lowlands in northeastern Maine, and moderately high in adjacent areas of New England, as well as in southeastern Indiana's Section 222F—Interior Low Plateau, Bluegrass.

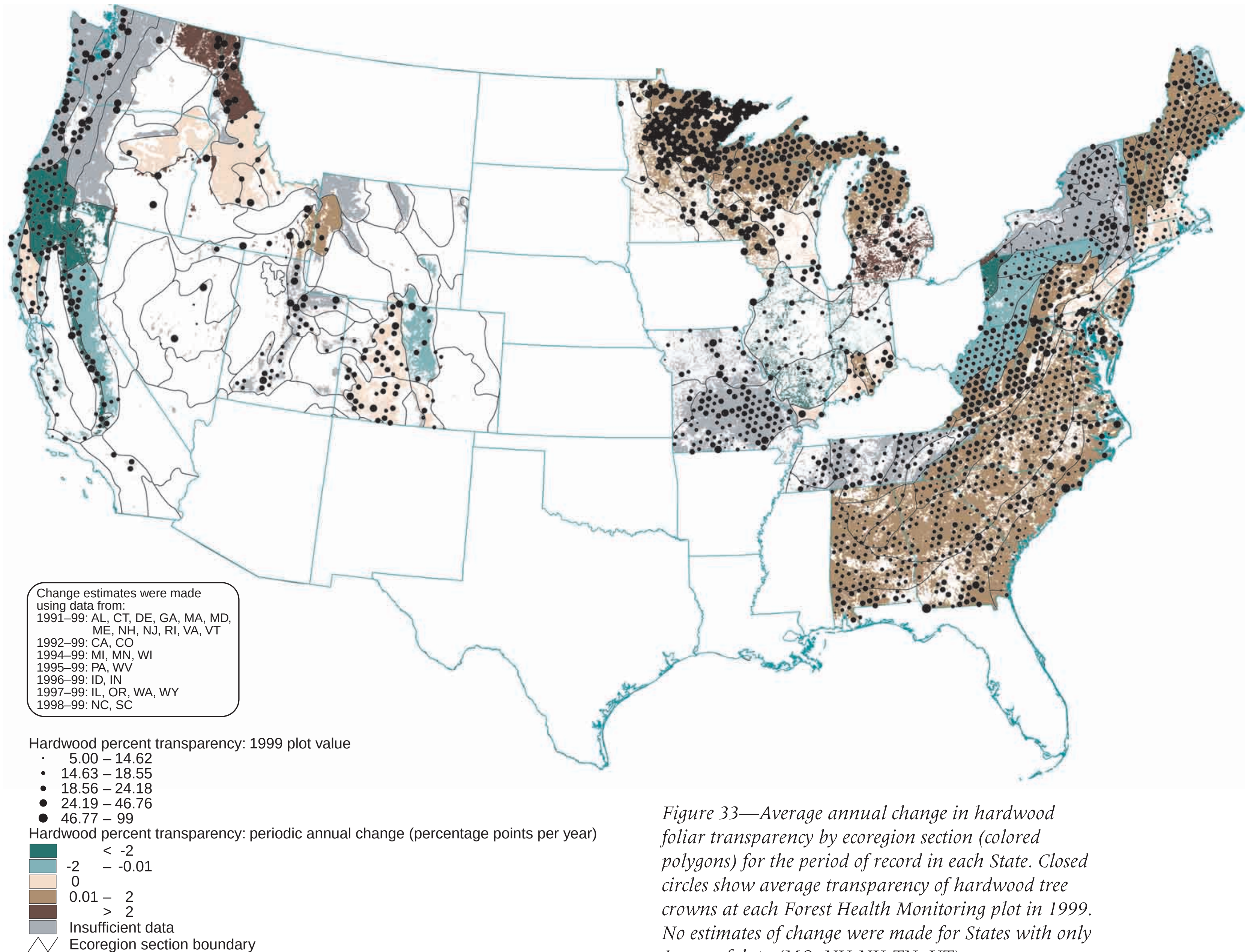

Figure 33—Average annual change in hardwood foliar transparency by ecoregion section (colored polygons) for the period of record in each State. Closed circles show average transparency of hardwood tree crowns at each Forest Health Monitoring plot in 1999. No estimates of change were made for States with only 1 year of data (MO, NV, NY, TN, UT).

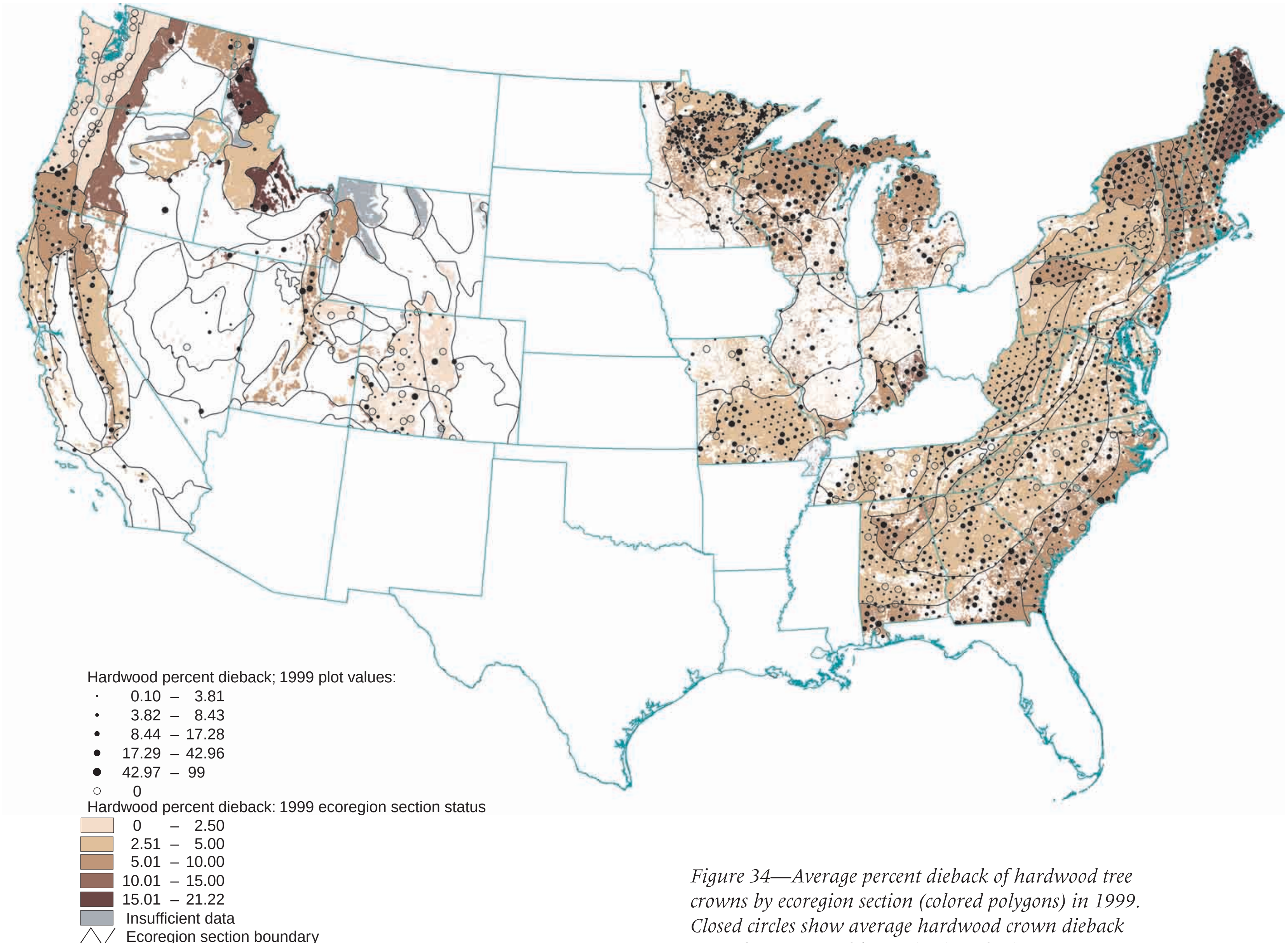

Figure 34—Average percent dieback of hardwood tree crowns by ecoregion section (colored polygons) in 1999. Closed circles show average hardwood crown dieback on each Forest Health Monitoring plot in 1999.

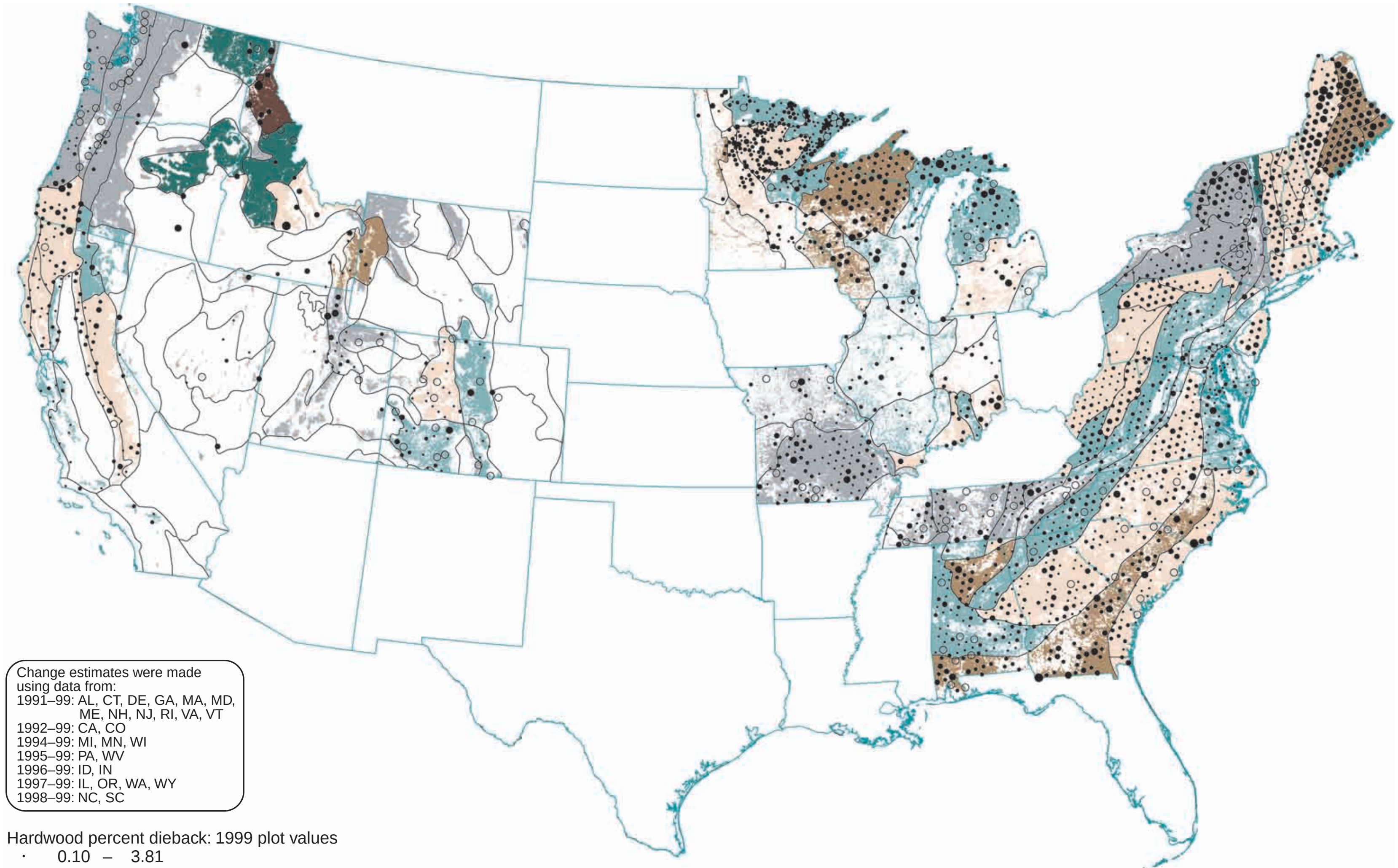

Figure 35—Average annual change in hardwood crown dieback by ecoregion section (colored polygons) for the period of record in each State. Closed circles show average hardwood crown dieback on each Forest Health Monitoring plot in 1999. No estimates of change were made for States with only 1 year of data (MO, NV, NY, TN, UT).

***Softwood crown condition*—**Softwood transparency was found to be increasing throughout most areas of the East and Pacific Northwest where FHM plots had been established. In the West, 1999 softwood foliar transparency was highest in Section M261C—Northern California Interior Coast Ranges and Section M261F—Sierra Nevada Foothills. However, there has been no change in average transparency in those sections since FHM plot establishment (fig. 36). The high transparency was found almost exclusively in stands of gray pine, a species having a very open crown and sparse foliage, which is an adaptation to arid environments that allows conservation of moisture. The high foliar transparency (highest observed for softwoods anywhere in the United States) is a normal condition for that species.

In the East, average 1999 softwood transparency values were highest in the Appalachian Mountains area (Section M221A—Northern Ridge and Valley, Section 221I—Southern Cumberland Mountains, and Section 221J—Central Ridge and Valley). Softwood foliar transparency was also increasing throughout much of this region (fig. 36), as well as along most of the east coast. Average softwood transparency levels were also relatively high and increasing in Section 212K—Western Superior and Section 222M—Minnesota and Northeastern Iowa, Morainal; which are located in Minnesota and Wisconsin.

Figures 37 and 38 show 1999 softwood dieback levels and the periodic annual change in dieback. Dieback levels were increasing in Section 212K—Western Superior, Section 212N—Northern Minnesota Draft and Lake Plains, and Section 212J—Southern Superior Uplands, located in Minnesota and Wisconsin (change shown in figure 38). Of these sections, 1999 dieback levels were highest in Section 212K—Western Superior (status shown in figure 37).

Softwood dieback also was increasing in several ecoregion sections in the West (fig. 38). Of these, 1999 dieback levels were highest in Section M331B—Bighorn Mountains in north-central Wyoming (fig. 37).

Nationally, the highest 1999 softwood dieback levels occurred in Section 212C—Fundy Coastal and Interior in eastern Maine (fig. 37). Softwood dieback levels also were high in Section 212B—Maine and New Brunswick Foothills and Eastern

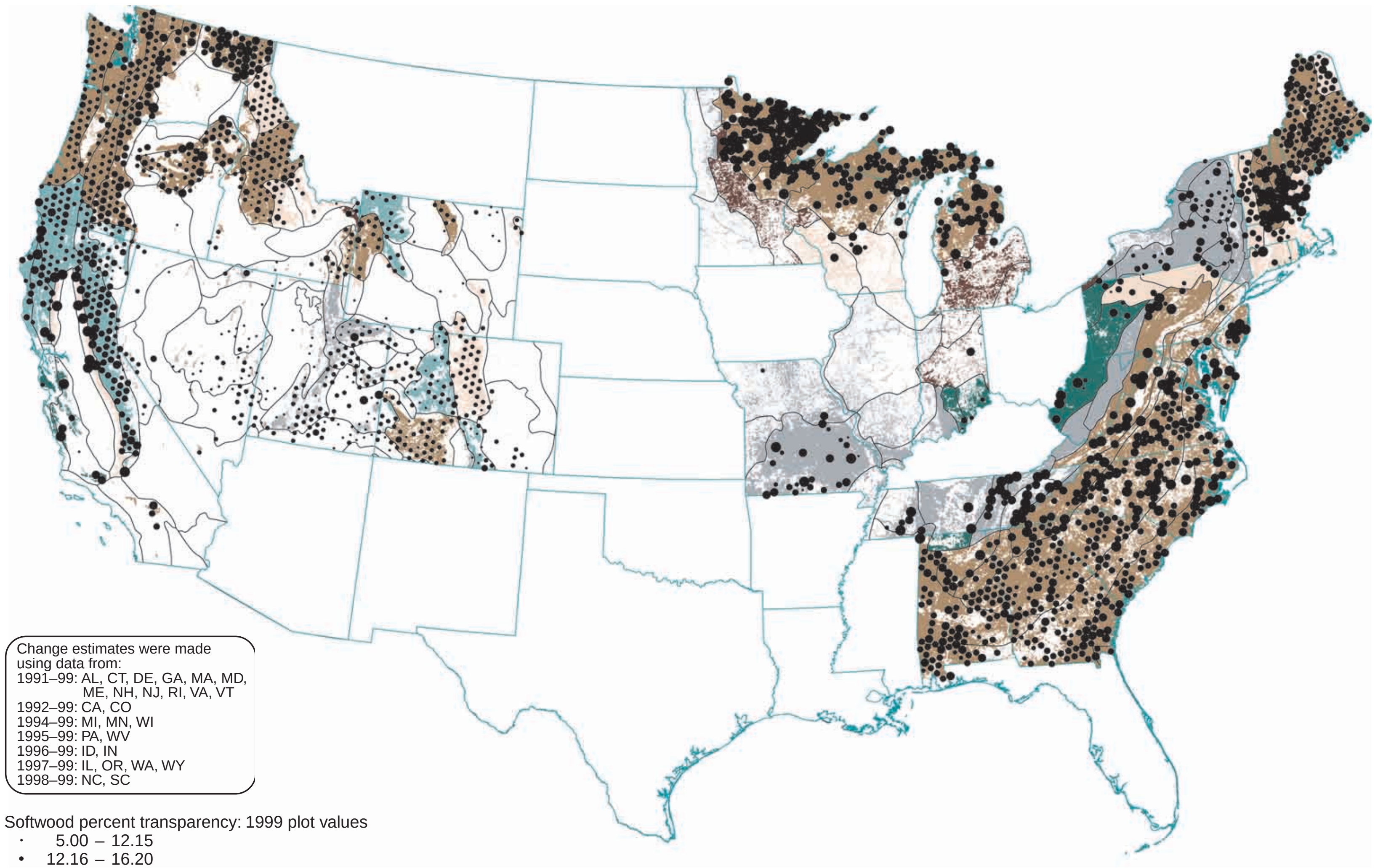

Figure 36—Average change in softwood foliar transparency by ecoregion section (colored polygons) for the period of record in each State. Closed circles show average softwood crown transparency on each Forest Health Monitoring plot in 1999. No estimates of change were made for States with only 1 year of data (MO, NV, NY, TN, UT).

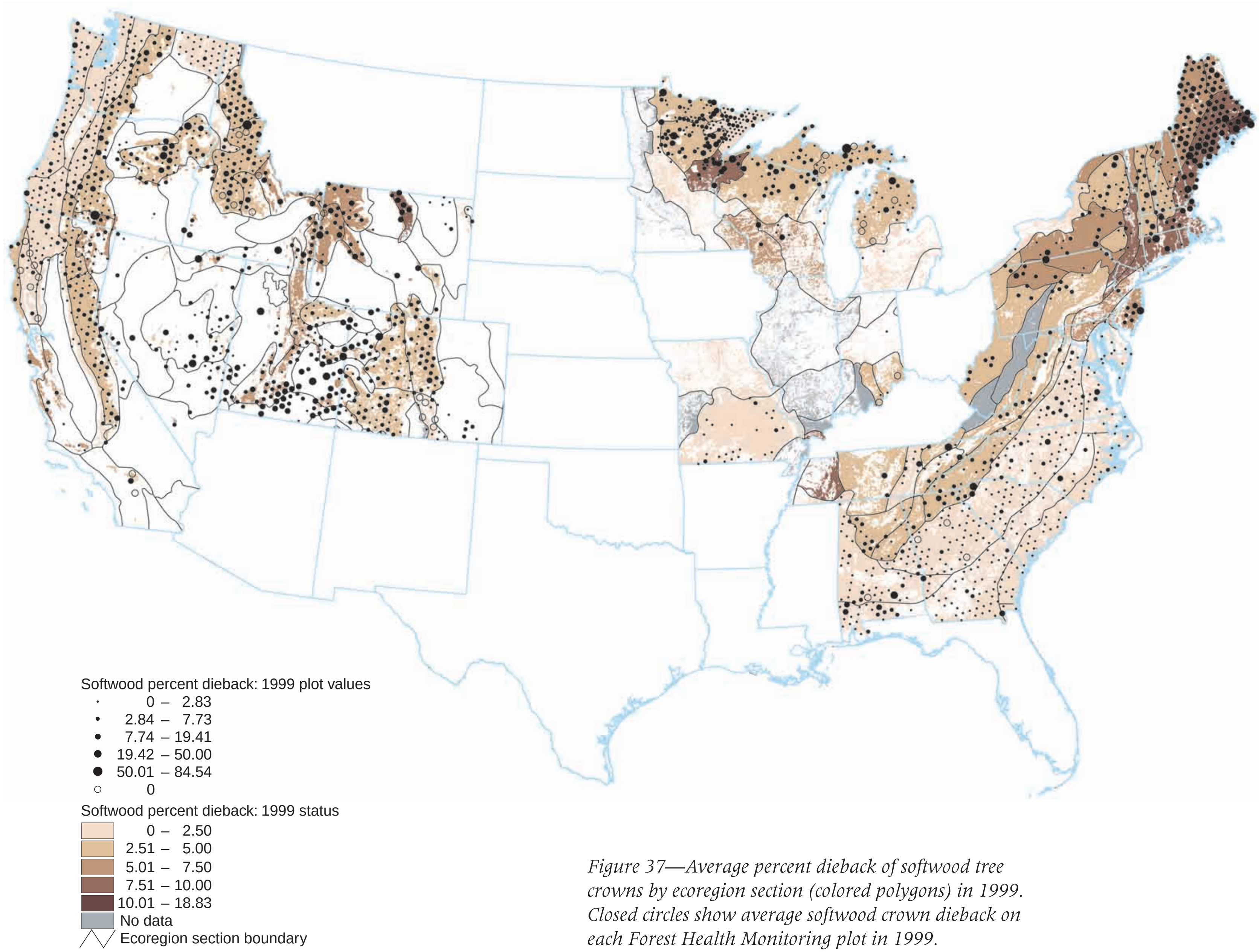

Figure 37—Average percent dieback of softwood tree crowns by ecoregion section (colored polygons) in 1999. Closed circles show average softwood crown dieback on each Forest Health Monitoring plot in 1999.

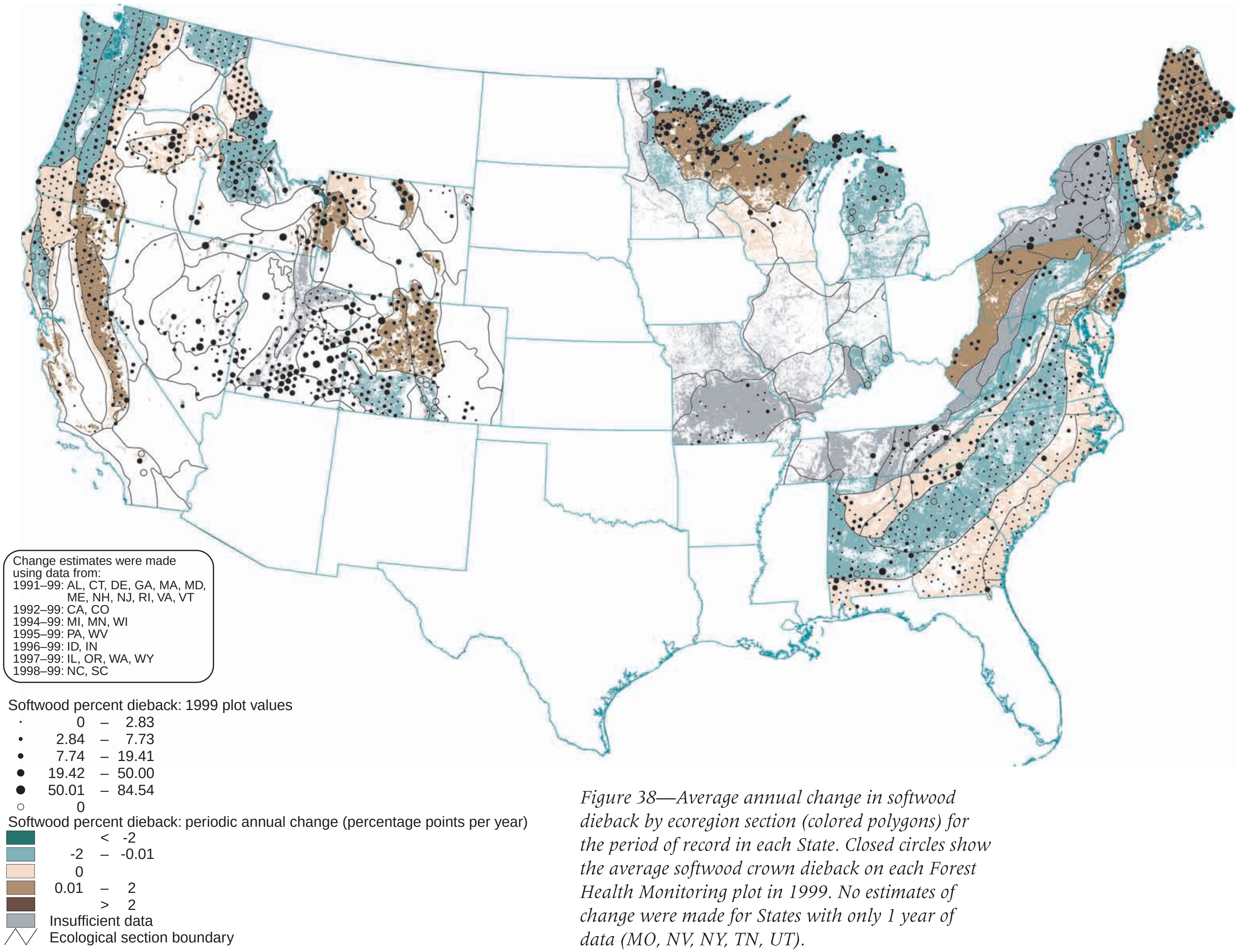

Figure 38—Average annual change in softwood dieback by ecoregion section (colored polygons) for the period of record in each State. Closed circles show the average softwood crown dieback on each Forest Health Monitoring plot in 1999. No estimates of change were made for States with only 1 year of data (MO, NV, NY, TN, UT).

Lowlands, Section 212D—Central Maine Coastal and Interior, Section 221A—Lower New England, and Section 221B—Hudson Valley. Softwood dieback levels were also increasing in all of these sections (fig. 38).

Within the national scope of this report, it was possible to analyze data to detect large-scale patterns in the forest health indicators. However, ecoregion analyses of status and change in crown conditions, such as have been presented here, only serve as a starting point for understanding forest health phenomena. More detailed analysis of FHM data at a regional scale will be needed to learn the implications of these indicators for forest health.

Tree damage—Damage caused by pathogens, insects, storms, and human activities can significantly affect tree growth, reproduction, and mortality. In the field, tree damage is recorded if it is considered serious enough to increase the probability of infection by lethal pathogens (damage such as open wounds or broken branches), premature death (presence of pathogenic conks, cankers, or broken roots), or severely depressed growth and/or reproduction (damage such as high defoliation or broken branches). To be recorded, damages must meet or exceed set thresholds; e.g., open wound > 20-percent bole circumference, > 30 percent of the foliage damaged > 50 percent (Mielke and others 1995). A score of zero does not necessarily mean that a tree is free of disease, storm, or defoliator damage. Insect pests or pathogens may be present on sample plots—and even affecting long-term forest productivity—but will not be recorded unless levels exceed predetermined thresholds. Thus, FHM damage indicators are not appropriate for estimating the extent of insects or pathogens.

A damage severity index (DSI) score was assigned to each damaged tree. The DSI score is determined by three variables: (1) type of damage symptom, (2) location of the damage on the tree, and (3) severity of the damage.[15] Location of injury affects the impact of damage. For example, injury near the base is more serious than injury near the tree's apex, because parts of the crown can be lost without killing the tree. Similarly, some damage symptoms are more serious than others. For example, open wounds may heal if they do not become infected and, therefore, are not as serious as cankers,

[15] Mielke, M.E. 1999. Forest health monitoring damage indicator report. Presented to the Forest Health Monitoring Management Team, May 1999. 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.

Table 5—Sample Damage Severity Index (DSI) look-up table for Damage Severity types 1 and 3 (cankers/galls and wounds)[a]

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

[a] A similar look-up table is available for each damage type.

which are caused by fungi that kill bark and cambium. The severity of the symptom is just an estimate of the area affected. For example, a canker affecting 80 percent of the tree-bole circumference is more serious than a similar canker affecting 30 percent of the circumference. A DSI score was assigned to each damage based on these three variables using a look-up table (table 5). The index value associated with each combination of damage type, location, and severity was determined following several workshops of Federal, State, and university experts in forest pathology and entomology.[16]

FHM field crews recorded information on up to three damages per tree. The DSI scale runs from zero to a theoretical maximum of 300, with zero indicating no damage above the minimum threshold recorded, and 300 indicating three damages of maximum severity. In fact, individual tree DSI scores rarely exceed 90; trees usually die before the damage level gets much higher. Generally, a high damage index indicated multiple damages, severe types of damage, and/or extensive damage occurring near the tree's base. Tree scores were aggregated to plot-level scores (plot-level mean) for hardwoods and softwoods. The mathematical formula for the plot-level DSI is presented in "Appendix A: Supplemental Methods, Tree Damage." For the analysis of tree damage, only the most recent measurement of each forested plot through 1999 was used. The DSI was calculated for each plot and presented on the map as plot values.

Because damage can be either a tree-level or a stand-level phenomenon, and most trees in U.S. forests show no damage (see

[16] Personal communication. 2001. Manfred Mielke, Forest Health Monitoring Specialist, USDA Forest Service, Northeastern Area State and Private Forestry, 1992 Folwell Avenue, St. Paul, MN 55108.

footnote 16), it is difficult to find a meaningful way to quantify damage on an ecoregion section basis. In preliminary analyses the percentage of plots manifesting any damage (DSI > 0) was determined for each ecoregion section (results not shown here). However, this approach potentially would count plots where only one or two trees have relatively minor damage, such as would be found in any relatively healthy forest stand. To exclude those plots and focus instead on plots with higher plot-level DSI scores, a DSI threshold of 15 was selected (see footnote 16). For the plot-level DSI to be 15 or greater, either some trees would have to be very severely damaged, possibly severely enough to cause mortality in the near future, or lower severity damage would have to be widespread on the plot. Either situation would perhaps merit attention, especially if plot-average values were consistently high throughout an ecoregion section. The percentage of plots with DSI scores of 15 or more was calculated for each ecoregion section (figs. 39 and 40).

As with the crown indicator analyses, hardwood damage analysis utilized data from all plots except those having fewer than three hardwood trees > 5 inches d.b.h. and < 10 percent of the basal area in hardwoods, and the softwood damage analysis excluded data from plots having fewer than three softwood trees > 5 inches d.b.h. and < 10 percent of the basal area in softwoods.

Interpreting tree damage and its relationship to forest health is complex because tree damage may be the result of a number of different processes, both deterministic and stochastic. Some of these are anthropogenic, some are part of the natural disturbance regime, and some are natural processes whose impacts have been altered by forest management practices.

Overall damage status is shown in figures 39 and 40. Throughout the eastern half of the United States, as well as in parts of the Pacific Northwest, overall damage levels were low, but there were locations with extremely high damage. The figures show that many areas with the highest amounts of damage were located in the drier areas of the West. The reason for this, at least in part, may be that in such areas severely damaged trees may survive for many years in the forest, while in wetter areas fungal diseases would kill the trees quickly.

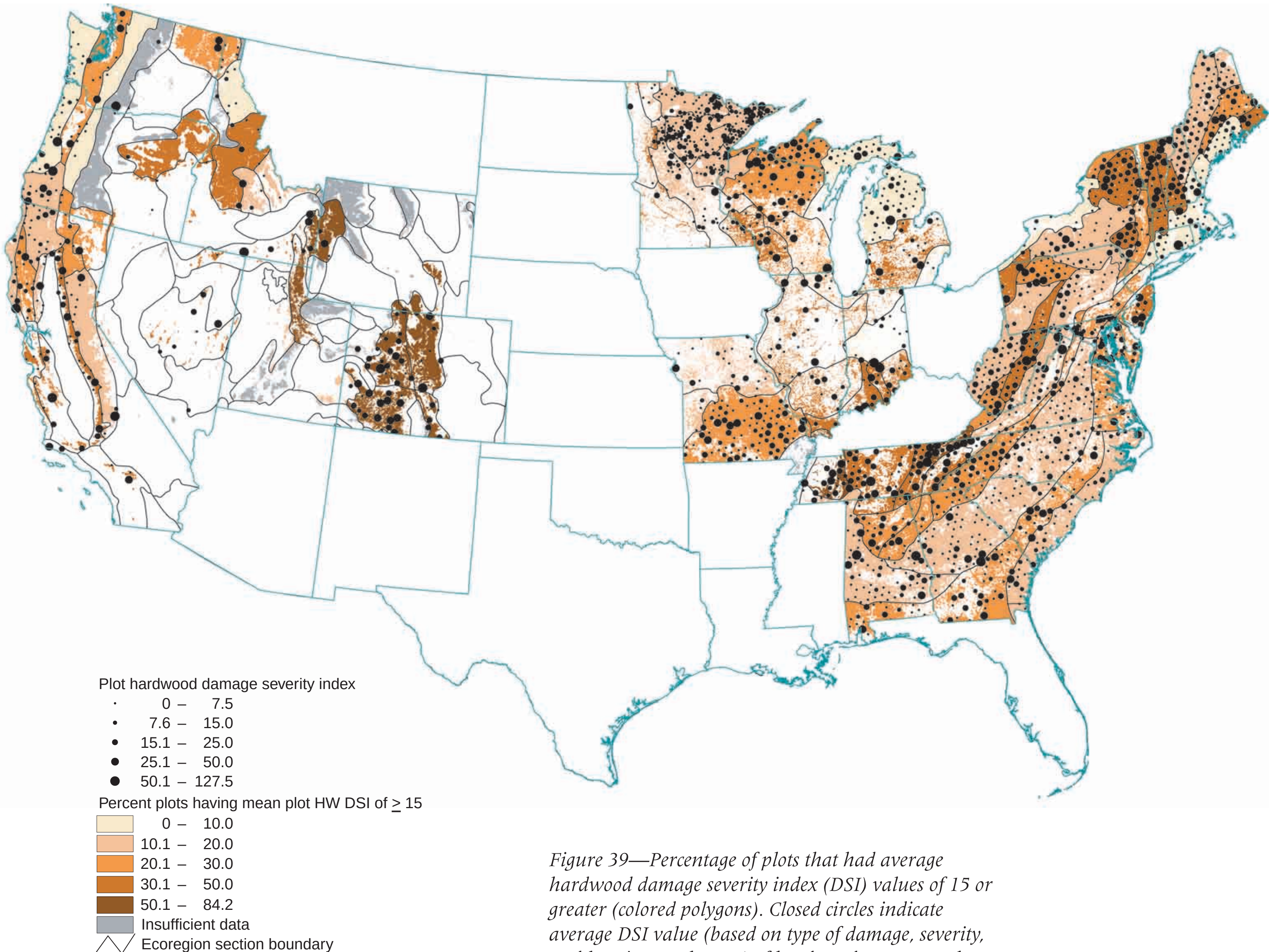

Figure 39—Percentage of plots that had average hardwood damage severity index (DSI) values of 15 or greater (colored polygons). Closed circles indicate average DSI value (based on type of damage, severity, and location on the tree) of hardwood trees on each Forest Health Monitoring plot.

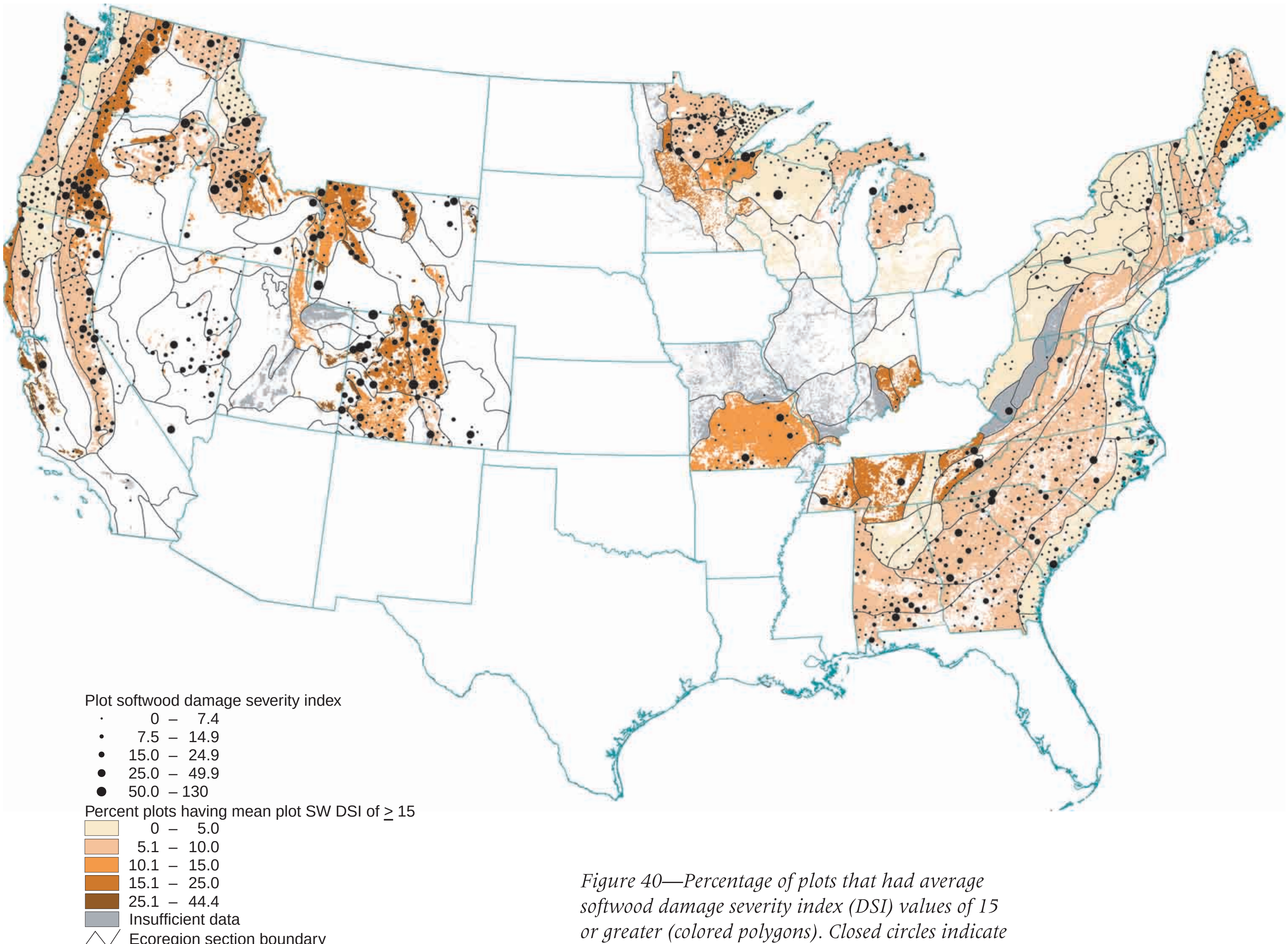

Figure 40—Percentage of plots that had average softwood damage severity index (DSI) values of 15 or greater (colored polygons). Closed circles indicate average DSI value (based on type of damage, severity, and location on the tree) of softwood trees on each Forest Health Monitoring plot.

Appendix tables B.11 and B.12 provide damage summary statistics by ecoregion section. Together with the damage maps, these tables allow the reader to interpret tree damage in ecoregion sections of interest. For example, in Section 231A—Southern Appalachian Piedmont, most plots showed some level of hardwood damage, but only 12.8 percent had a plot-level DSI score > 15. The mean DSI for plots with any damage was 7.74, but maximum plot DSI was 72.41. Although only 13.86 percent of trees were damaged overall, on the worst plot 89.7 percent of trees were damaged. This pattern suggests that the ecoregion section may have been affected by causal agents of a sporadic nature such as storm events or localized insect outbreaks.

Tree mortality—Tree mortality is a natural process in any forest ecosystem. FHM estimates annual mortality in terms of wood volume per acre, based on the trees and saplings that have died since plot establishment. However, because different forest types growing under different conditions grow and die at different rates, mortality volume alone is not a good national measure of forest health. For example, a greater volume may die annually in a healthy southeastern forest 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). An MRATIO value > 1 indicates that mortality exceeds growth, and that live standing volume is actually decreasing. MRATIOs were calculated for each ecoregion section using independently derived gross growth and mortality rates. For details see "Appendix A: Supplemental Methods, Tree Mortality."

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. To further analyze tree mortality, the ratio of the average dead tree diameter to the average live tree diameter (DDLD ratio) was also calculated for each plot where mortality occurred. Low (much < 1) DDLD ratios 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.

Figure 41 shows MRATIO values by ecoregion section, representing annual mortality over the time from the earliest plot establishment in each section through 1999, and the plot values of the DDLD ratio for the most recent plot measurement. Areas of highest mortality relative to growth were apparent in Section 222H—Central Till Plains, Beech-Maple in Illinois; Section 222D—Interior Low Plateau, Shawnee Hills in Indiana; and Section M261B—Northern California Coast Ranges in northwest California. In those sections mortality volume actually exceeded growth volume. Mortality relative to growth also was high (> 0.6 in figure 41) in northern Michigan and Wisconsin (Section 212H—Northern Great Lakes). Similar numbers were calculated for parts of central and eastern Washington and Oregon in Section M242C—Eastern Cascades and Section M332G—Blue Mountains, and for parts of central and eastern Idaho in Section M332A—Idaho Batholith, Section M332F—Challis Volcanics, Section 342B—Northwestern Basin and Range, and Section 342C—Owyhee Uplands.

Appendix table B.13 provides a summary of mortality statistics by ecoregion section. The reader can use these statistics to better understand what is occurring in particular regions of interest. For example, in Section M261B—Northern California Coast Ranges (fig. 41), mortality only occurred on 7 of 15 plots. The MRATIO was high, but so was its standard error, indicating large plot-to-plot variation in mortality relative to growth. DDLD values ranged from 0.243 to 7.018, and total mortality volume on plots that experienced mortality ranged from 1.8 to 4,049.1 cubic feet per acre. These statistics indicate that on some plots very large trees are dying. There are a number of possible causes for this mortality. Past management practices may have produced a large percentage of older stands that are senescing, insects or pathogens may be affecting key tree species, or more generalized stressors may be creating broader forest health problems. More detailed study on a regional scale will be necessary to determine the underlying causes of the mortality.

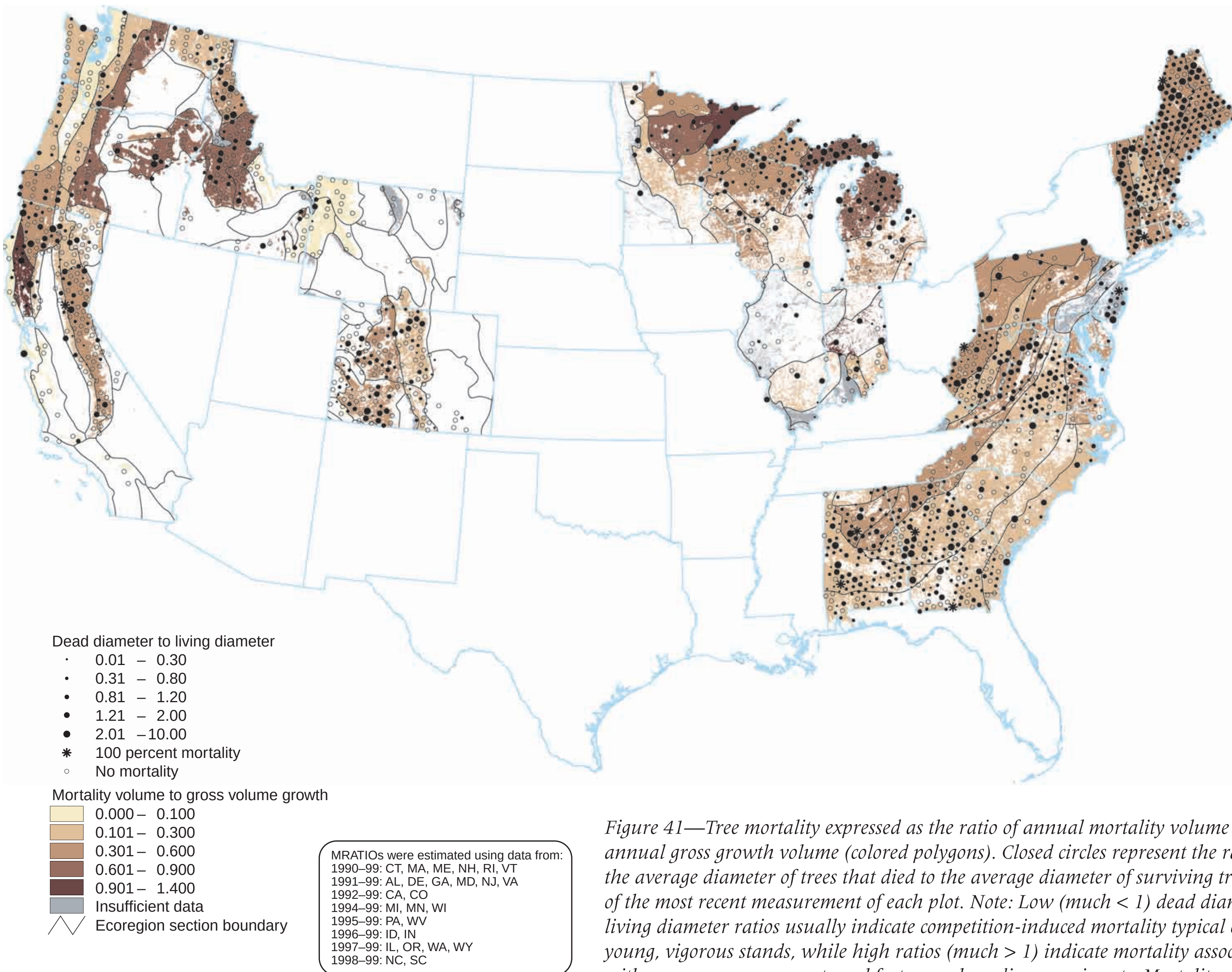

Figure 41—Tree mortality expressed as the ratio of annual mortality volume to annual gross growth volume (colored polygons). Closed circles represent the ratio of the average diameter of trees that died to the average diameter of surviving trees as of the most recent measurement of each plot. Note: Low (much < 1) dead diameter/living diameter ratios 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 disease or insects. Mortality volume/gross volume growth ratios > 1 indicate a decline in standing volume.

Criterion 4—

Conservation of Soil

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BARBARA L. CONKLING

This section addresses three indicators: (1) erosion, (2) chemical properties, and (3) physical properties (soil compaction). For each indicator or indicator group, background information is presented followed by data summaries. Details about individual analyses are given in "Appendix A: Supplemental Methods, Soil Erosion" and "Supplemental Methods, Soil Chemical Properties."

Soil status interests ecologists and forest managers worldwide because soils interact with vegetation, as well as aboveground and belowground microfaunal and microfloral communities, and it can significantly affect water quality in rivers and lakes. A soil's chemical and physical qualities reflect a number of soil-forming factors; e.g., climate, vegetation and soil fauna, relief, parent material, and time, that result in a mosaic of soil types across the landscape. Because of high local and regional variability in soil properties, interpretation of soil chemical data always must be made within the context of the underlying soil type and the soil's position in the landscape (Brady and Weil 1996, Jenny 1941).

Scientists with FHM are currently working with the USDA Forest Service FIA Program and the USDA Natural Resources Conservation Service (NRCS) to develop and prepare the appropriate soil maps and other tools needed to interpret the ground-plot soils information in a manner comparable with that used in reporting on other indicators by ecoregion section. Because this process is not yet complete, physical and chemical soils data are presented as plot-level averages, and erosion and compaction are summarized at both the plot and the subplot level (see "Appendix A: Supplemental Methods, Soil Erosion"). In future reports, soils information will be aggregated in a way such that it can be included in a multivariate analysis such as the one presented later in the section "A Multivariate Analysis of Forest Indicators."

Soil Erosion

Erosion is a term used to describe various forms and mechanisms that wear away the land surface (Brady 1984). Causes of soil erosion include running water, wind, ice, and other geologic processes. There also can be a human influence via management of the plant cover and other kinds of surface disturbance.

The Universal Soil Loss Equation (USLE) commonly has been used to estimate and predict the amount of soil loss based on several factors influencing erosion (Wischmeier and Smith 1965). However, the USLE was developed for cropland, and modifications have been made to adapt the model for use in assessing erosion of forest land, resulting in the Revised Universal Soil Loss Equation (RUSLE) (Dissmeyer and Foster 1981, 1985; Renard and others 1991).

The FHM soils indicator includes data for use in the RUSLE, which is used to estimate soil losses resulting from water erosion. FHM's staff are currently working with NRCS to identify appropriate values for equation factors not collected in the field. Analyses are incomplete, but preliminary results are expected soon. Although potential soil loss could not be calculated for this report, the percent bare soil variable was used to provide a preliminary look at erosion potential, because the amount of bare soil is a subfactor in the multiplicative RUSLE (see "Appendix A: Supplemental Methods, Soil Erosion").

In 1999, 1,131 of the 3,061 subplots evaluated for soils information had at least 1-percent bare soil (37 percent). Most of the subplots with bare soil had between 1 and 10 percent (fig. 42). The 5-percent class far exceeded any other—452 of the 1,131 subplots had greater than trace bare soil recorded (40 percent). The 10-percent class had the second largest number of subplots with 17 percent.

At the plot level, 260 of the 819 plots (32 percent) measured for the soils indicator had > 10-percent bare soil on 1 or more subplots (fig. 43). Fifty-nine plots, or about 7 percent, had at least 1 subplot with 50-percent bare soil or more (fig. 43).

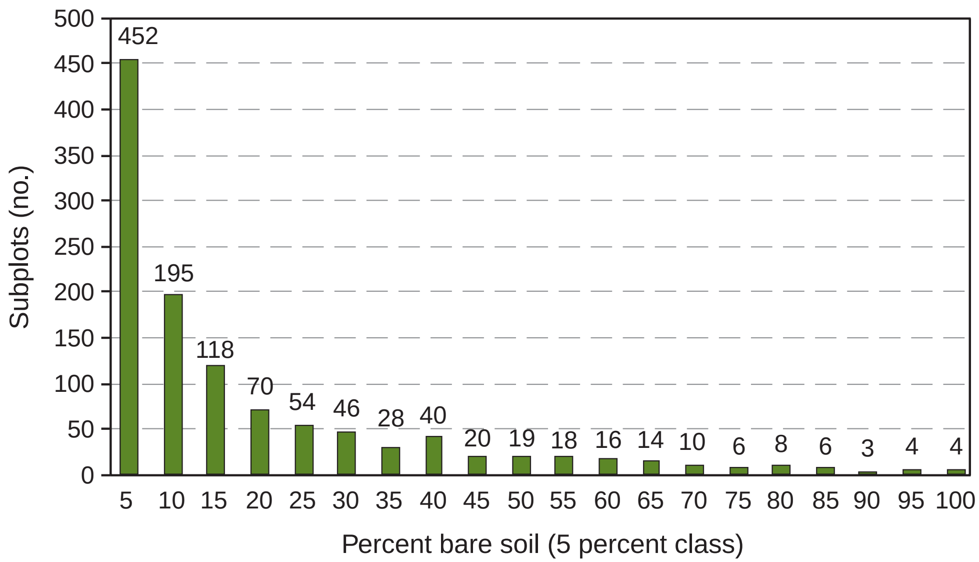

Figure 42—Number of subplots in each 5-percent class of percent bare soil from 1999 data.

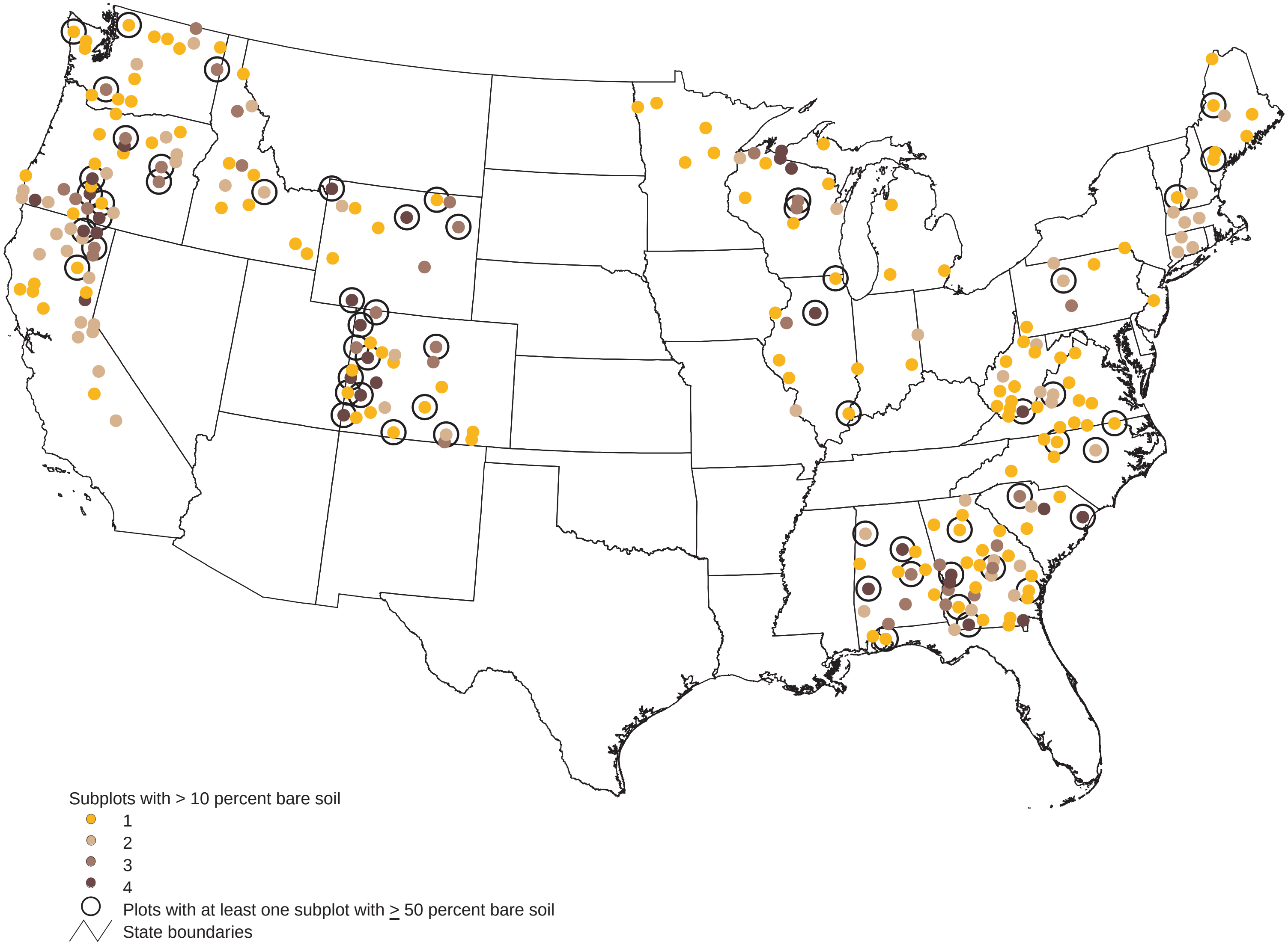

Figure 43—Number of subplots with > 10 percent bare soil, presented by plot for 1999. Open circles indicate that the plot had at least one subplot with 50 percent or more bare soil. States with no plots were not measured for soils in 1999.

Based on the preliminary 1999 data presented in this report, there appears to be low erosion potential on most of the measured plots. Although many plots had bare soil identified on at least one subplot, most subplots had low percent bare soil. Problem areas to evaluate further include plots with a relatively high percentage of bare soil on one or more subplots (fig. 43).

Chemical Properties

pH—By regulating soil nutrient availability, aggregate stability, and microbial activity, soil pH is a primary factor in determining soil fertility. In soils that are poorly buffered against acidic inputs; e.g., from acid deposition or chemical fertilizers, a reduction in pH may mobilize toxic quantities of aluminum and deplete important plant nutrients. Averaged across the United States, mean pH values in the upper mineral horizon in 1998 and 1999 were 5.0±0.9 standard deviation (water) and 4.8±0.8 standard deviation (salt). These values are somewhat lower than those reported in other studies and may be due in part to the use of oven-dried samples for analysis. For this reason, pH data are presented as relative values.

The spatial distribution of soil pH is influenced by a number of different physical and biological factors, including precipitation and vegetation. Generally, soil pH is lower in regions of higher precipitation, such as the Eastern United States and coastal regions of the Pacific Northwest (fig. 44). In those areas, high rainfall tends to leach base cations; e.g., calcium, magnesium, and potassium, from the surface of soil particles, resulting in increased acidity. Conversely, soils in the more arid regions, such the Interior West, tend to have a neutral to slightly alkaline pH.

A soil's ability to withstand changes in pH is related, in part, to its dominant clay mineralogy. Generally, highly weathered clays are less able than less weathered clays to withstand perturbations in pH. For this reason, distribution of strongly acidic soils (> 2 standard deviations below the mean) in the Eastern United States roughly corresponds to the distribution of Ultisols and Spodosols, both of which form on weathered and leached clays. Similarly, a localized region of strongly alkaline soils corresponds to the occurrence of Aridisols, soils with little evidence of a history of weathering or leaching. The Central United States tends to be dominated by partially weathered, near-neutral soils known as Mollisols.

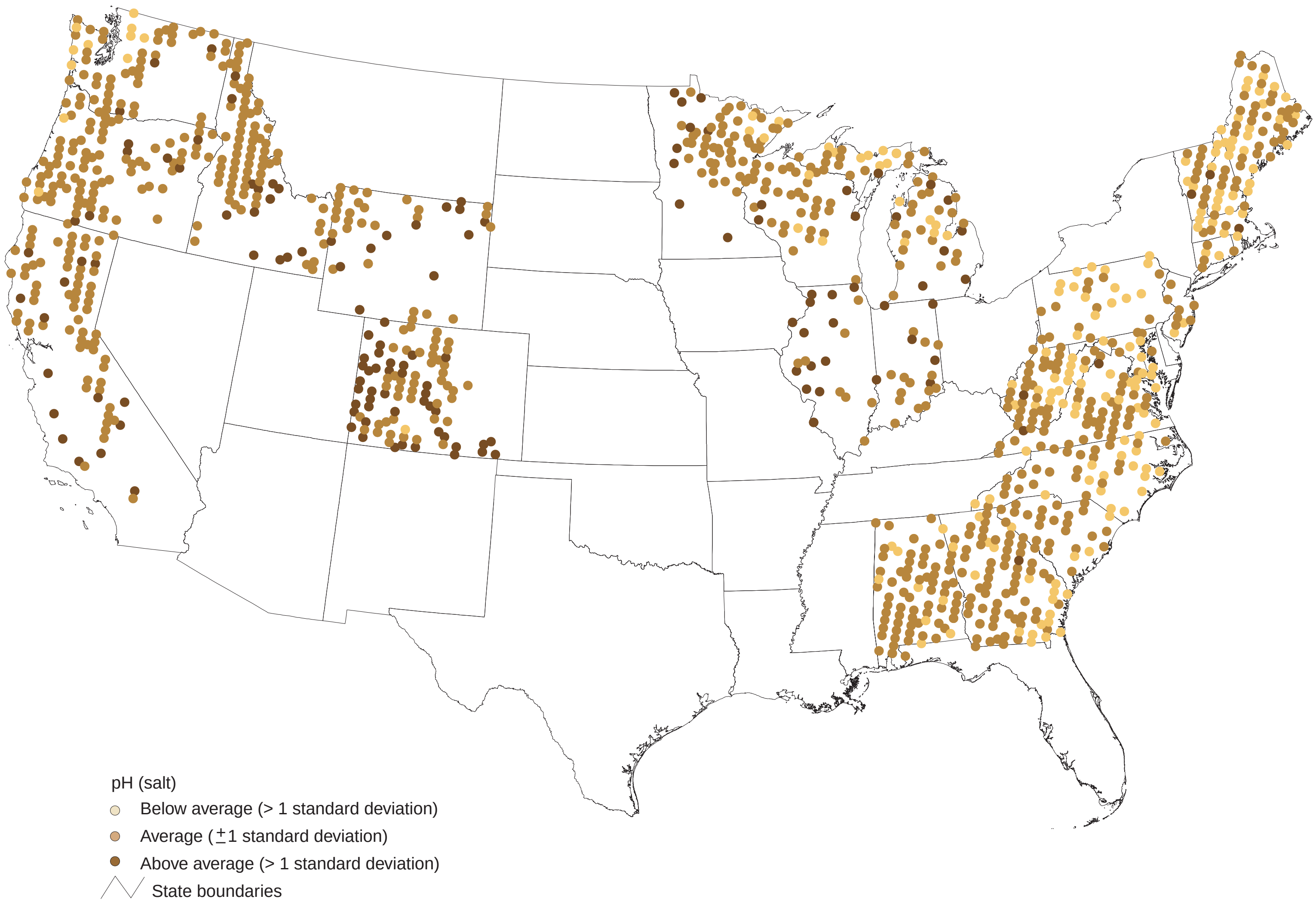

Figure 44—Plot-level salt pH data for 1998 and 1999 presented as values relative to a calculated mean pH averaged across the United States (4.8 ± 0.8 standard deviation).

Table 6—Typical carbon to nitrogen ratios for organic materials

Organic material	C/N ratio
Spruce sawdust	600:1
Hardwood sawdust	400:1
Wheat straw	80:1
Household compost	16:1
Average B horizon	9:1
Soil bacteria	5:1

C/N = carbon to nitrogen.

Nitrogen—Nitrogen (N) is an important component of plant proteins, genetic material (DNA), and chlorophyll. Although the vast majority of plant-available N in terrestrial systems is contained in the soil, the nutrient is frequently a limiting factor for forest productivity. As a result, distribution of N across the landscape is an important indicator of soil fertility and forest health.

For all soils analyzed in 1998 and 1999, the mean percent total N by weight in the forest floor and upper mineral horizons was 1.19±0.49 standard deviation and 0.25±0.19 standard deviation, respectively. Most soil N is contained within organic molecules (soil organic matter typically contains about 5 percent N). Higher N contents in the forest floor reflect greater concentrations of soil organic matter in that horizon. These findings agree with previous research, which suggests that the N content of surface mineral soils generally ranges between 0.02 to 0.5 percent (Brady and Weil 1996).

The spatial distribution of soil N across the landscape closely parallels that of organic carbon (C), with lower N concentrations found in the Southeastern United States and higher concentrations in northern regions (figs. 45 and 46). This pattern is a function of the close association between N and organic C in soil organic matter, as well as the higher rates of decomposition in warmer climates.

Carbon/Nitrogen ratios—Ecologists often use the ratio of organic C/N as an index of litter quality. As soil microorganisms decompose soil C, they withdraw nutrients such as N from the soil. On average, soil microorganisms must incorporate one part of N for every eight parts of C metabolized (C/N ratio of 8:1). As a result, the C/N ratio of organic matter tends to decline as organic material decomposes. Table 6 presents some typical C/N ratios for organic materials.

Averaged across all sites, the mean C/N ratio in the forest floor (31.7±21.3 standard deviation) was higher than in the upper mineral soil (17.3±12.2 standard deviation), reflecting the higher degree of decomposition with increasing depth in the soil profile. The spatial pattern of C/N ratios across the United States generally followed the distribution of organic C, with higher C/N ratios found in areas of higher precipitation, such as the eastern and western coastal regions (fig. 47).

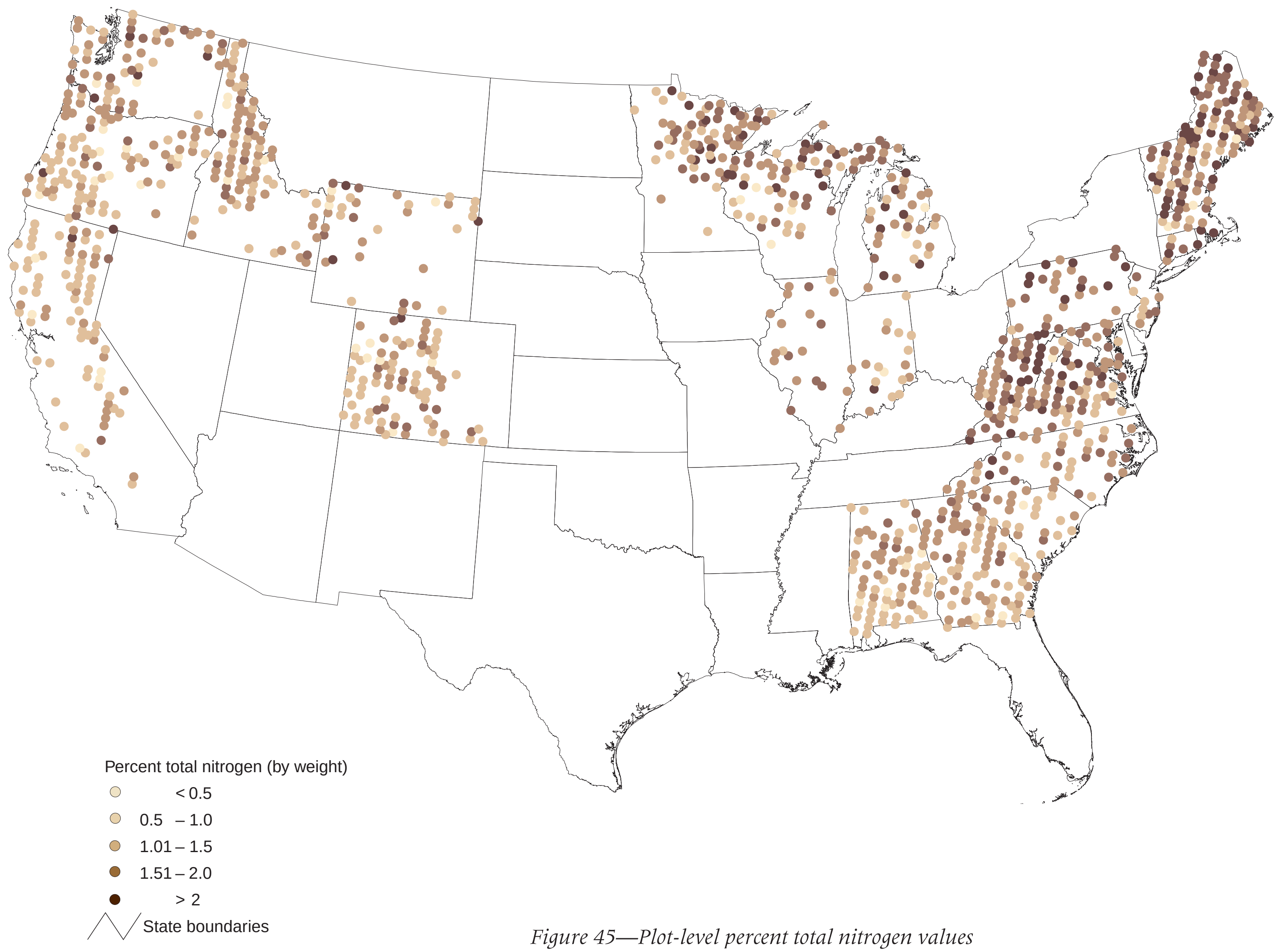

Figure 45—Plot-level percent total nitrogen values for the 1998 and 1999 forest floor samples.

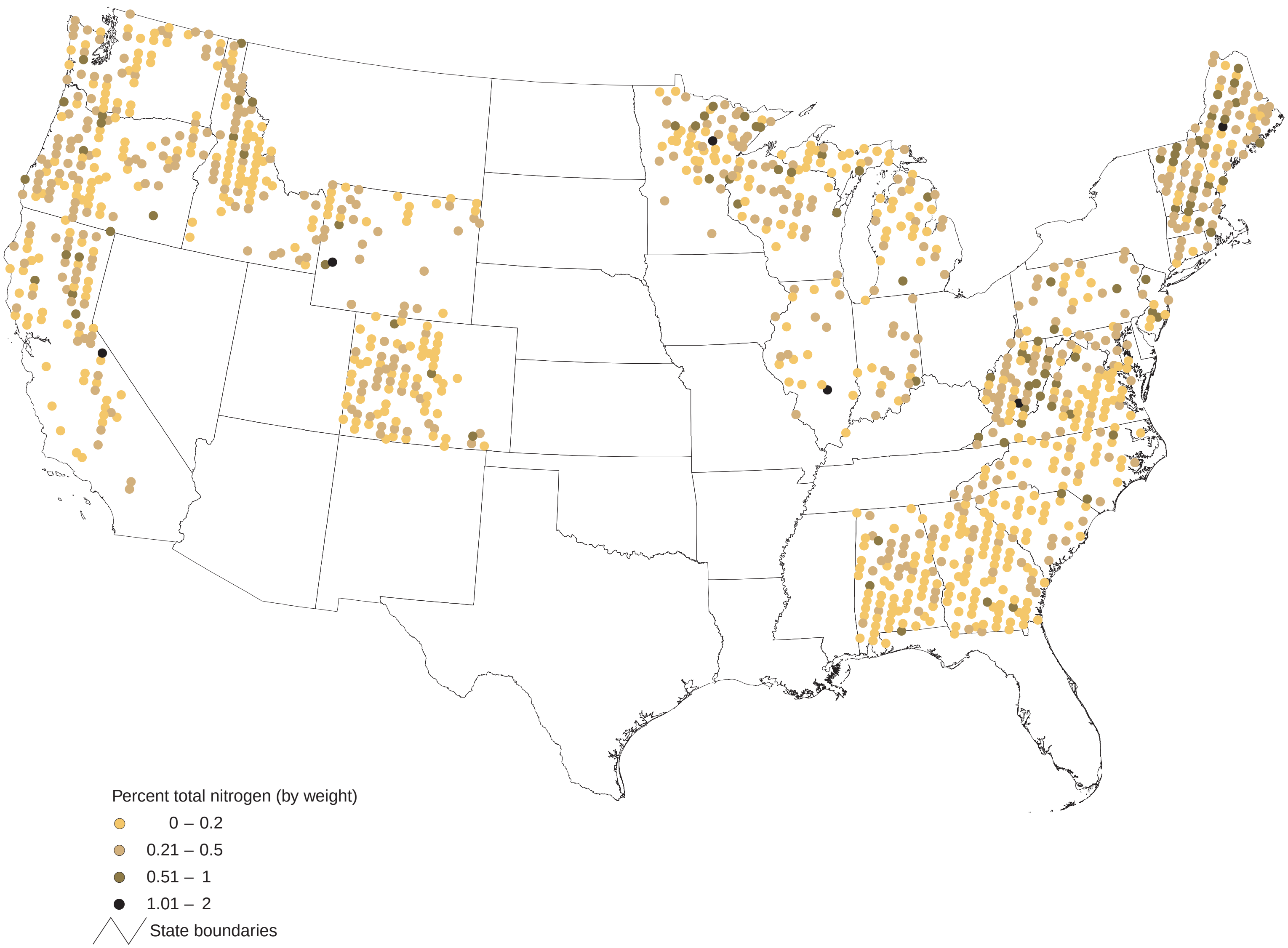

Figure 46—Plot-level percent total nitrogen values for the 1998 and 1999 surface mineral soil samples.

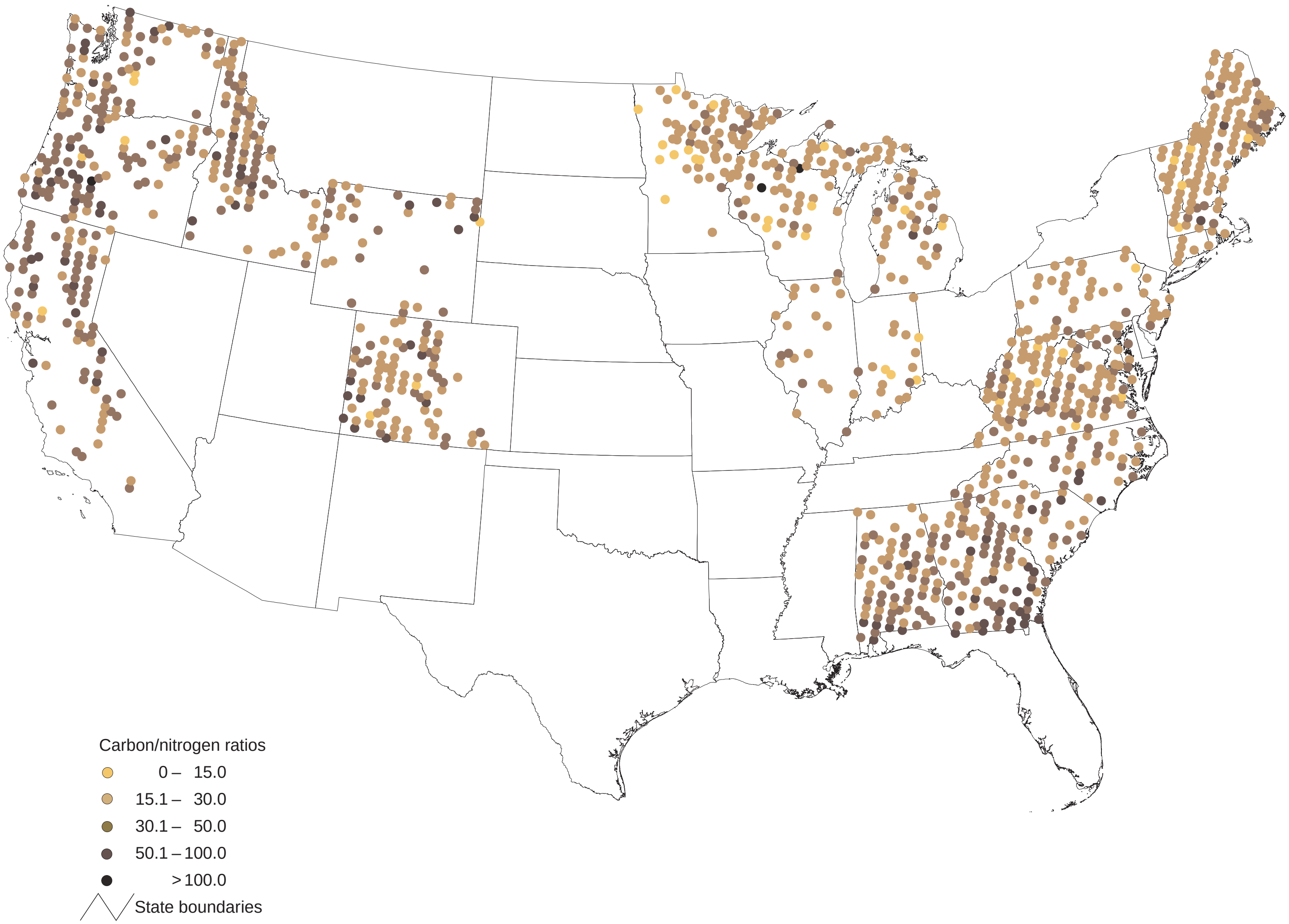

Figure 47—Plot-level carbon/nitrogen ratios for the 1998 and 1999 forest floor samples.

Exchangeable base cations (calcium, magnesium, sodium, and potassium)—Clay minerals and organic matter in the soil function as reservoirs for plant nutrients. Negatively charged sites on the surface of these particles bind with positively charged ions (cations) such as sodium, magnesium, calcium, and potassium. Those cations are not permanently bound to the particle and can be replaced (exchanged) by other cations as the chemistry of the soil solution changes. It is important to recognize that all exchangeable cations are not necessarily available for plant uptake; concentrations of those nutrients in the soil should only be taken as a general index of plant availability.

A soil's ability to retain exchangeable cations (cation exchange capacity) depends on a number of factors, including texture, mineralogy, and pH. Only clays and organic matter carry a net negative charge. As a result, fine-textured soils generally will have a higher capacity to retain soil cations than sandier soils. The mineralogy of the clay particles also is important. Generally, more highly weathered clay minerals have lower cation exchange capacities. As a result, the distribution of base cation concentrations across the landscape may be explained in part by the underlying soil parent material, with highly weathered soils in the Southeast retaining lower levels of base cations than less-weathered soils of the West and upper Midwest (fig. 48).

In addition to parent material, the ability of soil particles to hold and exchange nutrients in many forest soils is highly dependent on pH (fig. 49). As the hydrogen ion concentration in solution increases (pH declines), there is an increased tendency for H^+ to occupy available exchange sites, limiting the capacity of a soil to retain other cations. In the arid regions of the Interior West, this process is reflected in higher concentrations of total base cations found in regions of neutral-to-high pH.

Phosphorus—For both plants and animals, phosphorus (P) plays an essential role in nearly all metabolic processes. It forms a high-energy bond in the organic compound adenosine triphosphate and is a key component of both DNA and cellular membranes. Despite its great importance in plant metabolism, soil P often is bound in forms unavailable for plant uptake, and may become a limiting factor for site productivity.

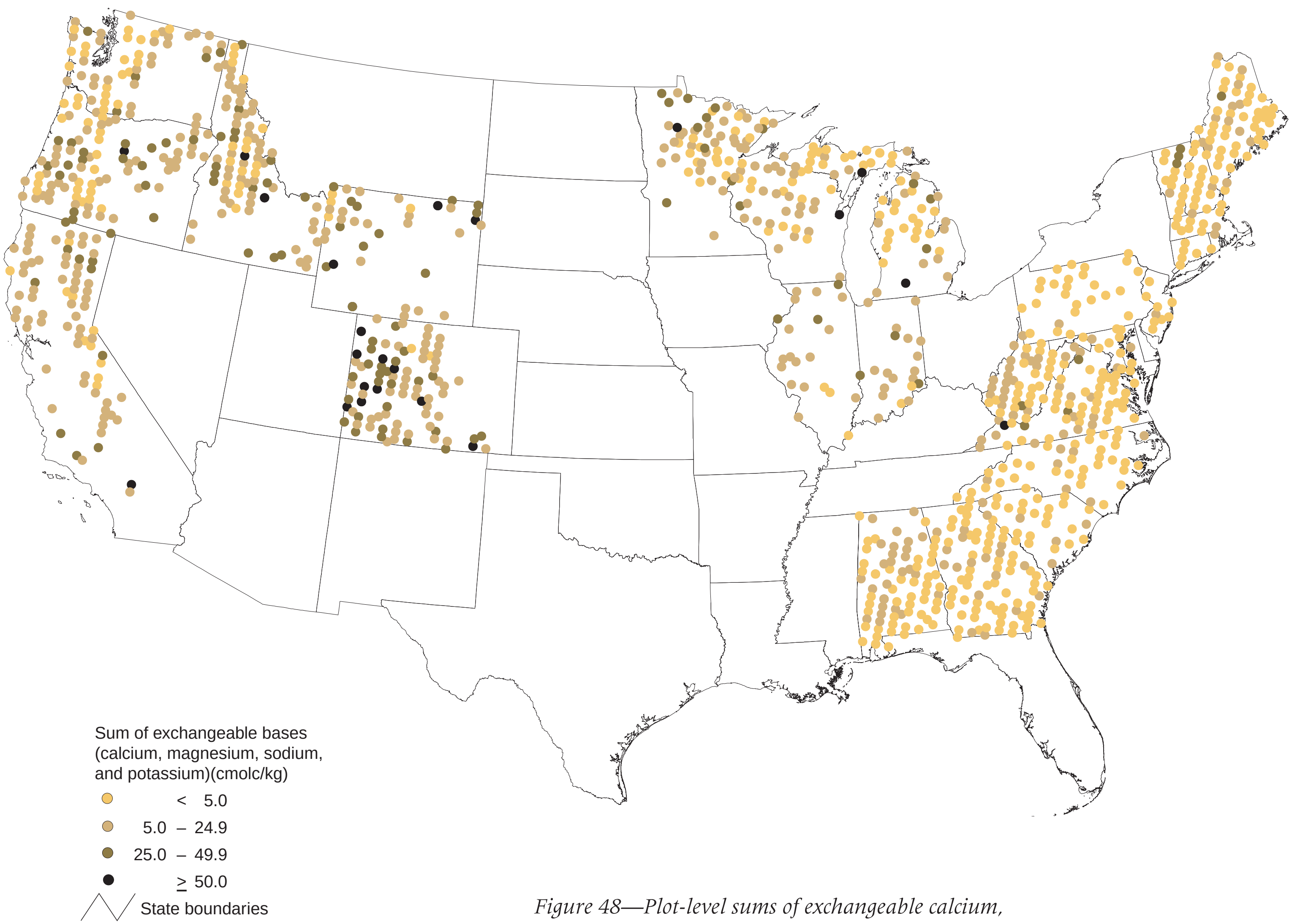

Figure 48—Plot-level sums of exchangeable calcium, magnesium, sodium, and potassium for the 1998 and 1999 surface mineral horizons.

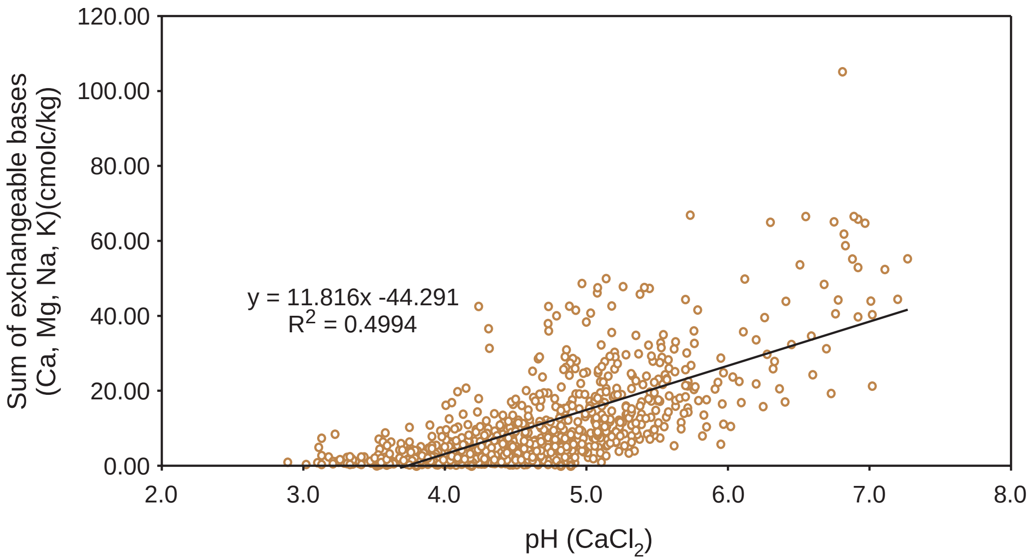

Figure 49—Sum of exchangeable bases (calcium, magnesium, sodium, and potassium) as a function of pH.

Determination of P availability is highly method-dependent. Extractants used in soil P determination estimate a soil's capacity to provide P by dissolving and/or desorbing a particular fraction of the labile P. For 1998 and 1999, the FHM Program extracted all soils with a Bray-1 extractant, which is useful for determining P in acidic soils but can produce erroneously high values in calcareous soils. For this reason, all samples with a pH > 6.5 were excluded from this discussion.

Generally, spatial patterns of extractable P correspond to patterns of nutrient retention. The highest levels are found in the North and the lowest levels in the South (fig. 50). Localized regions of very high P (> 200 mg/kg) in the Pacific Northwest appear to be spatially correlated with volcanic soils (Andisols). However, despite high concentrations, volcanic soils often hold P in forms not readily available to plants.

Soil Compaction

Compaction can have a variety of deleterious effects on soils (Hillel 1980). As soil is compacted, its density increases and its structure can be destroyed (Lenhard 1986). This, in turn, can result in decreased air diffusion and water infiltration and increased runoff and erosion. Root growth may decrease, as well as the roots' ability to absorb water, nutrients, and oxygen. In some soils, compaction can cause puddling, which is the loss of soil structure by particles being dispersed in water and settling to form a dense crust. Compaction also has been found to have varying effects on soil fauna, such as earthworms (Jordan and others 2000).

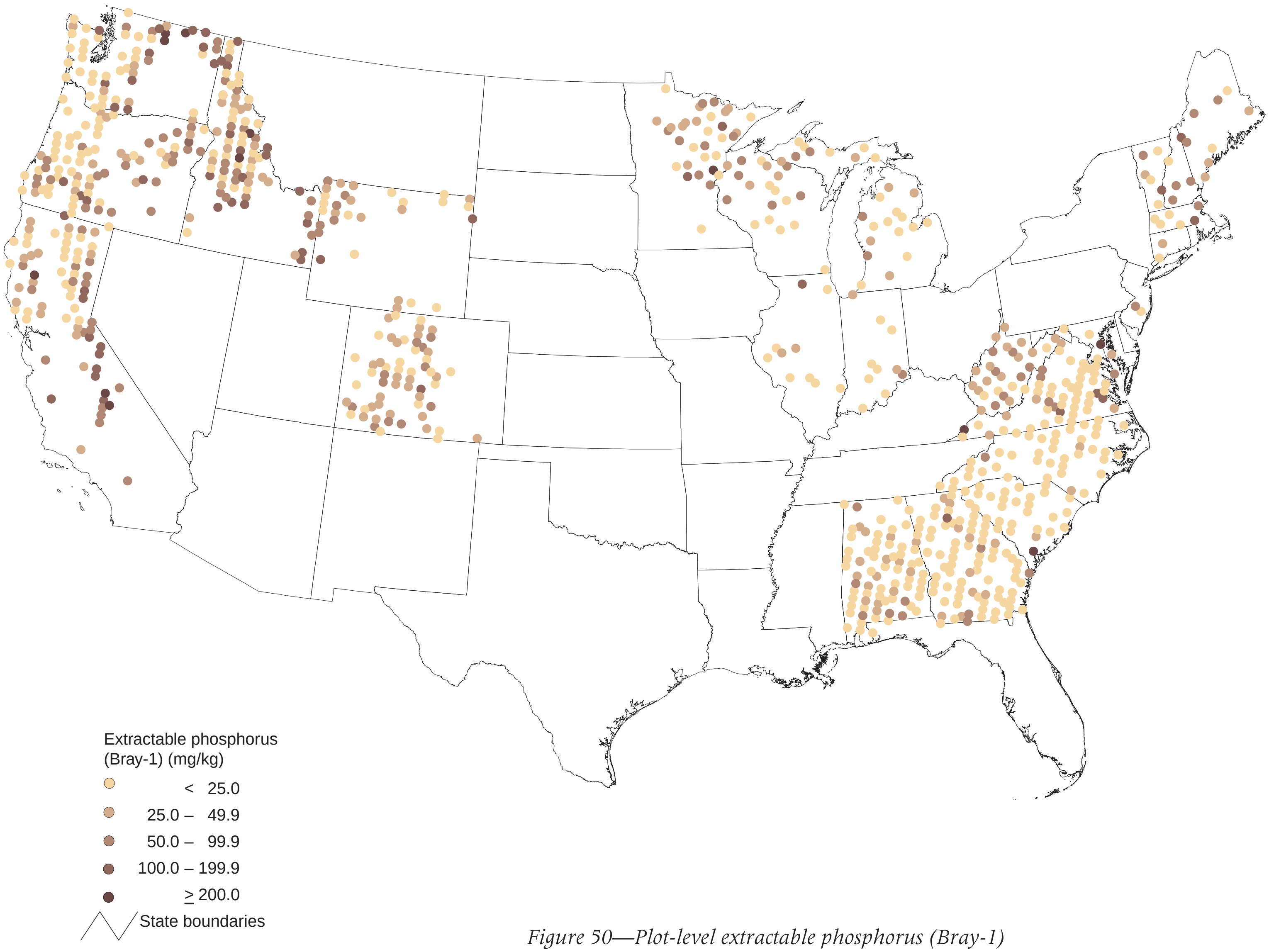

Figure 50—Plot-level extractable phosphorus (Bray-1) for the 1998 and 1999 surface mineral samples.

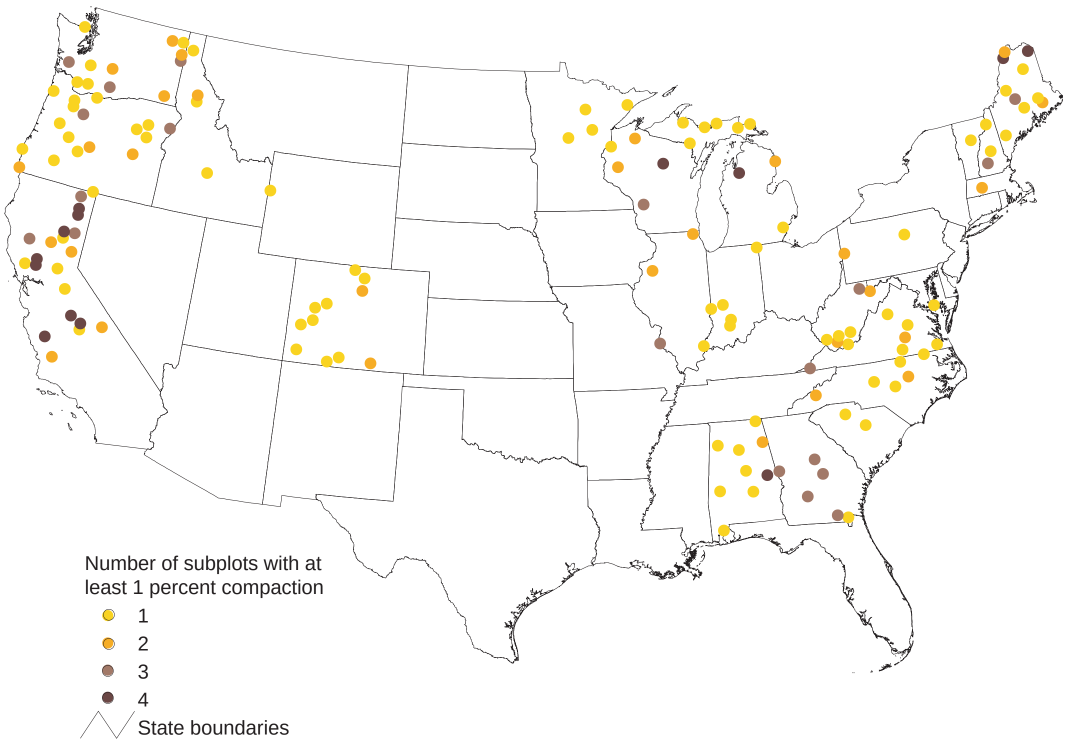

Figure 51—Number of subplots with at least 1 percent compaction, presented by plot, for 1999.

Compaction can negatively effect germination and root growth and contribute to erosion, all potential concerns at locations with compacted soil or increasing soil compaction over time.

In 1999, plots were evaluated for compaction. On each subplot, crews used five main criteria to determine compaction: (1) a change in density from nearby undisturbed soil, (2) presence of coarse platy structure, (3) formation of ruts in the soil, (4) loss of normal structure compared with nearby undisturbed soil, and (5) formation of mottles in the soil.[17] Where they found evidence of compaction, crews estimated the percentage of the subplot with compaction. Finally, the crews described the type or types of compaction.

In 1999, 161 of 819 plots measured for the soils indicator (about 20 percent) showed some evidence of compaction. Plots that had one or more subplots with at least 1 percent compaction are shown in figure 51. The majority of plots with three to four subplots showing compaction were in California.

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[17] 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, Research Triangle Park, NC 27709.

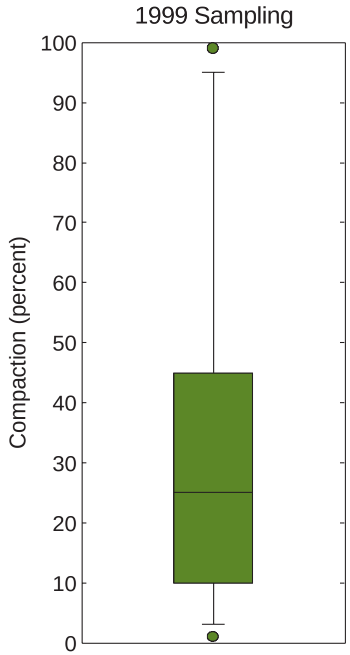

Figure 52—1999 soil compaction subplot data (285 subplots). The 25th and 75th percentiles are shown as a box centered about the 50th percentile; the 10th and 90th percentiles are shown as error bars; and the 5th and 95th percentiles and outliers are shown as points.

A more detailed analysis of compaction data used subplot-level data. Overall, 285 of 3,061 subplots measured (9 percent) showed some evidence of compaction. In subplots with measurable areas of compaction, the compacted area ranged from 1 to 99 percent, with a median of 25 percent (fig. 52). Most of the subplots had only a small area compacted (fig. 53, left side of the histogram). However, on a few subplots (38), most of the area was compacted, as seen on the right side of figure 53. These 38 represent 13 percent of all subplots showing compaction and only about 1 percent of all subplots measured.

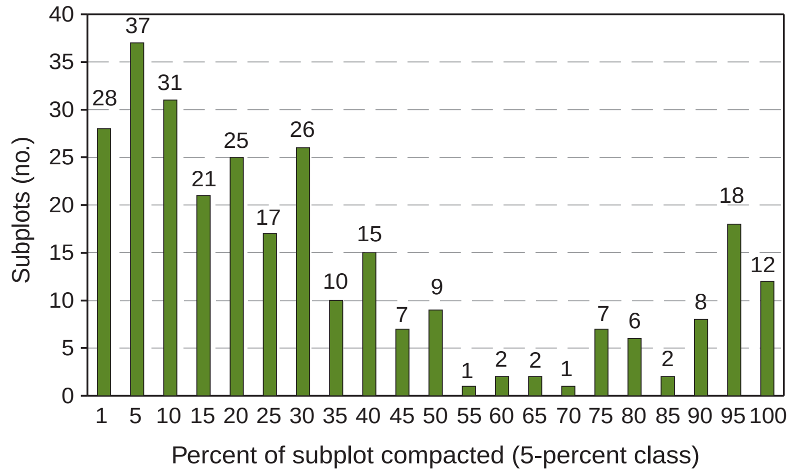

Figure 53—Number of subplots in each 5-percent class of subplot area compacted for 1999.

Most subplots (> 200) with evidence of compaction had one or two evidences (fig. 54). Only one subplot had five different evidences of compaction, and no subplots showed all six possible evidences. Of the six possible evidences, increased density was the most commonly observed, followed by loss of soil structure and presence of ruts (fig. 55). Mottling was the least common.

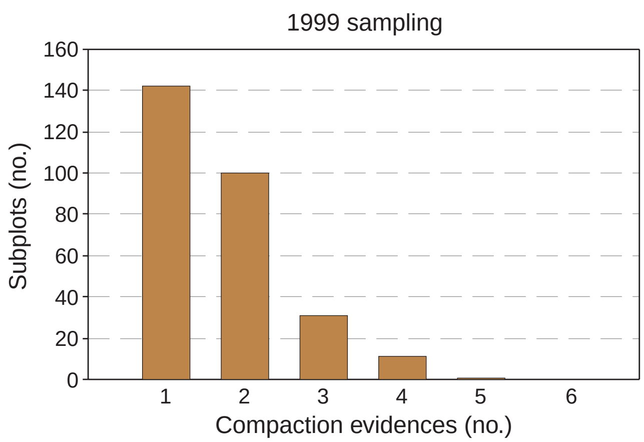

Figure 54—Number of subplots showing one or more evidences of compaction.

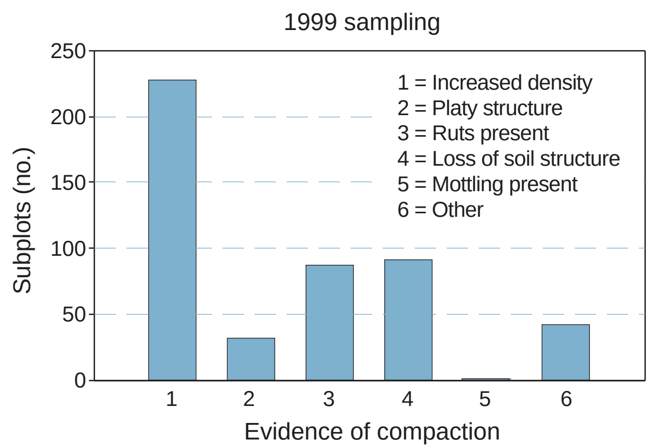

Figure 55—Number of subplots showing each evidence of compaction.

For each subplot where compaction was found, crews identified a compaction type or types to describe its occurrence (fig. 56). Compacted trail was the most common. Although only 1 type was present on most subplots (over 200), 2 or more were identified on > 50 subplots (fig. 57). Evidence of soil compaction was not found on most plots (80 percent). However, continued evaluation is warranted on plots that had more than one evidence and type of compaction on at least one subplot, or where there was compaction on multiple subplots.

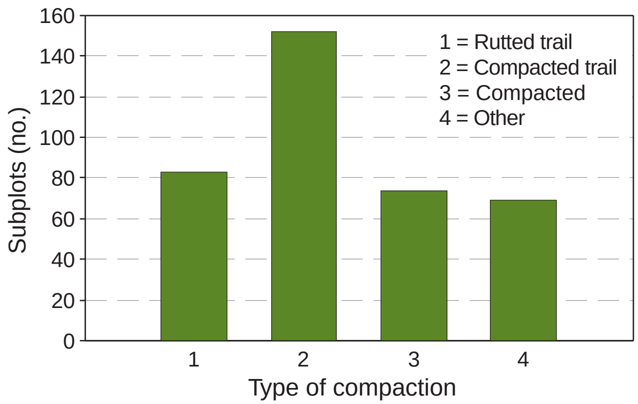

Figure 56—Number of subplots showing each type of compaction.

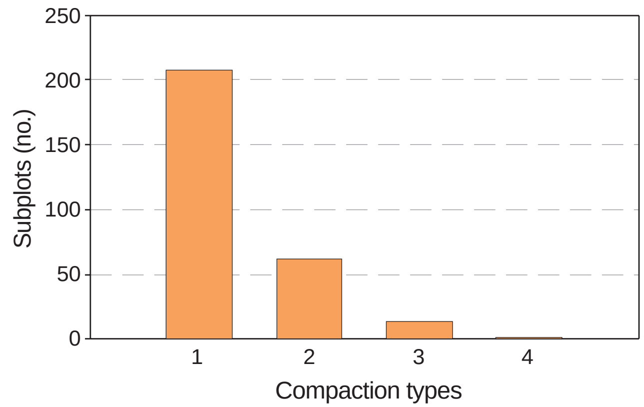

Figure 57—Number of subplots showing one or more types of compaction.

Criterion 5—

Carbon Cycling

MARK J. AMBROSE

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Carbon cycling is an essential process in all ecosystems. Changes in cycling patterns outside of expected variances can reflect major alterations in forest ecosystems. Plants bring C into the biological system by assimilating carbon dioxide (CO_2) from the atmosphere through photosynthesis. C is sequestered in the ecosystem for a time in a variety of forms and ultimately is re-released into the atmosphere through plant and animal respiration and the decomposition of dead organic matter. In forest ecosystems a substantial pool of C is sequestered in woody biomass (aboveground and belowground). Another portion eventually ends up in the upper soil horizons as dead organic matter and is incorporated into soils. Both forest biomass and forest soils serve as large C sinks (C storage) and are, therefore, an essential component of a stable ecosystem.

Sequestration of Atmospheric Carbon in Trees

Carbon storage in forest biomass is an important factor affecting CO_2 concentrations in the atmosphere. In the process of tree growth, C is removed from the atmosphere through photosynthesis. C is returned to the atmosphere either gradually through the decay of dead tree biomass, or rapidly by combustion (forest fires). When wood is harvested, approximately one-half of the C in the woody biomass is stored for long periods as wood products (Birdsey 1996). The exact proportion depends on the efficiency of wood utilization.

The amount of C stored or lost annually from FHM plots was estimated for the time period from FHM plot establishment to 1999, using a multistep process. First, tree bole volumes were determined using height and diameter data from FHM plots and published volume equations (see "Appendix A: Supplemental Methods, Productive Capacity"). Next, stem volume data were converted to estimates of total tree C (aboveground and belowground biomass) using published relationships (Birdsey 1996).

Plot-level estimates of C stored in standing trees were then found and expressed on a per-acre basis. Those estimates included the C associated with all live and standing dead trees and saplings. When a tree was harvested from a plot, approximately half of the biomass of the tree was considered to remain sequestered from the atmosphere (and, for purposes of this analysis, to still be stored in the trees). That one-half represents the proportion of harvested biomass utilized in durable form; e.g., bound books, wooden structures (Birdsey 1996). When a tree dies and falls, the C associated with it no longer is considered part of the C pool stored in the trees.

Using the generalized least squares regression modeling procedure described in "Appendix A: Supplemental Methods, Analysis Using Generalized Least Squares Models," the average annual change in C sequestered in trees (pounds per acre per year) since initial FHM plot establishment was estimated for each ecoregion province. Figure 58 presents the results of this analysis.

Rates of C sequestration generally followed climate gradients. The highest rates were found in those areas with long growing seasons and abundant rainfall, which are favorable for tree growth. Sequestration rates were lower in colder and drier regions. Increases in tree carbon were highest (2,501 to 5,898 pounds per acre per year) in the Willamette Valley and Puget Trough ecoregion of Oregon and Washington, on the California coast, and on the middle and lower Atlantic Coastal Plain of the Southeast. C sequestration was also high (1,501 to 2,500 pounds per acre per year) in the Piedmont and mountain areas of the Southeast and Mid-Atlantic States and in the Cascades and Coast Ranges of Washington and Oregon, as well as in the broadleaf forests of the Midwest (Province 222). The lowest sequestration rates (0 to 500 pounds per acre per year) were found in the desert and semi-desert regions of the West and the Prairie Parkland region (Province 251, including western Minnesota, much of northern and central Illinois, and part of northwestern Indiana). However, in two of these provinces, the Prairie Parkland (Province 251) and the American Semi-Desert and Desert (Province 322) in southeast California, the sequestration rate was not statistically different from 0 (p = 0.33). Therefore, it cannot be said with certainty whether the amount of C sequestered in those ecoregions is increasing, stable, or decreasing. In all the areas with the lowest C sequestration rates, low rainfall limits tree growth, and the natural vegetation is mostly prairie or desert species. In no region analyzed was there found to be a net decrease in C sequestered.

The rate of C sequestration is a function of the inherent site quality (abundant moisture, natural fertility, and moderate rainfall) and intensity of forest management (Burns and Honkala 1990). Net gains in the C sequestered by trees are the result of increasing stand volume, efficient utilization of harvested trees, and salvage of mortality, or some combination thereof. The highest rates of C sequestration were found in regions where site conditions most favored tree growth and where relatively large areas of forest are under intensive management. For example, plantations occupy approximately 17 and 19 percent of the forest area in the Pacific Northwest and Southeast, respectively, areas where C sequestration is highest. This compares to 1 to 4 percent in other areas.

The preceding analysis considers only the pool of C stored in trees (including durable wood products). When a dead tree falls, the C associated with it is no longer considered part of that C pool. Some C rapidly enters the pool of

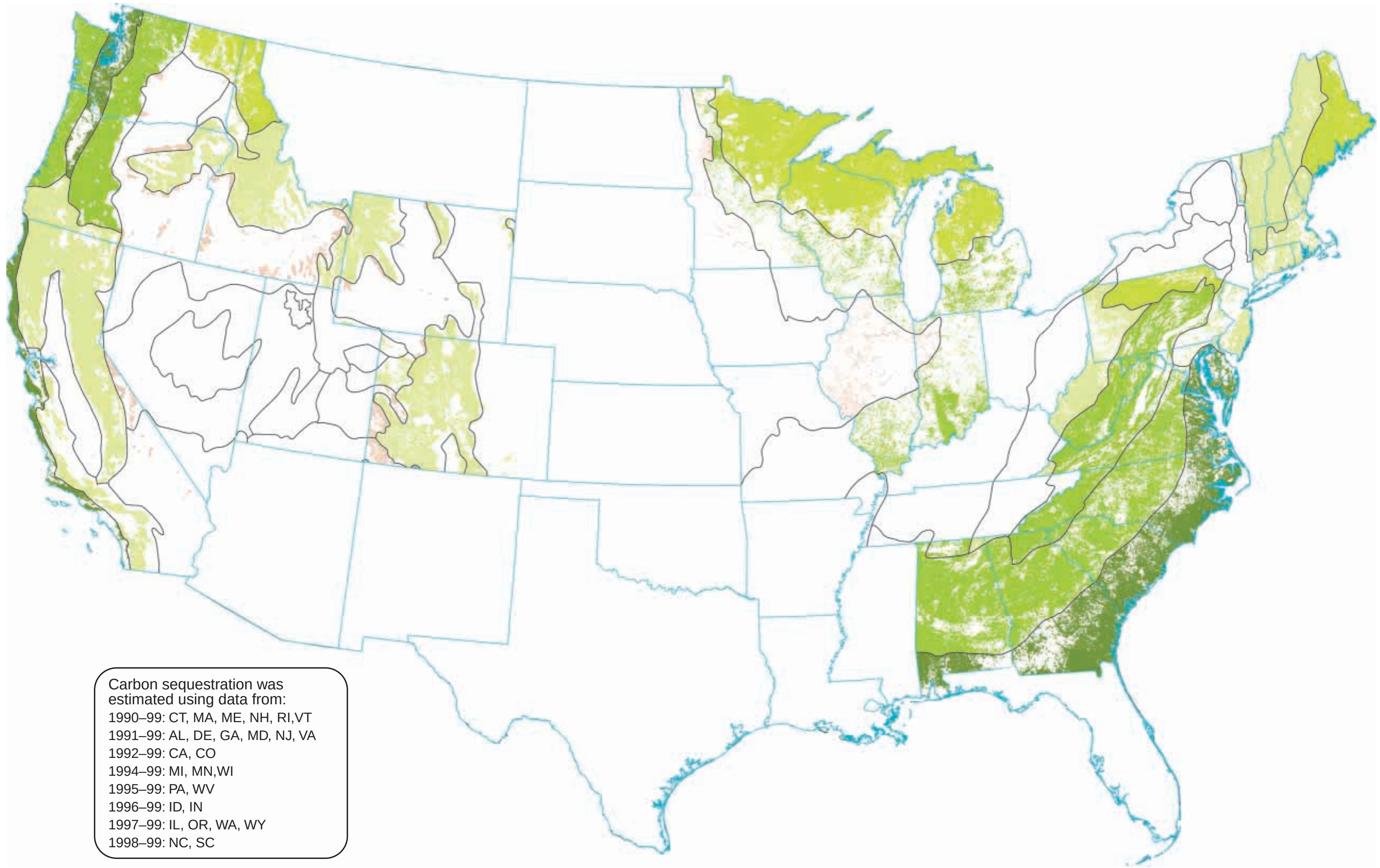

Figure 58—Annual change in carbon sequestered in tree biomass (pounds per acre per year) by ecoregion province. Values represent the estimated amount of carbon sequestered in living and standing dead trees, as well as wood and paper products made from harvested trees. Carbon values are estimated from growth, mortality, and harvest data from Forest Health Monitoring plots and published relationships regarding carbon pools (Birdsey 1996).

soil C, and another portion remains for some time on the forest floor as down woody debris. An analysis of soil C is provided in the next section of this report. Through 1999, FHM had insufficient data to adequately estimate the amount of C found on the forest floor in the form of woody debris. However, once the FIA phase 3 down woody debris indicator is fully implemented, it will be possible to estimate the amount of C stored on the forest floor and to produce more complete forest C budgets.

Soil Carbon

Soil organic matter (SOM) is an important indicator of forest health because of its importance as a regulator of soil chemical, biological, and physical properties. Organic matter aids in the transport of air and water through the soil by increasing moisture-holding capacity and promoting the development of soil aggregates. In addition, SOM contains large numbers of exchange sites that increase the soil's nutrient-holding capacity (cation exchange capacity). In highly weathered soils, such as those typical of the Southeast, SOM may provide the dominant reservoir for soil nutrients.

Soils also are the largest terrestrial reservoir for C and are estimated to contain more C than the atmosphere itself (Schlesinger 1995). As concern about possible climatic responses to increased CO_2 emissions grows, an improved understanding of the capacity of forested systems to sequester C in soils will continue to be critical when developing national policy initiatives.

The amount of C stored in the soil at any time represents the long-term balance between C inputs (from litter and roots) and C losses (by decomposition, fire, erosion, etc.). As a result, spatial patterns of organic C accumulation in forests tend to be strongly correlated with gradients of climate and vegetation. Generally, greater C concentrations in both the forest floor (fig. 59) and upper mineral soil (data not shown) were found in regions of high precipitation and low temperature, such as the Northern and Northeastern United States. Mean C concentrations in upper mineral horizons (4.2±3.8 standard deviation) were significantly lower than those of organic horizons (34.8±10.9 standard deviation), reflecting a higher degree of decomposition with depth in the soil profile.

With the addition of bulk density measurements to the soils protocol in 2000, future analyses will include C per unit volume. This will be an important addition to the soil C information.

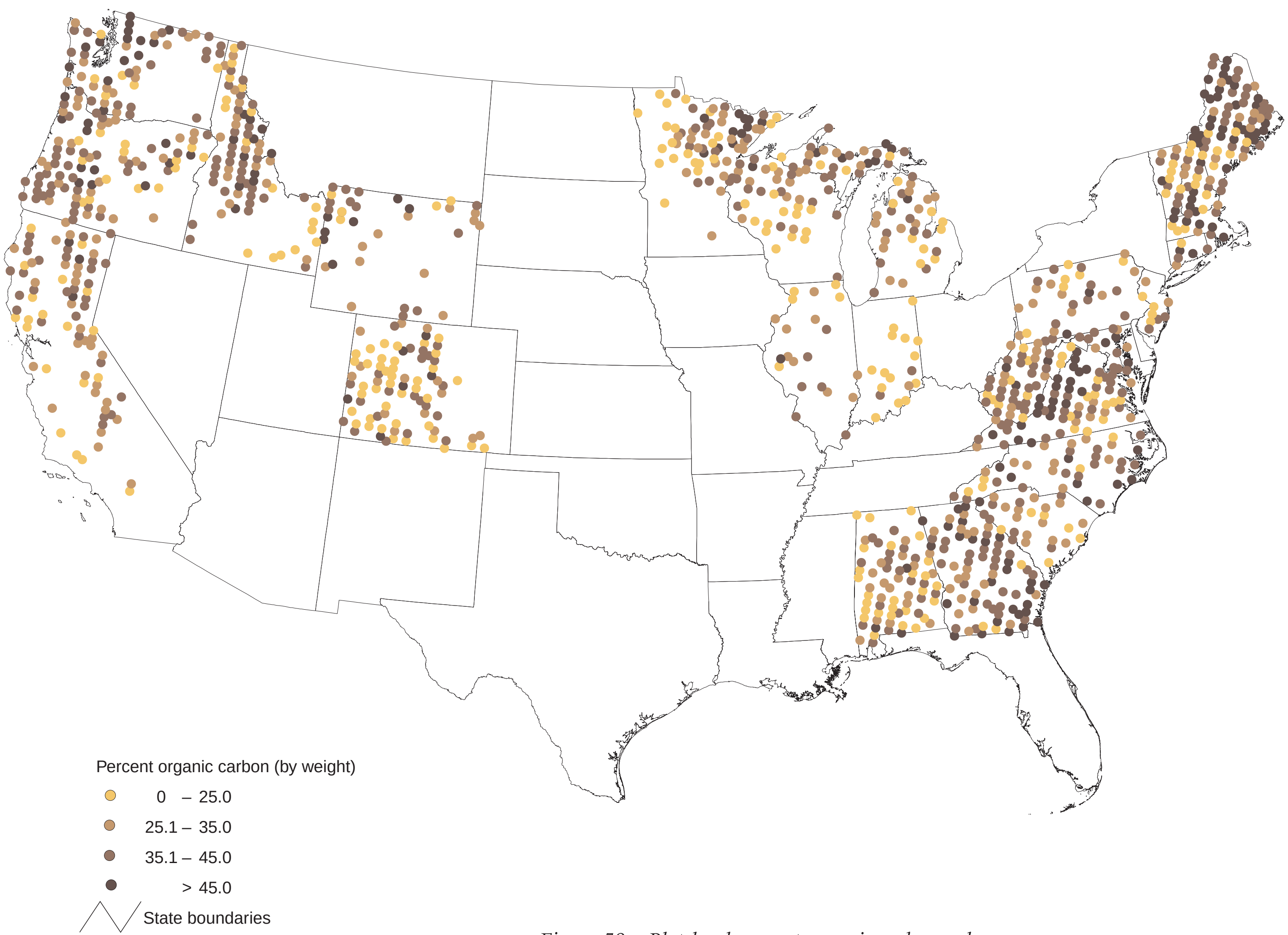

Figure 59—Plot-level percent organic carbon values for the 1998 and 1999 forest floor samples.

A Multivariate Analysis of Forest Indicators

John W. Coulston

Kurt H. Riitters

The main body of this report addressed individual indicators with only some discussion of possible relationships among them. While an integrated assessment of forest health indicators in relation to all possible causal agents is beyond the scope of this report,[18] this section presents a statistical summary of indicators as a first step towards the biological interpretation of the data. Multivariate statistical methods are used to condense information from all indicators into fewer statistical composite indicators, and the composite indicators are estimated for ecoregion sections where all measurements have been made. Maps of ecoregion section values are presented to help visualize the continental-scale patterns of forest health indicators.

Principal components analysis (PCA), e.g., Johnson and Wichern (1982), is a standard multivariate technique used for data reduction and interpretation. It often reveals underlying relationships and enables interpretations that otherwise would not be noticed. Thirty-two indicators for 59 ecoregion sections were used. The 32 indicators contain information about drought, insects and pathogens, fire condition class, crown condition, air pollution, tree species richness, growth, mortality, fragmentation, and C sequestration. The 59 ecoregion sections cover most of the forested area in the United States and were selected because all indicator data were available for those areas.

[18] The purpose of this report is to characterize ecoregion sections in terms of forest condition as measured by the indicators of sustainability. In addition to this report, the FHM Program produces periodic interpretive reports to address the causes and consequences of observed conditions.

Ecoregion section values for each indicator were standardized to a mean of zero and variance of 1. A PCA then was performed on the standardized indicators, and the resulting component axes were orthogonally rotated to help interpret the principal axes of indicator state space. The final axes represent independent factors (or 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 factor, and so each factor can be interpreted in terms of the specific indicators that have high loadings with that factor. In addition, for each factor, a factor score can be calculated for each ecoregion section that represents the value of that composite indicator for each ecoregion section. Details of the computations are contained in standard statistical textbooks, e.g., Johnson and Wichern (1982).

The analysis identified nine significant principal components (appendix table B.14). Taken together, these components accounted for 80 percent of the total covariance among indicators for the 59 ecoregion sections. As a result, the original 32 indicators could be consolidated into 9 independent principal components to explain 80 percent of the original covariance; i.e., the 9 components contain 80 percent of the information contained in the original 32 variables. Appendix table B.14 shows the correlations of each original indicator with each component after orthogonal rotation; each component has been interpreted in terms of the indicators that have high correlations with each component.

The fact that there were nine principal components was good because it indicates that statistically at least nine indicators are not redundant. This is not the same as saying that only nine indicators are important; some correlated indicators may have different biological interpretations, or may be required for other purposes. But for a purely statistical summary, it is easier to consider 9 independent composite indicators than 32 separate indicators that may or may not be independent.

Factor 1 explained 24.6 percent of the total sample variance. Because air pollution indicators such as hydrogen deposition, ammonium deposition, nitrate deposition, sulfate deposition, and rainfall pH had the greatest correlations with it (appendix table B.14), factor 1 was interpreted as a composite indicator of air pollution variables. As expected, the sign of the loading for rainfall pH was opposite that of the deposition variables. Figure 60 displays the factor 1 scores for each ecoregion section and is a spatial representation of factor 1. Ecoregion sections in the North and North Central FHM regions had the highest scores (more air pollution), the South region had moderate scores, and ecoregion sections in the West Coast and Interior West had the lowest scores.

While factor 1 was mostly a function of air pollution variables, the ozone bioindicator variable also had its greatest loading in factor 1 (appendix table B.14). There was more ozone bioindicator plant damage in areas of relatively high ion deposition pollution. But because ozone plant damage comes from ozone, not acid rain, this means that ozone concentration and ion deposition must be spatially correlated also. Tree species diversity also had its greatest loading in factor 1 (appendix table B.14).

Factors 2 and 3 were composites of the forest fragmentation indicators and will therefore be discussed together. Together they accounted for about 24 percent of the total sample variance. Average percent forest, forest connectivity, and area-weighted average patch size had the highest loadings for factor 2, whereas forest edge, number of forest patches, and landcover texture were most important for factor 3 (appendix table B.14). No single fragmentation measure had high loadings on both factors, and no other factor contained a high loading for any fragmentation measure. This means that factors 2 and 3 summarize two independent pieces of fragmentation information, and that other factors (1, and 4 through 9) can be interpreted without any confounding by fragmentation differences.

Factor 2 is easily interpreted as a measure of the absolute amount of forest in an average landscape within an ecoregion section (recall that all fragmentation measures were calculated within small landscapes and then aggregated to

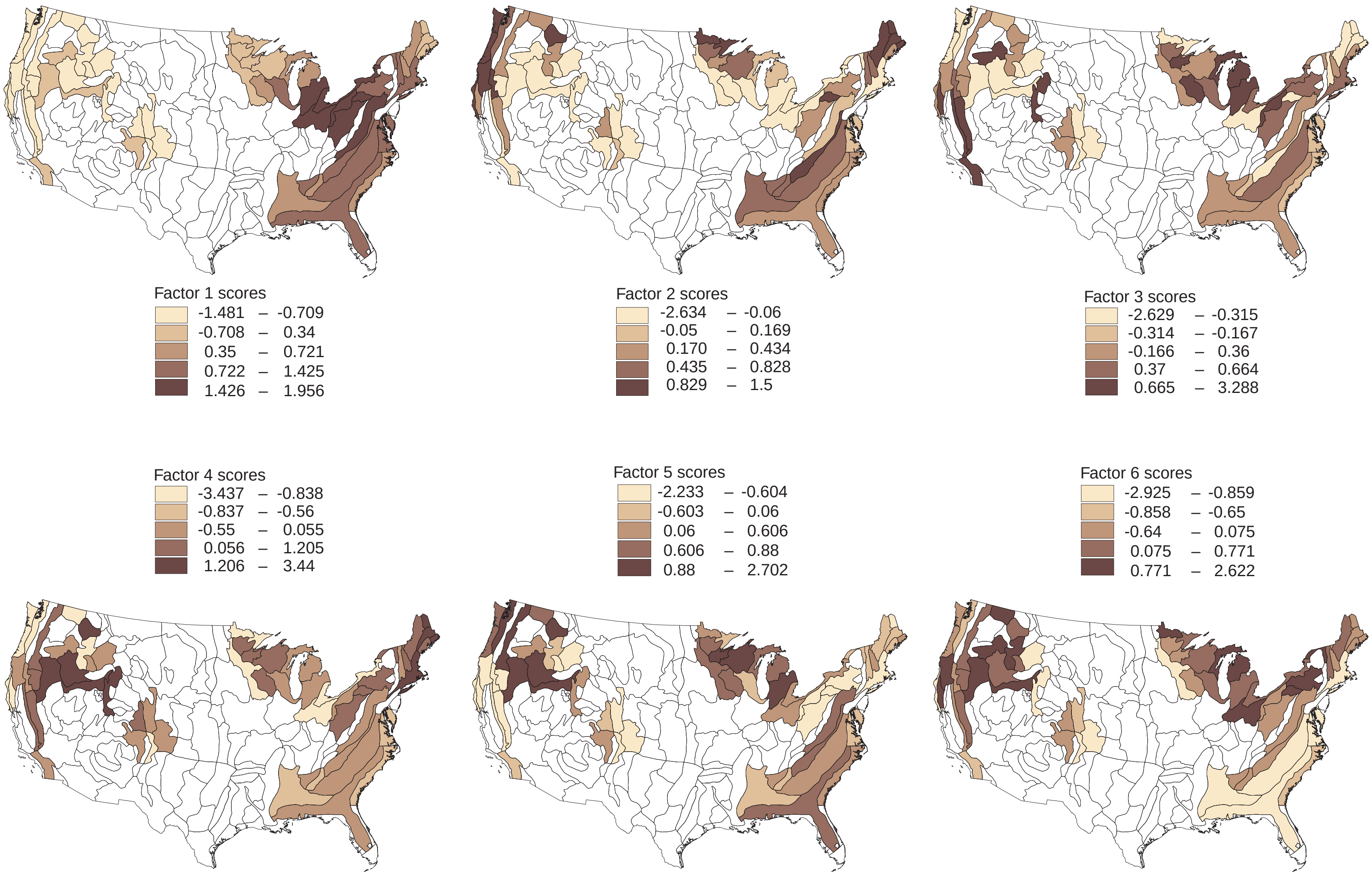

Figure 60—Six primary factors or components of a principal components analysis that used 32 indicators for 59 ecoregion sections. These 6 factors summarized about 80 percent of the statistical information contained in the original 32 indicators.

ecoregion scale). The indicator percent forest had the highest loading on factor 2, and two other fragmentation measures (average patch size and forest connectivity) known to be correlated with percent forest also have high loading.

Factor 3 was interpreted as a measure of fragmentation because it is independent of the absolute amount of forest (because factors 2 and 3 are orthogonal), and because indicators with the highest correlations are number of forest patches, forest edge, and landcover texture, all of which are known to be good fragmentation indicators. What is interesting about this approach is that fragmentation indicators typically are correlated with the amount of forest, and the PCA approach essentially factors out the influence of the amount of forest and permits a clean analysis of fragmentation indicators.

In summary, of the 7 fragmentation measures tested, 2 independent and significant pieces of information were obtained for the 59 ecoregion sections: amount of forest and fragmentation. The two best single univariate measures would have been percent forest and forest edge, because those two measures have the highest correlations with factors 2 and 3, respectively.

Not surprisingly, the map of factor scores for factor 2 (fig. 60) is similar to the map shown previously for percent forest (fig. 10). The maps differ somewhat because in figure 60, factor 2 is based on only 59 ecoregion sections. The map of factor scores for factor 3 (fig. 60) shows relative fragmentation among ecoregions that is not associated with amount of forest; i.e., ecoregion sections with large values that have more fragmentation than average among ecoregion sections with the same amount of forest. The map suggests there are several ecoregion sections where forest fragmentation is greater than expected: the Piedmont area in the South region, the Southern Great Lakes in the North Central region, and the mountain ranges adjacent to California's Central Valley (Sacramento and San Joaquin Valleys) in the West Coast region.

As mentioned in "Criterion 1—Biological Diversity: Forest Fragmentation," fragmentation was measured in terms of landcover, without regard to the specific landcover types that were the forest fragmenting agents. Observed forest fragmentation in the East almost certainly is anthropogenic and associated with urbanization and agricultural development. Fragmentation in foothills bordering California's Central Valley (and elsewhere in the West) is more likely to be natural forest fragmentation arising from juxtaposition of forest, grassland, and shrubland in undeveloped landscapes. The relative contribution of natural and anthropogenic causes cannot be determined from the present analysis but is the subject of current research.

It is also worth highlighting ecoregion sections where fragmentation is much less than average, for a given amount of forest. These ecoregion sections include several in the boreal forest (spruce-fir) zone (New England and Minnesota) and several ecoregion sections in the Interior West. The latter are of particular interest because they do not contain much forest (fig. 60, factor 2), yet the forest that is present is relatively intact.

Factors 4 and 5 are composites of crown-condition indicators and together explained about 15 percent of the total sample variance. Crown dieback variables (hardwood dieback status and change, and softwood dieback status and change) had the greatest loadings on factor 4, whereas crown transparency variables (hardwood foliar transparency status and change, and softwood foliar transparency change) had the highest loadings on factor 5 (appendix table B.14). As was the case for the fragmentation indicators, no single crown condition measure had high loadings on both factors 4 and 5, and no other factor (other than 4 and 5) contained a high loading for any crown condition measure. This means that factors 4 and 5 summarize two independent pieces of crown condition information, and that the other factors can be interpreted without any confounding by crown condition differences. Factor 4 is easily interpreted as a measure of crown dieback, and factor 5 is interpretable as a measure of crown transparency. The two best single univariate measures would have been softwood dieback and hardwood transparency change, because those two have the highest correlations (loadings) with factors 4 and 5, respectively.

The map of factor 4 scores (fig. 60) identifies ecoregion sections with relatively high dieback syndromes, including several in New England, northern Wisconsin, and the Interior West. Ecoregion sections with relatively high transparency include some of the same areas (one in Wisconsin and three in the Interior West region) and several others in the Pacific Northwest and Great Lakes areas (fig. 60, factor 5). The New England ecoregion sections that had high dieback scores did not have high transparency scores. Some ecoregion sections had relatively low dieback and transparency factor scores, including three in southern Idaho and three on the Colorado Plateau.

Factor 6, a composite of mortality variables and fire condition class, explained an additional 5.4 percent of the total sample variance. The MRATIO, the mean DDLD, and the percent of each ecoregion province in fire condition class 3 (major deviation from the historic fire regime) had the highest loadings for factor 6 (appendix table B.14). These loadings suggest that ecoregion sections with mortality volume exceeding growth (high MRATIO) and with mortality probably caused by senescence (high DDLD) are in the same ecoregion provinces with a relatively high percent of the forest in fire condition class 3. One plausible explanation is that factor 6 identifies ecoregion sections with a history of fire suppression where stands are near biological rotation ages. The map of factor scores (fig. 60, factor 6) suggests that most ecoregion sections in the Northwest and upper Great Lakes may be in this condition.

Although factors 7, 8, and 9 were statistically significant (appendix table B.14), together they explained only about 10 percent of the total sample variance, and each had only one or two individual indicators with high loadings. Generally, at least three high loadings were necessary in order to discuss a factor as some sort of composite variable.

In summary, of 32 indicators tested in 59 ecoregion sections, a principal components and factor analysis identified at least 6 composite variables that were used to rank ecoregion sections relative to one another in terms of air pollution, amount of forest, forest fragmentation, crown dieback, crown transparency, and mortality/fire. Individual ecoregion sections appeared to have relatively high or low values for composite variables, and these indications are expected to be starting points for additional in-depth investigations.

A Brief Look Ahead

New opportunities and challenges for data analysis have come with the integration of FHM's groundplot component with FIA in 2000. Modifications in data collection have occurred, such as shifting the damage indicator from phase 3 to phase 2, resulting in data from more plots and adding bulk density samples to the soil samples collected in the field, resulting in data needed to go beyond reporting concentration of C and nutrients in soils.[19] [20] Nationwide implementation of the vegetation structure and down woody debris indicators also has begun, resulting in data needed for better estimates of biodiversity, forest C, wildlife habitat, and fuel loading. All of these changes are resulting in new data to fit into the forest health picture.

There also remain many relationships among current indicators to explore, quantify, and evaluate. Causes and effects and specific topics of concern need to be studied and presented in more detail than is practical in a report such as this. However, an annual report will provide scientists and land managers an opportunity to consider a national overview of the FHM and phase 3 indicator data and to explore how these and other national data fit into the Santiago Declaration's Criteria and Indicators framework. The FHM annual national report also will continue to provide an opportunity to share analysis procedures appropriate for large assessment units. Readers are encouraged to investigate specific forest health concerns in regions or States by accessing the reports and forest health highlights listed in the "Introduction" of this report and by visiting the FHM (http://www.fhm.fs.fed.us) and USDA Forest Service (www.fs.fed.us) home pages.

[19] U.S. Department of Agriculture, Forest Service. 2001. Forest inventory and analysis national core field guide: field data collection procedures for phase 2 plots. Version 1.5. Vol. 1. Internal report. [Not paged]. On file with: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis, 201 14th St. NW, Washington, DC 20250.

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APPENDIX A

Supplemental Methods

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Analysis Using Generalized Least Squares Models

Several indicators (productivity, crown dieback and transparency, mortality, and carbon sequestration rate) were analyzed using a generalized least squares (GLS) model. Using this approach, the population-level current mean value and annual change are estimated from linear mixed models for repeated measurements. This approach is discussed thoroughly by Gregoire and others (1995), Urquhart and others (1993), and Van Deusen (1989). In particular, Van Deusen (1989) demonstrated that the GLS approach using a mixed estimator extends to estimating compatible components of growth as presented by Beers (1962), uses all the data, generalizes for any number of remeasurements, and can be easily extended to estimate quantities other than current volume and growth. In addition, Gregoire and others (1995) demonstrated that the procedure is particularly useful in unbalanced designs where all plots have not been measured at the same time intervals.

The analysis for change is based on the general linear model,

$$y_{ij} = B_0 + B_1\,(t_j - t_0) + \eta_1 + \varepsilon_{ij}$$

Model (1)

where

y_{ij} = the value of the indicator on plot *i* at time *j*

β_0 = estimated mean of the value of all plots at year zero

β_1 = estimated change in *y* over time

t_0 = time of initial measurement

t_j = time of measurement *j*

η_i = plot effect (spatial) variability

ε_{ij} = within-plot (temporal) variability

A component of the between- and within-plot variability is measurement error. Measurement error δ is assumed to be normally distributed with a mean = 0 and variance = σ^2. This assumption is critical to detecting change. This requirement can be relaxed if it can be assumed that a nonzero measurement error (bias) does not change with time. For example, if the error in measurement is of a consistent direction and magnitude, the measurement of change is minimally affected by measurement error. Because this analysis method does not partition measurement error from random variation, all standard error, probability estimates, and R^2 statistics reflect both sources of error.

Estimating Current Status and Change for a Region

The initial value, β_0, and the annual change, β_1, are estimated for each region of interest; e.g., Bailey's ecoregion section, with SAS PROC MIXED (SAS Institute 1999) using empirical GLS (Littell and others 1996). The models are termed "mixed," in that they contain both fixed and random variables. Random implies that the observations are a random sample of all possible response levels in the population. For FHM data, the random effects are the individual plots. The fixed effect is time. Specific estimation procedures are presented in greater detail in Smith and Conkling (2005).

The prediction equation is

$$\hat{y}_j = B_0 + B_1 (t_j - t_0)$$

The change is β_1, and the current status for the region is $\hat{y}_j$.

Estimating the Current Values of Individual Plots in Nonmeasured Years

Parameter estimates resulting from the previous models can be used to predict values for years in which a particular plot was not measured. This is particularly useful for spatially displaying all plot values as of a single point in time. As more mechanistic models are developed, the procedure also can be used to develop predictive models for future years based on current conditions.

Much of the information in this section comes from Smith and Conkling (2005). The predicted values are referred to as Best Linear Unbiased Predictors (BLUPs). BLUPs are best in that they have the minimum mean square error, linear in that they are linear functions of the data, unbiased in that the average value of the estimate is equal to the average value of the quantity being estimated, and predictors in that they are predictors of random effects (Robinson 1991). BLUPs are commonly used in quantitative genetics, statistical quality control, time series, and geostatistics (Christensen 1991, Robinson 1991). In this report BLUPs are used to predict the value of particular plot attributes, such as transparency and volume from a population of random effects.

Given model (1) above, the BLUP for predicting the value of plot i at time k is

$$blup\,(y_{ik}) = \underbrace{\hat{y}_{ik}}_{\text{mean}} + \underbrace{\frac{n_i\sigma_p^2}{\sigma_\varepsilon^2 + n_i\sigma_p^2}}_{\text{weight}} \underbrace{\left(\bar{y}_i - \frac{1}{n_i}\sum_{j=1}^{n_i}\hat{y}_{ij}\right)}_{\text{mean deviation}} = \hat{y}_{ik} + \frac{n_i\sigma_p^2}{\sigma_\varepsilon^2 + n_i\sigma_p^2}\left(\frac{1}{n_i}\sum_{j=1}^{n_i}(y_{ij} - \hat{y}_{ij})\right)$$

where

y_{ik} = the value of plot i at time k

$\hat{y}_{ik}$ = the fitted value for plot i at time k; i.e., the expected value of all plots within an ecoregion

n_i = the number of measurements on plot i

y_{ij} = the value of plot i at time j

$\bar{y}$ = the mean of all measurements of plot i

σ_p^2 = the between-plot variance

σ_ε^2 = the residual within-plot (temporal) variance

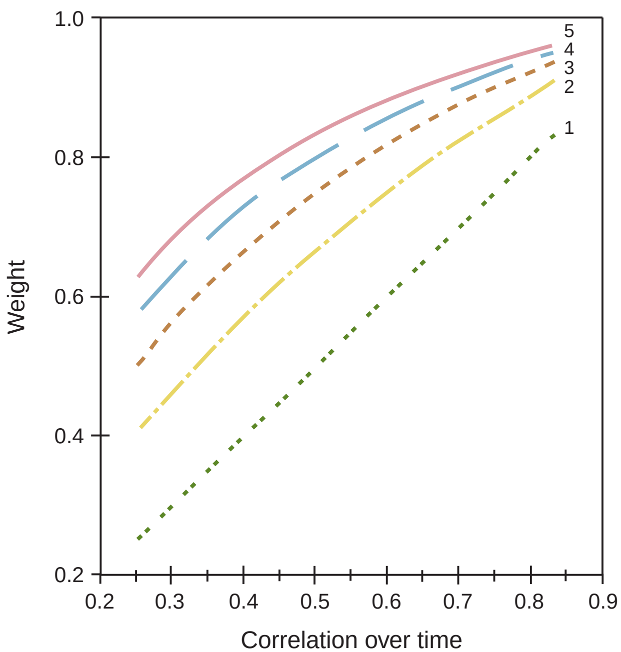
The BLUP consists of the mean value of all plots within the group measured at time k plus the mean deviation of the predicted values of plot i from the actual value in the years the plot was measured multiplied by a weighting factor. The weight term reflects the number of times the plot was measured and the plot and residual variance.

The weight increases as the number of measurements increases and/or as the correlation over time increases. This reflects the statistical confidence in the estimate. If the estimate is based on very few measurements or the correlation over time is small, the weight approaches zero, and the best estimate of the plot value is the mean of the population. The procedure can be better understood by examining a simple numerical example:

Plot i was measured in years one and four and an estimate of the plot i value at year five is needed. Assuming the model is $\hat{y}_j = 10+2\,(t_j - t_0)$, the estimate for year zero is 10, and the change over the 5-year interval is 2 units per year. Then the mean value of all plots in the region in year five is 10+2(5) or 20. If, in addition, the weight assigned to plot i is 0.7, and the observed and fitted values for plot i are:

Year	0	1	2	3	4	5	Mean
Observed (y_{ij})	.	9	.	.	13	.	11
Fitted ($\hat{y}_j$)	.	12	.	.	18	.	15

Then the average deviation of the fitted from the observed value is 11-15 = -4.0; i.e., in the years when plot *i* was measured, its average was 4.0 units less than the mean of the fitted values. Therefore, the BLUP for year five is 20+ weight (-4.0). Given a weight of 0.7, the best estimate of the value of plot *i* in year five is 20+0.7(-4.0) = 17.2.



The behavior of this estimate is better understood by considering some other possible conditions relating to this example(Smith and Conkling 2005):

1. When predicting the value of a plot that has never been measured, the mean deviation is zero, and the best estimate is the mean of all plots in the group (20).

2. If the value of the plot in the first measurements was 5 greater than the mean, and at the second measurement the value was 5 less than the mean, then the mean deviation is zero, and the best estimate for year five is again 20, which is the mean estimate of all plots in the group. The mean deviation of 0.0 indicates that the within-plot variability is probably due to measurement error or seasonal variability in contrast to the initial example, where the plot was consistently lower (-4.0) than the mean of all plots.

3. If the correlation over time were 0.3 instead of 0.7, the weight would be approximately 0.45 instead of 0.8 (appendix fig. A.1). This

Appendix figure A.1—Relationship between correlation over time and number of times a plot has been measured with weight of best linear unbiased predictors adjustment. The numerical annotation on the graph is the number of times the plot was measured. For the example in the text, use the line labeled 2 (plot was measured two times) (Smith and Conkling 2005).

would indicate that there is a high degree of within-plot variability due to measurement error or seasonal variability, and the best estimate is 20+0.45(-4.0) = 18.2.

Species Diversity

Ecologists have proposed a number of measures of beta β diversity (Gray 2000, Wilson and Shmida 1984). For this report, β diversity is calculated as simply

$$\beta = \gamma / \bar{\alpha}$$

where

γ = the total number of species from all samples taken in a region

$\bar{a}$ = the average number of species in each sample (Whittaker 1960)

Using this formulation, β represents the number of distinct communities present; i.e., a β value of 2 would represent the amount of heterogeneity in species distribution across a region equivalent to two communities that had no species in common (Whittaker 1972, Wilson and Shmida 1984).

Percentage of Richness on the Median Plot

The percentage of richness on the median plot gives an indication of the portion of the total ecoregion species richness that may be found on a so-called typical plot.

$$P = M/T * 100$$

where

P = percentage of richness on the median plot

M = median plot species richness

T = total ecoregion section species richness

Productive Capacity

Estimates of forest productivity were made using tree and sapling data from FHM 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; e.g., Ek and others 1984, Garman and others 1995, Moore and others 1996, and a tool developed by William Bechtold and Stanley Zarnoch.[1] Greater accuracy in estimation was obtained by conditioning the equation through the measured heights of the site trees. This approach commonly has been used in growth and yield models (Clutter and others 1983).

The simplest regional height-diameter equation of the form

$$log\ (H_i) = a + b\ /\ D_i$$

where

H_i = total height of the i^{th} tree

D_i = d.b.h. (diameter at breast height; 4.5 feet above ground level) of the i^{th} tree

a = species- and region-specific estimate of the intercept

b = species- and region-specific estimate of the slope

The equation was conditioned through the dominant height of the stand because

$$log\ (H_d) = a + b\ /\ D_d$$

where

H_d = average total height of the dominant trees

D_d = average d.b.h. of the dominant trees

The two equations then were combined by subtraction and solved for H_i, yielding

$$log\ (H_i) = log\ (H_d) + b(1/D_i - 1\ /\ D_d)$$

where

H_i = the predicted height of the i^{th} tree

D_i = the measured diameter of the i^{th} tree and then transformed to the exponential form

$$(H_i) = H_d\, e^{b(1/D_i - 1/D_d)}.$$

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 the species present on the plot

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

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.

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

Total gross volume was put on a per-acre basis for each plot. The annual change in gross volume was then estimated for each ecoregion section using a GLS model of the form described at the beginning of this appendix.

Insects and Pathogens

Short-term spatial trends (1998–99) in mortality and defoliation were assessed on a county basis within each FHM region in a relative exposure analysis. This analysis was based on observed vs. expected amounts of mortality and defoliation, where expected values were based on a Poisson model. The goal was to identify areas in each FHM region where the reported area of mortality- or defoliation-causing agents was relatively high with respect to the rest of the region. Technical details follow.

Probabilities from a Poisson distribution are given by $P(Y = K) = e^{-u}u^{K}K!^{-1}$. In the case of presence or absence data, K is restricted to values of 1 and 0, respectively. When $K = 1$ the model simplifies to $P(Y = 1) = e^{-u}u$, which represents the probability of the presence of some attribute in a population given an incident rate of u. With presence/absence data, the incident rate (u) is defined as the proportion of the population (U) with the attribute of interest present. The expected frequency of $Y = 1$ is $Ue^{-u}u$.

Under the assumption of complete spatial or spatiotemporal randomness, which is synonymous with a homogenous Poisson process (Cressie 1993), U is bounded by some region r, and the frequency of $Y = 1$ is independent and uniformly distributed within r. It follows that the expected frequency of $Y = 1$ for any subregion c within r is $U_{cr}e^{-u}u$, where

U_{cr} is the population of subregion c within region r. Relative exposure is the ratio of the observed vs. the expected frequency of $Y = 1$ for each subregion c. The metric is relative in that it allows for valid comparisons between any c within r.

In the relative-exposure analysis, u was calculated for each r (FHM region) as the proportion of forest land with mortality- or defoliation-causing agents present. Each r region was subdivided into counties (c). The expected amount of forest land with mortality- or disease-causing agents present in each county within the region was $U_{cr} e^{-u} u$, where U_{cr} was the amount of forest land in each county c, with region r and u defined earlier. The relative exposure of county c within region r is then $O_{cr} / U_{cr} e^{-u} u$, where O_{cr} is the observed amount of forest land with mortality- or disease-causing agents present. This method identified forested areas within the region that were hot spots when compared to the rest of the region for the 1998–99 time period.

Drought

Using Brocklebank and Dickey's (1986) procedure, a spectral analysis was performed to assess whether there was some underlying frequency (ω) in growing season drought. The dependent variable was percent of the conterminous United States with growing season drought; the independent variable was time. The sum of squares for each Fourier frequency ω_j was calculated,

where

$$\omega_i = 2\pi\, j / t$$

where

t = time step in years, $j = 0, 1, \ldots t/2$

This forces ω_j to be equally spaced in the interval $0 \leq \omega_j \leq \pi$ The largest peak in the sum of squares was at a period of 26 years (2π radians per 26 years). There also was a signal at a period of 13 years (2π radians per 13 years), identified by a slightly lower peak in the sum of squares. These periods then were tested against the null hypothesis that there was no component of frequency ω using the model

$$D_t = \mu + A \sin(\omega_1 t) + B \cos(\omega_1 t) + C \sin(\omega_2 t) + D \cos(\omega_2 t) + e_t$$

where

μ = mean of the time series

ω_1 = frequency of $2\pi/26$ (2π radians per 26 years)

ω_2 = frequency of $2\pi/13$ (2π radians per 13 years)

t = time step from 1 to 104

The null hypothesis was rejected, and the alternative hypothesis that a significant cycle of 26 and 13 years was accepted with a probability of a greater F of 0.0001.

The frequencies of moderate, severe, and extreme drought, based on the number of years of growing season droughts from 1895 through 1999 and 1990 through 1999, were calculated for each ecoregion section using a weighted average. The following equation was used:

$$D_k = \sum \frac{D_{jk} A_{kj}}{A_k}$$

where

D_k = the number of years of growing season drought in ecoregion section k

D_{jk} = the number of years of growing season drought in climate division j within ecoregion section k

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

A_k = the total forested area in ecoregion section k

Ozone Bioindicator Plants

This section provides details about the plot-level index for the ozone bioindicator. Each observed plant was rated for percent injury and average injury severity using a modified Horsfall-Barrett scale (Horsfall and Cowling 1978) with breakpoints at 6, 25, 50, 75, and 100 percent. This information was used to calculate an injury value for each plant, a mean value for each species, and an overall plot mean. The incidence of injury on a plot also was considered. The formulation is based on the fact that each plant has a unique response to ozone, depending on its genotype and microhabitat at the time of exposure. The formulation of the ozone indicator plot-level index was completed with the assistance of David Randall (Statistician, USDA Forest Service, Northeastern Research Station, Washington Office).

For each plant:

AMT = injury amount

SEV = injury severity

For each species:

N_1 = number of injured plants

N_2 = number of evaluated plants

$A = N_1 \div N_2$

$B = \sum (AMT * SEV) \div N_1$

Species_index = A ∗ B

For each hexagon (ozone biomonitoring site):

N_3 = number of evaluated species

Plot_index = $\sum (Species\_index) \div N_3$

Possible impacts from ambient ozone exposure will vary by bioindicator response categories and assumption of risk.

The assumption of risk assigned to each bioindicator response category is a relative measure of tree-level or ecosystem-level disturbance to the forest resource from ambient ozone exposure.

Bioindicator response category	Assumption of risk	Possible impact
Little or no foliar injury Plot-level index = 0 to < 5.0	None	Visible injury to leaves and needles Tree-level response
Low-to-moderate foliar injury Plot-level index = 5.0 to < 25.0	Low to moderate	Visible and invisible injury Tree-level response
Severe foliar injury Plot-level index ≥ 25.0	High	Visible and invisible injury Structural and functional changes Ecosystem level response

Ion Deposition

The spatial extent of exposure levels for specific air pollutants was examined. Wet hydrogen deposition, nitrate deposition, ammonium deposition, total nitrogen deposition, sulfate deposition, precipitation pH, and ozone exposure were interpolated for the conterminous United States average annual concentrations (1979 through 1995) of each deposition ion, and average precipitation pH were interpolated using data from National Atmospheric Deposition Program (NADP), Clean Air Status and Trends Network (CASTNET), and Canadian Air and Precipitation Monitoring Network (CAPMON). EPA ozone monitoring sites were used to interpolate average annual ozone concentration for years 1993 through 1996. Those sites classified as urban were excluded because ozone levels there may not be representative of levels found in forests. For each variable, an inverse distance squared weighting (ID²W) interpolated grid was produced by

$$\hat{v} = \frac{\sum_{i=12}^{n} \frac{1}{d_i^2} v_i}{\sum_{i=12}^{n} \frac{1}{d_i^2}}$$

where

$\hat{v}$ = estimated value

n = number of EPA monitoring stations within the maximum search radius; the minimum number of monitoring stations used to estimate $\hat{v}$ was 12

i = EPA monitoring station where i = 12 to n

v_i = value at each location i

d_i = linear distance between the locations of $\hat{v}$ and v_i . d_i was restricted to the maximum search radius

The grid cell size was 25 km² (5-km edges) for wet deposition ions and 4 km² (2-km edges) for ozone. For each interpolated cell, a minimum of 12 monitoring stations was used, and the maximum search radius was 500 and 300 kilometers for wet deposition ions and ozone, respectively.

Crown Condition

Hardwood and softwood crown indicators were analyzed separately. The hardwood indicator analyses used data from all plots except those having fewer than three hardwood trees > 5 inches d.b.h. and having < 10 percent of the basal area in hardwoods. Similarly, the softwood analyses excluded data from plots having fewer than three softwood trees > 5 inches d.b.h. and < 10 percent of the basal area in softwoods. For purposes of this analysis, if an ecoregion section contained fewer than five forested plots meeting these criteria, it was combined with adjacent section(s) in the same ecoregion province.

For each ecoregion section, an average crown indicator value was estimated using the GLS modeling procedure described at the beginning of this appendix, "Analysis Using Generalized Least Squares Models," using current as well as all prior plot measurements to simultaneously estimate current status as well as periodic annual change in the crown indicator. This procedure was selected because it makes efficient use of data from temporally unbalanced sample designs (Gregoire and others 1995), such as FHM's rotating panel design.

For some ecoregion sections, the only data were from FHM plots first measured in 1999. For those sections, current status of each crown indicator was estimated as the mean of the plot values, and no estimate was made of annual change.

Change values represent periodic annual change; i.e., the average annual change in indicator value from initial measurement to 1999. Five condition classes for average annual change in percent hardwood and softwood dieback and transparency were developed. Condition classes were based on significant changes ($p < 0.33$). All values that were not significant at the $p < 0.33$ level were considered to represent no change (the $p = 0.33$ level was selected for significance determination in order to be consistent with FIA practice). A decrease of > 2 percent was considered a substantial improvement in condition, and a decrease of 2 percent to 0.01 percent was considered a marginal improvement. An increase of 0.01 to 2 percent was considered a marginal decline in condition, and > 2 percent increase was considered a substantial decline.

Tree Damage

The DSI score is based on three variables: (1) type of damage symptom, (2) location of damage on the tree, and (3) severity of damage. Up to three incidents (damages) per tree may be scored. The DSI scale runs from zero to a theoretical maximum of 300, with zero indicating no damage above the minimum threshold being recorded and 300 indicating three damages of maximum severity. Generally, a high tree-level DSI score indicates multiple damages, severe types of damage, and/or extensive damage with the damages occurring near the base of the tree.

Tree scores were aggregated to plot-level scores (plot-level mean). The plot-level DSI is computed as

$$DSI_{plot} = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{3} f\,(d_{ij}, l_{ij}, s_{ij}) = \frac{1}{n}\sum_{i=1}^{n} DSI_i$$

where

d_{ij} = damage type (1 to 3 per tree)

l_{ij} = location of damage (1 to 3 per tree)

s_{ij} = severity of damage (1 to 3 per tree)

n = number of trees per plot

$f\,(d,l,s)$ = the severity index value for each damage to the tree found in the appropriate look-up table

DSI_i = damage severity index for tree i

Tree Mortality

The volumes of trees that died since plot establishment were estimated using the same procedure used to derive the live tree volumes used to estimate productivity. Mortality then was modeled as the annual change in accumulated dead volume using the GLS procedure described in the beginning of this appendix, “Analysis Using Generalized Least Squares Models.”

The mortality rate was divided by the previously derived gross volume growth rate to give the MRATIO.

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 from the most recent measurement of each plot. The DDLD ratio was calculated as the ratio of the quadratic mean d.b.h. of dead trees to the quadratic mean d.b.h. of live trees on the plot. If there were no live trees on the plot because the area had been logged, the DDLD ratio was calculated as the ratio of the quadratic mean d.b.h. of dead trees to the quadratic mean d.b.h. of cut trees, where the cut diameters are taken from the previous measurement of the plot.

In the West, if the forest on the plot was a type dominated by western woodland species, the DDLD ratio 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 ratio 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 ratio was calculated if all mortality was in woodland species and all survivors on the plot were nonwoodland species, or vice versa.

Soil Erosion

Data were collected by the FHM Program staff for use in the RUSLE. Appendix figure A.1 shows the FHM plot design for soil sampling. The general form of the equation is (Renard and others 1991):

$$A = RKLSCP$$

where

A = computed soil loss

R = rainfall-runoff erosivity factor: R represents the erosivity of the climate at a particular location. This represents the input driving the sheet and rill erosion process. Erosivity ranges from < 8 (U.S. customary units) in the Western United States to about 700 for New Orleans.[2]

K = soil erodibility factor: K is an empirical measure of soil erodibility as affected by intrinsic soil properties such as soil texture (including amount of fine sand), organic matter, structure, and permeability of the soil profile. K is influenced by detachability of the soil, infiltration and runoff, and transportability of sediment eroded from the soil. Generally, low K values result from soils that are resistant to detachment, soils with high infiltration rates and reduced runoff, and soil with sediment that is not easily transported if detached. Values typically range from 0.10 to 0.45.

L = slope length factor: see S factor.

S = slope steepness factor: the L and S factors together represent the effect of slope length, steepness, and shape on the production of sediment. L is greater when erosion is caused primarily by surface runoff (rill erosion) and increases in a downslope direction. Erosion caused by raindrop impact (interrill erosion) is uniform along a slope. Erosion increases with slope steepness, but the RUSLE does not differentiate between rill and interrill erosion in the S factor.

C = cover-management factor: C represents the effect of land use on erosion. C represents the effects of differences among vegetation communities, tillage systems, and addition of mulches. Therefore, because these variables

[2] Definitions are taken from information available on the USDA ARS National Sedimentation Laboratory Web site, Revised Universal Soil Loss Equation Project, http://www.sedlab.olemiss.edu/rusle, and Renard and others (1991).

change throughout the year, *C* is an average annual value for soil-loss ratio that is weighted according to the variation or distribution of erosivity during a year. Soil-loss ratio is the ratio of soil loss from a specific land use to that from the unit at a given time. *C* values can vary from near zero for a well-protected soil to 1.5 for a soil highly susceptible to rill erosion.

P = supporting practices factor: *P* describes effects of surface conditions on the water flow. *P* is influenced by practices such as contouring, strip cropping, concave slope, terraces, sediment basins, grass hedges, silt fences, straw bales, and subsurface drainage.

FHM scientists are working with the NRCS to identify appropriate values for nonfield-collected factors. Analyses have not been completed, but preliminary results are expected soon. Documentation for the current version of the RUSLE along with core values for data inputs can be found in U.S. Department of Agriculture, Agriculture Handbook 703 (Renard and others 1997).

The percent bare soil variable was used as a preliminary proxy for erosion potential because the cover-management factor (*C*) from the RUSLE has percent bare soil as a component of its surface cover subfactor (*SC*)

$$C = (PLU)(CC)(SC)(SR)$$

where

C = cover-management factor

PLU = prior land use subfactor

CC = canopy subfactor

SC = surface cover subfactor

SR = surface roughness subfactor

and

$$SC = exp(-bM)$$

where

SC = surface cover subfactor

b = assigned coefficient: *b* values should range from about 0.025 (when interrill erosion is the primary mechanism for soil loss) to about 0.050

(when rill erosion is the primary mechanism). *b* may vary depending on the general type of vegetation in rangeland and pasture situations.

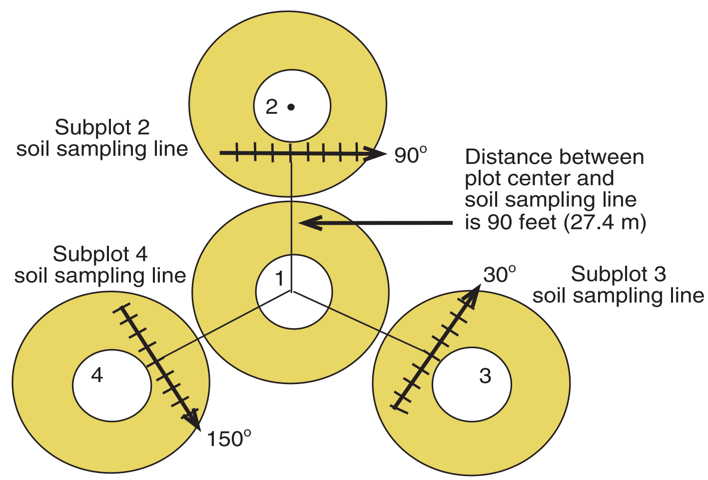
M = 100 minus percent bare soil

Because the model is multiplicative, we can see an indication of erosion potential by observing the effect that changes in percent bare soil have on the product of the other factors; e.g., as percent bare soil approaches 100 percent, SC approaches 1.

Soil Chemical Properties

Soil sampling protocols for presented data are found in the 1998 and 1999 FHM field methods guides.[3] [4] For mineral soil samples, data reported represent the mean of three soil samples collected from subplots 2, 3, and 4 (appendix fig. A.2). Forest floor samples were collected from within a 12-inch diameter sampling frame at one location on each plot (subplot 2). In places where the O horizon was > 5-cm thickness, the two layers (litter and organic soil layer) were collected and analyzed separately. Data were combined prior to reporting.

Due to a change in sampling method between 1998 and 1999, only a portion of the mineral soil data collected was included in this report. In 1998, mineral soil samples were collected by genetic horizon using an excavation method. In 1999, mineral soil samples were collected by depth increments using a 2-inch diameter impact-driven soil core sampler (AMS, American Falls, ID). Cores were collected over depth increments of 0 to 10 cm and 10 to 20 cm using the mineral-organic interface as the baseline. Mineral soil data reported in the tables and figures were determined by combining the A horizon from 1998 and the 0- to 10-cm depth



Appendix figure A.2—Forest Health Monitoring plot layout for soil sampling.

[3] U.S. Department of Agriculture, Forest Service. 1998. Forest health monitoring 1998 field methods guide. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, National Forest Health Monitoring Program. 473 p. On file with: The Forest Health Monitoring Program National Office, Research Triangle Park, NC 27709.

[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, Research Triangle Park, NC 27709.

increment from 1999. Although these two sets of samples do not completely overlap, the aggregated data do provide a reasonable representation of conditions present in the upper portion of the mineral soil profile.

All laboratory analyses were conducted by the Soil Characterization Laboratory at the University of Missouri-Columbia. Soil pH was determined using a glass and reference electrode with a pH meter on a 1 to 1 suspension; salt pH was measured in 1 M $CaCl_2$. Exchangeable cations were determined by ammonium acetate (NH_4OAc) extraction and atomic absorption spectrophotometry. P was determined colorimetrically using a Bray-1 (0.03 M NH_4F+0.025 M HCl) extractant. Total C and total N were determined by dry combustion using a LECO™ analyzer. All samples were oven-dried at 105 °C prior to analysis, which may have affected some of the chemical analyses discussed in the main text. Chemical data were averaged to the plot level for presentation.

pH—Total soil acidity can be divided into three pools: (1) active acidity, a measure of the H^+ activity in the soil solution at a given time; (2) salt-replaceable acidity, which reflects the hydrogen and aluminum that are easily exchangeable by other cations in an unbuffered salt solution; and, (3) residual acidity. The FHM soils program measured the first two. Active acidity was measured by extracting the soil with deionized water (water pH); salt-replaceable acidity was measured by extraction in a solution of calcium chloride (salt pH). Because extraction in salt removes H^+ ions sorbed to soil particles, salt pH is lower than water pH. For brevity, only salt pH values are presented in this report.

Appendix B

Supplemental Tables

Appendix table B.1—Tree species diversity

Ecoregion section code	Ecoregion species richness (γ) Total	Canopy	Sapling	Seedling	Plots	Plot species richness (α) Mean	Median	Max.	Min.	Std. dev.	β diversity ($\overline{\gamma/\alpha}$)	Species on median plot
	- - - number of species present - - -				*no.*	*- - - - - number of species present - - - - -*						*percent*
212A	31	19	21	26	14	8.14	9.0	17	1	4.40	3.81	29.03
212B	38	26	24	33	29	9.69	10.0	13	1	2.51	3.92	26.32
212C	24	16	13	20	7	8.14	8.0	11	5	1.86	2.95	33.33
212D	36	27	21	30	19	9.47	9.0	17	4	3.55	3.80	25.00
212E	37	20	19	31	10	8.40	9.0	18	2	4.40	4.40	24.32
212F	61	48	28	34	48	7.46	8.0	15	2	2.86	8.18	13.11
212G	34	28	12	22	18	7.11	7.0	11	2	2.14	4.78	20.59
212H	59	42	38	53	92	7.18	7.0	15	1	2.70	8.21	11.86
212J	60	40	37	53	82	8.57	8.5	21	2	3.62	7.00	14.17
212K	49	34	25	37	36	7.08	7.0	14	1	3.56	6.92	14.29
212L	34	26	21	30	77	5.32	5.0	12	1	1.95	6.39	14.71
212M	36	25	21	28	55	4.91	4.0	10	1	2.68	7.33	11.11
212N	51	37	33	41	100	5.80	5.0	14	1	3.26	8.79	9.80
221A	62	41	37	49	49	9.65	10.0	20	1	4.25	6.42	16.13
221B	30	24	13	17	8	8.00	8.0	12	4	2.45	3.75	26.67
221C	28	24	17	15	12	6.00	6.0	7	4	0.95	4.67	21.43
221D	38	31	14	18	16	7.13	6.5	13	2	3.50	5.33	17.11
221E	69	56	43	52	45	12.00	12.0	23	4	5.56	5.75	17.39
221F	23	18	8	11	6	6.50	6.5	8	4	1.52	3.54	28.26
221H	55	42	28	45	20	12.35	13.0	19	1	4.88	4.45	23.64
221I	39	28	14	30	9	13.33	13.0	20	4	4.72	2.93	33.33

continued

Appendix table B.1—Tree species diversity (continued)

Ecoregion section code	Ecoregion species richness (γ) Total	Canopy	Sapling	Seedling	Plots	Plot species richness (α) Mean	Median	Max.	Min.	Std. dev.	β diversity (γ/$\bar{\alpha}$)	Species on median plot
	- - - number of species present - - -				*no.*	*- - - - - number of species present - - - - -*						*percent*
221J	55	43	20	45	12	15.83	16.5	35	2	8.91	3.47	30.00
222A	71	55	47	57	89	10.46	11.0	20	1	3.95	6.79	15.49
222C	51	39	24	43	16	14.56	15.0	24	2	6.12	3.50	29.41
222D	40	26	13	33	9	13.22	13.0	21	7	4.71	3.03	32.50
222E	58	48	37	49	36	11.81	12.0	25	3	4.93	4.91	20.69
222F	36	20	14	26	8	9.88	10.0	15	5	3.80	3.65	27.78
222G	39	26	11	28	9	8.89	9.0	14	5	3.79	4.39	23.08
222H	38	32	16	22	11	10.00	10.0	16	1	4.40	3.80	26.32
222I	34	30	12	14	10	5.70	5.0	12	2	3.27	5.96	14.71
222J	55	42	25	42	25	7.52	7.0	14	1	3.48	7.31	12.73
222K	36	28	15	29	18	5.33	5.0	11	2	2.40	6.75	13.89
222L	41	31	21	32	20	7.90	7.0	15	3	3.46	5.19	17.07
222M	53	45	24	37	45	6.78	7.0	13	1	3.18	7.82	13.21
222N	6	4	4	5	5	3.00	3.0	4	2	0.71	2.00	50.00
231A	119	88	79	97	215	11.78	12.0	27	1	5.19	10.10	10.08
231B	78	64	54	62	73	10.60	10.0	21	4	3.92	7.36	12.82
231C	55	36	28	49	21	12.95	12.0	26	4	5.84	4.25	21.82
231D	51	37	21	35	12	12.92	13.0	20	5	4.76	3.95	25.49
232A	71	57	39	53	53	9.42	9.0	20	2	4.40	7.54	12.68
232B	90	64	61	71	119	7.57	7.0	27	1	3.98	11.89	7.78
232C	77	67	46	55	68	7.00	7.0	17	1	3.62	11.00	9.09
232G	13	7	8	9	4	5.75	6.0	8	3	2.63	2.26	46.15
242A	21	20	11	15	33	3.30	3.0	6	1	1.36	6.36	14.29
251A	18	14	7	14	4	6.75	7.0	10	3	3.77	2.67	38.89
251C	49	42	22	36	27	7.48	5.0	18	1	5.06	6.55	10.20
251D	47	32	20	40	16	9.63	8.5	26	2	6.58	4.88	18.09
263A	22	21	8	10	30	4.60	5.0	7	2	1.33	4.78	22.73

continued

Appendix table B.1—Tree species diversity (continued)

Ecoregion section code	Ecoregion species richness (γ) Total	Canopy	Sapling	Seedling	Plots	Plot species richness (α) Mean	Median	Max.	Min.	Std. dev.	β diversity ($\gamma/\bar{\alpha}$)	Species on median plot
	- - - number of species present - - -				*no.*	*- - - - - number of species present - - - - -*						*percent*
313A	8	8	5	5	25	1.96	2.0	4	1	0.79	4.08	25.00
322A	7	5	3	2	4	2.25	2.0	3	2	0.50	3.11	28.57
331A	9	7	7	9	7	3.57	3.0	7	2	1.90	2.52	33.33
331G	2	2	2	2	6	1.33	1.0	2	1	0.52	1.50	50.00
331I	9	6	4	8	14	2.36	3.0	4	1	1.01	3.82	33.33
341A	11	10	5	5	14	2.21	2.0	4	1	0.89	4.97	18.18
341B	9	9	2	4	23	2.26	2.0	5	1	1.10	3.98	22.22
341D	5	5	1	2	8	1.63	1.5	3	1	0.74	3.08	30.00
341E	2	2	0	0	4	1.75	2.0	2	1	0.50	1.14	100.00
341F	7	6	5	3	18	2.06	2.0	5	1	0.87	3.41	28.57
341G	3	3	3	3	7	2.14	2.0	3	2	0.38	1.40	66.67
342B	16	15	5	10	23	1.91	1.0	6	1	1.35	8.36	6.25
342C	7	7	2	4	9	1.78	1.0	5	1	1.30	3.94	14.29
342G	4	4	1	3	4	1.50	1.0	3	1	1.00	2.67	25.00
342H	5	5	2	4	8	1.88	1.5	4	1	1.13	2.67	30.00
M212A	46	31	30	43	70	9.83	10.0	15	3	2.42	4.68	21.74
M212B	40	29	23	32	21	11.00	10.0	17	6	3.45	3.64	25.00
M212C	37	25	24	31	20	9.20	9.5	14	1	3.29	4.02	25.68
M212D	38	31	22	26	36	7.31	7.5	14	3	2.89	5.20	19.74
M212E	18	17	7	10	9	5.89	5.0	10	3	2.37	3.06	27.78
M221A	84	68	47	67	79	10.78	11.0	24	3	4.06	7.79	13.10
M221B	52	41	25	37	28	9.18	9.0	15	4	3.13	5.67	17.31
M221C	55	38	28	45	18	13.72	12.5	23	6	4.61	4.01	22.73
M221D	95	83	47	77	70	12.56	12.0	28	3	5.13	7.57	12.63
M242A	30	27	15	14	56	3.43	3.0	7	1	1.48	8.75	10.00
M242B	31	26	17	23	52	3.90	4.0	8	1	1.60	7.94	12.90
M242C	35	27	20	29	67	3.00	3.0	8	1	1.76	11.67	8.57

continued

Appendix table B.1—Tree species diversity (continued)

Ecoregion section code	Ecoregion species richness (γ)					Plot species richness (α)					β diversity (γ/α)	Species on median plot
	Total	Canopy	Sapling	Seedling	Plots	Mean	Median	Max.	Min.	Std. dev.		
	- - - number of species present - - -				*no.*	*- - - - - number of species present - - - - -*						*percent*
M261A	41	36	21	24	53	4.43	4.0	9	1	1.83	9.25	9.76
M261B	20	17	11	15	13	4.62	5.0	9	1	2.10	4.33	25.00
M261C	6	3	2	5	7	2.14	2.0	5	1	1.35	2.80	33.33
M261D	28	24	16	19	28	3.29	3.0	8	1	1.80	8.52	10.71
M261E	29	25	20	25	61	3.16	3.0	8	1	1.67	9.17	10.34
M261F	15	14	5	8	15	2.67	2.0	7	1	1.84	5.62	13.33
M261G	15	12	7	10	21	2.48	2.0	5	1	1.47	6.06	13.33
M262A	8	8	1	2	10	1.60	1.5	3	1	0.70	5.00	18.75
M262B	13	11	2	6	7	2.43	3.0	3	1	0.98	5.35	23.08
M331A	9	8	7	7	19	2.58	3.0	5	1	1.26	3.49	33.33
M331B	5	5	2	4	5	2.60	3.0	3	1	0.89	1.92	60.00
M331D	18	18	12	14	45	2.76	3.0	5	1	1.33	6.53	16.67
M331E	12	10	9	8	18	2.39	2.0	5	1	1.24	5.02	16.67
M331F	12	12	7	10	13	2.69	2.0	5	1	1.60	4.46	16.67
M331G	24	18	13	19	43	2.79	3.0	7	1	1.37	8.60	12.50
M331H	11	11	7	6	24	2.17	2.0	4	1	1.05	5.08	18.18
M331I	16	12	12	12	49	3.14	3.0	6	1	1.31	5.09	18.75
M331J	7	6	2	3	4	3.00	3.5	4	1	1.41	2.33	50.00
M332A	17	13	12	16	52	3.46	4.0	7	1	1.35	4.91	23.53
M332E	11	7	4	7	7	3.00	2.0	5	1	1.63	3.67	18.18
M332F	11	10	7	8	11	2.91	3.0	5	1	1.14	3.78	27.27
M332G	19	18	9	11	44	3.16	3.0	8	1	1.54	6.01	15.79
M333A	20	18	12	15	39	4.08	3.0	10	1	2.52	4.91	15.00
M333D	16	14	12	13	26	4.69	4.0	9	1	2.24	3.41	25.00
M341A	8	8	4	5	26	1.92	2.0	5	1	0.89	4.16	25.00
M341B	10	7	9	7	17	2.53	2.0	5	1	1.33	3.95	20.00
M341C	17	17	11	13	31	3.13	3.0	7	1	1.61	5.43	17.65

Appendix table B.2—Lichen species diversity

Ecoregion section code	Total lichen species recorded (γ)	Plots	Plot species score (α) Mean	Median	Max.	Min.	Std. dev.	β diversity ($\gamma/\bar{\alpha}$)	Species on median plot
	no. of species present	*no.*	*- - - - - - - number of species present - - - - - -*						*percent*
212A	48	5	16.60	13.0	27	11	6.8044	2.892	27.08
212B	62	10	15.90	14.5	30	8	6.3325	3.899	23.39
212C	29	3	15.33	17.0	17	12	2.8868	—	—
212D	36	6	15.83	16.0	21	8	4.4460	2.274	44.44
212E	9	1	9.00	9.0	9	9	NA	—	—
212F	10	3	4.33	3.0	10	0	5.1316	—	—
212G	23	5	9.60	6.0	16	5	5.8566	2.396	26.09
212H	24	9	9.44	10.0	12	3	3.0046	2.541	41.67
212J	58	14	12.71	11.5	21	6	4.0082	4.562	19.83
212K	44	9	12.89	12.0	17	9	2.7588	3.414	27.27
212L	68	9	16.00	16.0	22	12	3.2787	4.250	23.53
212M	54	8	15.25	13.0	26	10	6.1120	3.541	24.07
212N	60	16	15.81	16.0	23	8	4.2774	3.794	26.67
221A	42	10	9.40	9.0	16	6	3.1693	4.468	21.43
221C	37	3	14.67	16.0	16	12	2.3094	—	—
221D	5	2	3.50	3.5	5	2	2.1213	—	—
221E	42	11	14.00	16.0	20	4	5.3666	3.000	38.10
221F	6	1	6.00	6.0	6	6	NA	—	—
221I	14	1	14.00	14.0	14	14	NA	—	—
222A	4	1	4.00	4.0	4	4	NA	—	—
222D	11	1	11.00	11.0	11	11	NA	—	—
222E	17	5	7.80	7.0	9	7	1.0954	2.179	41.18
222F	14	2	9.50	9.5	11	8	2.1213	—	—
222G	13	3	6.67	7.0	8	5	1.5275	—	—
222H	7	2	5.00	5.0	6	4	1.4142	—	—
222J	21	10	6.80	5.5	12	5	2.4855	3.088	26.19

continued

Appendix table B.2—Lichen species diversity (continued)

Ecoregion section code	Total lichen species recorded (γ)	Plots	Plot species score (α) Mean	Median	Max.	Min.	Std. dev.	β diversity ($\gamma/\bar{\alpha}$)	Species on median plot
	no. of species present	*no.*	*- - - - - - - number of species present - - - - - -*						*percent*
222K	18	3	8.67	7.0	14	5	4.7258	—	—
222L	20	3	11.33	10.0	14	10	2.3094	—	—
222M	34	5	12.00	13.0	16	6	3.8079	2.833	38.24
231A	87	39	10.79	11.0	21	0	5.7910	8.059	12.64
231B	62	22	9.27	10.0	17	1	4.7427	6.686	16.13
231C	28	5	9.20	12.0	14	0	5.8052	3.043	42.86
231D	37	3	15.33	21.0	22	3	10.6927	—	—
232A	37	12	7.58	8.0	14	0	3.8954	4.879	21.62
232B	68	26	8.19	8.5	18	2	4.4183	8.300	12.50
232C	30	4	11.50	11.0	15	9	3.0000	—	—
232G	6	1	6.00	6.0	6	6	NA	—	—
242A	72	15	14.73	15.0	25	1	6.3860	4.887	20.83
251A	26	1	19.00	19.0	19	19	NA	—	—
251D	12	5	5.40	6.0	8	3	1.9494	2.222	50.00
262A	16	2	8.50	8.5	13	4	6.3640	—	—
263A	32	8	10.25	11.5	14	4	4.0267	3.122	35.94
313A	14	1	14.00	14.0	14	14	NA	—	—
322A	9	1	9.00	9.0	9	9	NA	—	—
331A	35	7	12.00	10.0	20	9	4.0825	2.917	28.57
331F	5	1	5.00	5.0	5	5	NA	—	—
331G	14	4	5.75	6.0	8	3	2.2174	—	—
331I	21	8	5.50	5.0	10	1	3.3806	3.818	23.81
341B	9	1	9.00	9.0	9	9	NA	—	—
341C	5	1	5.00	5.0	5	5	NA	—	—
342A	14	3	5.33	6.0	8	2	3.0551	—	—

continued

Appendix table B.2—Lichen species diversity (continued)

Ecoregion section code	Total lichen species recorded (γ)	Plots	Plot species score (α) Mean	Median	Max.	Min.	Std. dev.	β diversity ($\gamma/\bar{\alpha}$)	Species on median plot
	no. of species present	*no.*	*- - - - - - - number of species present - - - - - -*						*percent*
342B	30	9	6.89	5.0	17	3	4.4001	4.355	16.67
342C	27	6	8.83	9.0	16	3	4.5789	3.057	33.33
342D	14	3	6.67	6.0	12	2	5.0332	—	—
342E	4	1	4.00	4.0	4	4	NA	—	—
342F	8	3	3.00	3.0	6	0	3.0000	—	—
342G	12	4	3.50	4.0	5	1	1.7321	—	—
342H	23	4	10.00	10.5	12	7	2.1602	—	—
M212A	84	20	16.50	16.5	29	5	6.9396	5.091	19.64
M212B	42	7	11.71	13.0	15	8	2.4300	3.585	30.95
M212C	23	5	7.60	7.0	10	6	1.5166	3.026	30.43
M221A	90	27	14.22	13.0	27	4	7.3711	6.328	14.44
M221B	48	9	12.56	12.0	21	3	7.2992	3.823	25.00
M221C	45	5	19.60	20.0	32	12	8.0187	2.296	44.44
M221D	50	8	12.25	11.0	23	5	6.6494	4.082	22.00
M242A	79	21	15.38	16.0	27	0	7.9213	5.136	20.25
M242B	78	16	19.81	19.0	29	11	5.5163	3.937	24.36
M242C	67	25	14.04	12.0	26	5	6.7791	4.772	17.91
M261A	91	23	16.87	18.0	28	4	6.7777	5.394	19.78
M261B	31	4	12.50	13.0	16	8	3.6968	—	—
M261C	15	2	11.50	11.5	12	11	0.7071	—	—
M261D	49	10	11.20	11.5	28	2	8.2435	4.375	23.47
M261E	48	19	7.00	6.0	17	0	5.4772	6.857	12.50
M261F	22	3	10.33	10.0	13	8	2.5166	—	—
M261G	24	6	9.67	8.0	17	7	3.8816	2.483	33.33
M262A	2	1	2.00	2.0	2	2	NA	—	—
M262B	14	3	6.33	7.0	7	5	1.1547	—	—

continued

Appendix table B.2—Lichen species diversity (continued)

Ecoregion section code	Total lichen species recorded (γ)	Plots	Plot species score (α) Mean	Median	Max.	Min.	Std. dev.	β diversity (γ/$\bar{\alpha}$)	Species on median plot
	no. of species present	*no.*	- - - - - - - *number of species present* - - - - - -						*percent*
M331A	22	16	5.81	6.0	11	1	2.4005	3.785	27.27
M331B	18	5	7.00	7.0	11	4	2.5495	2.571	38.89
M331D	29	24	6.75	6.0	11	4	1.9616	4.296	20.69
M331E	5	1	5.00	5.0	5	5	NA	—	—
M331F	23	7	8.71	9.0	14	6	2.6277	2.639	39.13
M331G	59	29	9.93	9.0	31	3	5.5158	5.941	15.25
M331H	28	10	8.40	8.0	13	5	2.3190	3.333	28.57
M331I	56	29	9.55	10	20	1	4.8002	5.863	17.86
M331J	13	4	5.00	5.5	6	3	1.4142	—	—
M332A	56	52	8.63	8.0	18	0	4.2933	6.486	14.29
M332E	23	7	7.71	9.0	10	5	2.2887	2.981	39.13
M332F	21	11	5.36	5.0	11	0	2.9757	3.915	23.81
M332G	50	17	13.24	12.0	22	4	5.0439	3.778	24.00
M333A	63	25	17.56	16.0	28	6	6.2455	3.588	25.40
M333D	44	25	12.12	13.0	17	6	3.4919	3.630	29.55
M341B	11	4	6.00	6.0	8	4	1.6330	—	—

— = beta diversity and percent of species on median plots were not calculated for ecoregion sections with fewer than five lichen plots (for those ecoregion sections, the total species richness (γ) may be significantly underestimated); NA = standard deviation cannot be calculated when the sample size = 1.

Appendix table B.3—Hardwood transparency status summary statistics

Ecoregion section code[a]	Hardwood transparency	Standard error	90% confidence interval		Plots
			Lower	Upper	
	percent				*no.*
212A	16.42	0.93	14.85	17.98	9
212B	16.04	0.50	15.21	16.87	26
212C	16.87	1.43	14.45	19.28	6
212D	16.42	0.65	15.34	17.50	18
212E	17.84	1.30	15.49	20.20	9
212F	15.17	0.72	13.83	16.52	46
212G	14.51	0.58	13.45	15.58	18
212H	21.18	1.29	19.04	23.32	79
212J	22.08	0.69	20.95	23.22	77
212K	25.31	1.10	23.46	27.17	29
212L	21.27	0.85	19.85	22.68	60
212M	23.74	0.78	22.42	25.07	40
212N	21.59	0.62	20.56	22.61	74
221A	15.02	0.62	14.00	16.04	46
221B	17.87	1.73	14.50	21.23	7
221C	17.00	0.72	15.78	18.21	11
221D	17.82	0.96	16.08	19.55	14
221E	15.75	0.50	14.92	16.58	44
221F	14.77	1.04	8.21	21.33	6
221H	16.25	0.39	15.54	16.96	18
221I	17.54	1.79	14.26	20.81	9
221J	14.82	0.62	13.69	15.95	11
222A	18.14	0.32	16.14	20.14	88
222C	16.19	0.78	14.82	17.56	16
222D	18.84	1.50	15.32	22.37	9
222E	17.19	0.48	16.36	18.01	36
222F	19.69	1.66	16.15	23.22	7

continued

Appendix table B.3—Hardwood transparency status summary statistics (continued)

Ecoregion section code[a]	Hardwood transparency	Standard error	90% confidence interval Lower	Upper	Plots
	percent				*no.*
222G	17.76	0.65	16.38	19.14	9
222H	17.66	1.02	15.73	19.59	11
222I	15.93	1.18	13.14	18.71	10
222J	23.21	1.27	21.08	25.33	25
222K	22.48	1.60	19.71	25.25	15
222L	25.30	1.28	23.13	27.48	20
222M, 222N	22.11	0.64	21.05	23.18	46
231A	15.95	0.38	15.32	16.58	174
231B	14.93	0.40	14.26	15.60	64
231C	15.00	0.82	13.64	16.37	21
231D	14.75	0.69	13.58	15.91	9
232A	16.27	0.69	15.13	17.41	49
232B	18.96	1.78	16.03	21.89	85
232C, 232G	16.89	1.61	14.19	19.59	46
242A	26.74	2.88	21.14	32.34	17
251A, 251B	23.41	0.80	21.95	24.86	6
251C, 251E	18.93	0.85	17.48	20.37	29
251D	17.67	1.13	15.63	19.71	16
263A	18.70	1.66	15.83	21.57	15
313A	14.28	0.12	13.55	15.02	2
331I	15.00	—	15.00	15.00	1
341A, 341B, 341D, 341F, 341G	17.82	2.42	13.39	22.26	10
342B, 342C	24.13	2.82	18.80	29.47	11
M212A	16.17	0.54	15.29	17.06	61
M212B	18.76	0.84	17.36	20.15	20
M212C	18.05	1.18	16.09	20.01	20
M212D	16.40	0.44	15.65	17.14	34

continued

Appendix table B.3—Hardwood transparency status summary statistics (continued)

Ecoregion section code[a]	Hardwood transparency	Standard error	90% confidence interval		Plots
			Lower	Upper	
	percent				*no.*
M212E	18.72	1.33	16.25	21.19	9
M221A	19.34	0.44	18.62	20.07	77
M221B	17.23	0.78	15.93	18.52	27
M221C	21.86	1.04	20.11	23.60	18
M221D	17.84	0.90	16.35	19.32	63
M242A, M242B	21.91	1.18	19.85	23.96	31
M242C	28.69	3.38	7.38	50.00	3
M261A	17.73	0.95	16.12	19.34	35
M261B	17.68	1.32	15.32	20.04	10
M261C	21.85	2.12	17.83	25.86	8
M261D, M261G	14.98	1.56	12.03	17.94	8
M261E	19.27	0.90	17.73	20.81	19
M261F	21.35	1.56	18.60	24.09	16
M262A, 261A	15.90	1.40	13.26	18.54	11
M262B, 261B	19.28	3.45	12.33	26.23	6
M331D	19.72	1.47	16.27	23.18	18
M331E	20.55	2.41	15.42	25.68	5
M331F, M331G	20.79	1.96	17.44	24.13	23
M331H	19.79	2.27	15.82	23.77	13
M331I	21.60	1.57	18.85	24.34	14
M332A, M332G	20.11	1.61	16.68	23.54	6
M332E, M332F	20.01	3.68	12.59	27.43	6
M333A	25.44	2.34	21.09	29.78	7
M333D	32.84	12.09	7.06	58.62	7
M341A	18.81	3.65	11.03	26.59	5
M341B, M341C	15.63	0.63	11.68	19.57	2

[a] Plots from ecoregion sections appearing together were aggregated and analyzed as a group because there was an insufficient number of plots to analyze each section individually.

Appendix table B.4—Hardwood transparency change summary statistics

Ecoregion section code[a]	Std. error	Degrees of freedom	t-value[b]	Probability of > t	Hardwood transparency annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - *no.*	- - - - - - -	
212A	0.26	47	-1.03	0.3087	-0.27	9	57	0.138
212B	0.13	140	1.99	0.0488	0.26	26	167	0.171
212C	0.22	31	3.09	0.0042	0.69	6	38	0.216
212D	0.16	99	1.17	0.2463	0.19	18	118	0.249
212E	0.19	10	-1.56	0.1494	-0.29	3	14	0.236
212F	0.44	8	-2.22	0.0569	-0.99	13	22	0.122
212G	0.68	9	-2.73	0.0234	-1.85	18	28	0.429
212H	0.30	168	3.09	0.0024	0.93	79	248	0.796
212J	0.18	155	8.66	0.0000	1.55	77	233	0.347
212K	0.61	38	2.77	0.0087	1.69	29	68	0.547
212L	0.50	58	-0.71	0.4822	-0.35	60	119	0.199
212M	0.29	34	4.40	0.0001	1.26	40	75	0.216
212N	0.20	74	4.72	0.0000	0.96	74	149	0.133
221A	0.14	235	-0.27	0.7863	-0.04	44	280	0.204
221C	0.10	52	7.99	0.0000	0.77	11	64	0.495
221D	0.61	10	1.02	0.3337	0.62	14	25	0.642
221E	0.24	89	-4.46	0.0000	-1.07	44	134	0.416
221F	0.04	1	-46.71	0.0136	-2.04	5	7	0.776
221H	0.01	9	88.43	0.0000	0.72	2	12	0.292
221I	0.47	9	3.23	0.0103	1.52	2	12	0.324
222D	0.46	3	-0.06	0.9586	-0.03	9	13	0.832
222E	0.25	19	3.30	0.0037	0.82	9	29	0.634
222F	0.50	4	0.93	0.4032	0.47	7	12	0.774
222G	0.90	4	-3.53	0.0241	-3.18	9	14	0.307
222H	0.47	7	-1.96	0.0907	-0.92	11	19	0.225
222I	0.26	3	9.35	0.0026	2.39	2	6	0.790
222J	0.31	44	7.68	0.0000	2.36	25	70	0.717
222K	0.53	18	0.18	0.8625	0.09	15	34	0.287
222L	0.37	31	4.19	0.0002	1.55	20	52	0.542

continued

Appendix table B.4—Hardwood transparency change summary statistics (continued)

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Hardwood transparency annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - *no.*	- - - - - - -	
222M, 222N	0.20	51	6.74	0.0000	1.32	46	98	0.275
231A	0.08	478	11.64	0.0000	0.92	174	654	0.197
231B	0.07	256	10.51	0.0000	0.74	61	318	0.281
231C	0.12	88	5.69	0.0000	0.69	21	110	0.283
231D	0.11	45	5.78	0.0000	0.65	9	55	0.164
232A	0.13	133	5.03	0.0000	0.63	49	183	0.332
232B	0.31	241	4.39	0.0000	1.35	85	327	0.243
232C, 232G	0.19	50	2.34	0.0236	0.44	46	97	0.872
242A	0.90	6	4.16	0.0059	3.76	17	24	0.966
251A, 251B	0.21	10	6.40	0.0001	1.34	6	17	0.398
251D	0.76	11	-4.94	0.0004	-3.75	16	28	0.463
263A	0.57	18	-2.30	0.0336	-1.32	15	35	0.439
331I	0.67	0	3.28	—	2.20	3	5	0.868
342B, 342C	1.22	7	2.34	0.0519	2.85	8	16	0.753
M212A	0.10	338	1.25	0.2123	0.13	61	400	0.346
M212B	0.10	110	4.68	0.0000	0.46	20	131	0.229
M212C	0.16	91	1.31	0.1932	0.20	18	110	0.518
M221A	0.14	182	6.76	0.0000	0.92	72	255	0.119
M221B	0.47	56	-1.87	0.0664	-0.88	27	84	0.413
M221C	0.31	53	3.73	0.0005	1.14	18	72	0.197
M221D	0.15	112	6.46	0.0000	1.00	61	174	0.435
M242A, M242B	0.96	18	2.86	0.0105	2.74	31	50	0.165
M242C	2.65	1	2.63	0.2314	6.96	3	5	0.417
M261A	0.57	33	-3.89	0.0005	-2.23	35	70	0.438
M261B	0.44	11	-0.80	0.4416	-0.35	10	23	0.506
M261C	0.42	7	-3.05	0.0185	-1.27	8	17	0.826
M261D, M261G	0.90	7	-2.51	0.0404	-2.26	8	17	0.228
M261E	0.49	23	-1.21	0.2380	-0.60	19	44	0.585

continued

Appendix table B.4—Hardwood transparency change summary statistics (continued)

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Hardwood transparency annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - *no.*	- - - - - - -	
M261F	0.66	14	-3.46	0.0039	-2.29	16	32	0.850
M262A, 261A	0.29	7	-1.05	0.3303	-0.30	11	20	0.622
M262B, 261B	0.93	5	-0.41	0.6969	-0.38	6	13	0.709
M331D	1.01	3	1.52	0.2255	1.53	5	9	0.628
M331F, M331G	0.55	27	0.11	0.9142	0.06	23	52	0.531
M331H	0.74	15	-0.23	0.8238	-0.17	13	30	0.240
M331I	0.41	16	-2.12	0.0504	-0.87	14	32	0.813
M332A, M332G	0.99	4	-0.23	0.8322	-0.22	6	11	0.471
M332E, M332F	1.43	5	0.17	0.8692	0.25	6	12	0.547
M333A	1.18	8	2.55	0.0342	3.00	7	16	0.426
M333D	4.14	4	1.30	0.2620	5.40	7	12	0.660

[a] Plots from ecoregion sections appearing together in the table were aggregated and analyzed as a group because there was an insufficient number of plots to analyze each section individually.

[b] H_0: annual change in hardwood transparency equals zero.

[c] Change values represent the average annual change in the indicator value over the period from initial measurement to 1999. Each of the five condition classes for percent hardwood transparency were based on significant changes where $p < 0.33$. All values that were not significant at this level were considered to be no change.

[d] Each observation represents one visit to a plot.

Appendix table B.5—Hardwood dieback status summary statistics

Ecoregion section code[a]	Hardwood dieback	Standard error	90% confidence interval		Plots
			Lower	Upper	
	percent				*no.*
212A	21.22	4.92	12.96	29.49	9
212B	10.23	1.15	8.32	12.14	26
212C	14.06	3.63	7.90	20.22	6
212D	10.74	1.14	8.85	12.64	18
212E	9.45	2.65	4.64	14.25	9
212F	3.81	0.42	3.03	4.59	46
212G	5.24	1.72	2.08	8.40	18
212H	6.18	1.57	3.60	8.77	79
212J	7.89	1.08	6.10	9.69	77
212K	4.41	1.13	2.50	6.31	29
212L	4.44	0.85	3.01	5.87	60
212M	4.46	0.91	2.93	5.99	40
212N	5.38	0.69	4.23	6.52	74
221A	6.19	0.59	5.21	7.16	46
221B	4.09	1.07	2.02	6.17	7
221C	6.24	1.05	4.47	8.00	11
221D	3.09	0.84	1.56	4.61	14
221E	3.35	0.33	2.80	3.91	44
221F	2.32	0.89	-3.30	7.93	6
221H	3.58	0.99	1.75	5.41	18
221I	4.18	1.73	1.02	7.35	9
221J	3.10	0.90	1.47	4.73	11
222A	4.09	0.44	1.29	6.89	88
222C	4.77	1.17	2.72	6.82	16
222D	8.38	3.30	0.62	16.13	9
222E	3.47	0.57	2.49	4.45	36
222F	13.59	6.94	-1.20	28.39	7
222G	2.08	0.80	0.37	3.79	9

continued

Appendix table B.5—Hardwood dieback status summary statistics (continued)

Ecoregion section code[a]	Hardwood dieback	Standard error	90% confidence interval Lower	Upper	Plots
	percent				*no.*
222H	3.92	0.98	2.06	5.78	11
222I	2.69	0.98	0.38	5.00	10
222J	5.75	1.92	2.52	8.98	25
222K	7.45	2.20	3.64	11.26	15
222L	6.93	0.99	5.24	8.62	20
222M, 222N	5.53	0.75	4.27	6.79	46
231A	4.24	0.54	3.36	5.12	174
231B	3.28	0.56	2.35	4.20	64
231C	5.30	1.32	3.10	7.50	21
231D	3.14	0.72	1.93	4.35	9
232A	3.96	0.91	2.45	5.46	49
232B	8.08	2.23	4.40	11.75	85
232C, 232G	5.37	1.85	2.27	8.48	46
242A	-2.09	1.42	-4.85	0.68	17
251A, 251B	6.16	1.16	4.06	8.26	6
251C	3.39	1.05	1.59	5.18	26
251C, 251E	4.06	0.93	-1.80	9.93	29
251D	5.30	1.10	3.33	7.28	16
263A	3.44	0.60	2.40	4.48	15
313A	13.53	8.13	-37.82	64.89	2
331I	12.22	—	12.22	12.22	1
341A, 341B, 341D, 341F, 341G	4.46	1.05	2.53	6.39	10
342B, 342C	10.28	2.74	5.09	15.47	11
M212A	8.89	1.13	7.03	10.76	61
M212B	6.67	0.84	5.28	8.06	20
M212C	7.66	1.31	5.49	9.84	20
M212D	6.37	0.88	4.89	7.85	34
M212E	2.75	0.68	1.50	4.01	9

continued

Appendix table B.5—Hardwood dieback status summary statistics (continued)

Ecoregion section code[a]	Hardwood dieback	Standard error	90% confidence interval Lower	Upper	Plots
	percent				*no.*
M221A	3.46	0.32	2.94	3.99	77
M221B	4.80	0.57	3.84	5.76	27
M221C	4.71	0.78	3.40	6.02	18
M221D	3.49	0.57	2.55	4.44	63
M242A, M242B	2.10	0.75	0.80	3.41	31
M242C	10.21	4.47	-18.01	38.43	3
M261A	5.74	0.94	4.14	7.33	35
M261B	3.57	0.87	2.02	5.13	10
M261C	3.53	0.94	1.79	5.27	8
M261D, M261G	5.49	1.15	3.34	7.63	8
M261E	4.97	1.39	2.59	7.35	19
M261F	5.76	1.40	3.31	8.22	16
M262A, 261A	3.34	0.93	1.60	5.08	11
M262B, 261B	3.59	1.30	1.06	6.12	6
M331D	7.27	2.07	2.39	12.16	18
M331E	2.06	1.08	-0.25	4.36	5
M331F, M331G	2.42	1.90	-0.81	5.65	23
M331H	2.29	1.13	0.31	4.26	13
M331I	2.29	0.81	0.89	3.70	14
M332A, M332G	2.55	1.02	0.38	4.72	6
M332E, M332F	18.25	10.79	-3.49	40.00	6
M333A	7.80	4.99	-1.48	17.07	7
M333D	20.64	15.08	-11.52	52.79	7
M341A	2.28	0.91	0.33	4.23	5
M341B, M341C	6.04	0.21	4.73	7.36	2

[a] Plots from ecoregion sections appearing together in the table were aggregated and analyzed as a group because there was an insufficient number of plots to analyze each section individually.

Appendix table B.6—Hardwood dieback change summary statistics

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Hardwood dieback annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.*	- - - - - - -	
212A	0.68	47	1.09	0.2821	0.74	9	57	0.640
212B	0.20	140	1.82	0.0715	0.36	26	167	0.395
212C	0.54	30	2.68	0.0118	1.45	6	37	0.427
212D	0.21	99	1.16	0.2484	0.24	18	118	0.097
212E	0.60	10	-3.53	0.0054	-2.14	3	14	0.763
212F	0.23	8	0.67	0.5204	0.16	13	22	0.241
212G	0.64	9	0.38	0.7138	0.24	18	28	0.636
212H	0.23	168	-1.99	0.0478	-0.46	79	248	0.869
212J	0.27	155	1.63	0.1041	0.44	77	233	0.613
212K	0.69	38	-1.16	0.2514	-0.80	29	68	0.628
212L	0.51	58	-1.87	0.0664	-0.95	60	119	0.730
212M	0.31	34	-1.38	0.1754	-0.43	40	75	0.562
212N	0.20	74	-0.66	0.5139	-0.13	74	149	0.635
221A	0.08	235	-0.89	0.3757	-0.08	44	280	0.388
221C	0.14	52	-0.87	0.3882	-0.13	11	64	0.429
221D	0.08	10	-2.69	0.0228	-0.21	14	25	0.466
221E	0.11	89	0.65	0.5169	0.07	44	134	0.259
221F	0.05	1	-20.57	0.0309	-1.12	5	7	0.570
221H	0.43	8	0.69	0.5119	0.30	2	11	0.490
221I	0.67	9	-0.82	0.4309	-0.56	2	12	0.144
222D	1.14	3	0.67	0.5503	0.76	9	13	0.645
222E	0.20	19	-1.57	0.1334	-0.31	9	29	0.099
222F	2.02	4	0.96	0.3936	1.93	7	12	0.700
222G	0.72	4	-2.64	0.0576	-1.90	9	14	0.306
222H	0.43	7	0.53	0.6147	0.23	11	19	0.011
222I	0.18	3	-2.83	0.0663	-0.50	2	6	0.083
222J	0.45	44	0.38	0.7072	0.17	25	70	0.458
222K	0.66	18	-1.46	0.1624	-0.97	15	34	0.718

continued

Appendix table B.6—Hardwood dieback change summary statistics (continued)

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Hardwood dieback annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.*	- - - - - - -	
222L	0.16	31	1.03	0.3124	0.17	20	52	0.766
222M, 222N	0.26	51	0.28	0.7786	0.07	46	98	0.517
231A	0.11	478	-0.63	0.5266	-0.07	174	654	0.289
231B	0.07	256	-3.03	0.0027	-0.22	61	318	0.346
231C	0.21	86	1.00	0.3207	0.21	21	108	0.246
231D	0.19	45	-2.31	0.0255	-0.43	9	55	0.059
232A	0.13	133	-2.79	0.0061	-0.35	49	183	0.398
232B	0.36	241	1.42	0.1571	0.52	85	327	0.280
232C, 232G	0.40	50	-0.13	0.8972	-0.05	46	97	0.824
242A	2.17	6	-2.54	0.0439	-5.53	17	24	0.128
251A, 251B	0.26	10	1.15	0.2786	0.30	6	17	0.307
251D	0.56	11	-1.04	0.3196	-0.58	16	28	0.581
263A	0.12	19	-0.38	0.7111	-0.05	15	35	0.670
331I	0.49	1	-1.29	0.4205	-0.63	3	5	0.911
341A, 341B, 341D, 341F, 341G	0.04	0	-34.26	—	-1.30	2	3	0.998
342B, 342C	1.00	7	0.64	0.5455	0.63	8	16	0.719
M212A	0.20	338	-0.53	0.5937	-0.10	61	400	0.555
M212B	0.14	110	-0.06	0.9540	-0.01	20	131	0.324
M212C	0.14	91	-0.36	0.7227	-0.05	18	110	0.543
M221A	0.07	182	-4.75	0.0000	-0.34	72	255	0.474
M221B	0.27	56	-0.03	0.9737	-0.01	27	84	0.523
M221C	0.13	53	-1.69	0.0961	-0.22	18	72	0.227
M221D	0.12	112	-2.04	0.0441	-0.25	61	174	0.445
M242A, M242B	0.48	18	-0.89	0.3867	-0.42	31	50	0.473
M242C	0.38	1	-0.05	0.9685	-0.02	3	5	0.994
M261A	0.24	34	-0.12	0.9024	-0.03	35	70	0.744
M261B	0.26	12	-0.53	0.6091	-0.14	10	23	0.011

continued

Appendix table B.6—Hardwood dieback change summary statistics (continued)

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Hardwood dieback annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.*	- - - - - - -	
M261C	0.24	8	-1.32	0.2224	-0.32	8	17	0.639
M261D, M261G	0.52	8	-2.45	0.0402	-1.27	8	17	0.392
M261E	0.34	24	-0.18	0.8588	-0.06	19	44	0.562
M261F	0.24	15	0.46	0.6487	0.11	16	32	0.636
M262A, 261A	0.25	8	-3.37	0.0098	-0.86	11	20	0.366
M262B, 261B	0.23	6	-1.77	0.1274	-0.40	6	13	0.803
M331D	0.54	3	1.52	0.2261	0.82	5	9	0.180
M331F, M331G	0.73	28	-1.97	0.0592	-1.44	23	52	0.459
M331H	0.22	16	-0.42	0.6815	-0.09	13	30	0.008
M331I	0.30	17	-2.38	0.0292	-0.70	14	32	0.835
M332A, M332G	0.79	4	-3.63	0.0221	-2.87	6	11	0.684
M332E, M332F	3.18	5	-0.44	0.6764	-1.41	6	12	0.913
M333A	2.29	8	-1.63	0.1415	-3.74	7	16	0.866
M333D	4.30	4	1.18	0.3030	5.08	7	12	0.837

[a] Plots from ecoregion sections appearing together in the table were aggregated and analyzed as a group because there was an insufficient number of plots to analyze each section individually.
[b] H_0: annual change in hardwood dieback equals zero.
[c] Change values represent the average annual change in the indicator value over the period from initial measurement to 1999. Each of the five condition classes for percent hardwood dieback were based on significant changes where $p < 0.33$. All values that were not significant at this level were considered to be no change.
[d] Each observation represents one visit to a plot.

Appendix table B.7—Softwood transparency status summary statistics

Ecoregion section code[a]	Softwood transparency	Std. error	90% confidence interval Lower	Upper	Plots
	percent				*no.*
212A	16.46	1.13	14.57	18.35	11
212B	15.41	0.55	14.50	16.32	27
212C	17.37	0.97	15.74	19.00	7
212D	18.04	0.78	16.74	19.34	18
212E, 212F, 212G	17.29	0.96	15.58	18.99	29
212H	21.61	0.73	20.41	22.82	58
212J	20.55	0.85	19.13	21.97	39
212K	23.83	1.44	21.36	26.30	17
212L	19.36	0.74	18.13	20.59	60
212M	19.77	1.05	18.01	21.54	35
212N	21.92	1.00	20.25	23.60	46
221A, 221B	19.96	1.69	17.17	22.75	28
221C, 221D	22.88	1.91	19.66	26.09	9
221E, 221F	19.60	2.99	14.33	24.86	11
221H	24.59	1.62	21.57	27.61	9
221I, 221J	28.58	2.64	23.89	33.28	13
222A	17.86	0.88	16.36	19.36	25
222C	22.43	2.63	16.82	28.03	5
222E, 222F	17.94	2.61	11.78	24.09	6
222H, 222I, 222J	22.48	1.26	20.09	24.87	7
222K, 222L	21.00	3.03	15.56	26.45	6
222M	24.17	2.36	18.62	29.72	5
231A	19.07	0.50	18.24	19.90	154
231B	18.03	0.73	16.82	19.24	47
231C	21.01	3.64	14.92	27.09	13
231D	18.03	0.50	17.18	18.88	9
232A	19.67	0.95	18.09	21.25	28

continued

Appendix table B.7—Softwood transparency status summary statistics (continued)

Ecoregion section code[a]	Softwood transparency	Std. error	90% confidence interval Lower	Upper	Plots
	percent				*no.*
232B	18.06	0.59	17.08	19.04	85
232CG	20.02	0.70	18.84	21.20	48
242A	16.43	0.82	14.98	17.89	26
251C	18.13	3.13	-1.61	37.86	2
263A	21.47	1.78	18.31	24.62	12
313A	12.09	0.61	8.25	15.92	23
331A	16.73	1.00	14.36	19.09	5
331F, 331G	11.79	1.51	8.74	14.84	7
331I	13.55	0.89	11.94	15.16	12
341A	7.68	0.59	6.60	8.75	11
341B, 341C	12.36	0.81	10.00	14.72	23
341D, 341E	13.31	1.31	10.91	15.71	10
341F	13.25	0.89	10.65	15.85	20
341G	9.12	1.20	6.79	11.44	7
342A, 342E, 342F, 342G	11.22	1.00	9.38	13.06	10
342B, 342C	13.79	0.93	12.16	15.42	26
342D	17.74	1.11	14.51	20.97	2
342H, 342I	16.23	1.42	13.38	19.09	10
M212A	16.99	0.51	16.15	17.83	55
M212B	21.56	0.91	20.05	23.08	17
M212C	17.89	1.13	16.01	19.77	15
M212D, M212E	15.17	0.79	13.81	16.53	21
M221A	25.87	2.12	22.32	29.43	21
M221D	22.34	1.12	20.47	24.21	32
M242A, M242B	15.47	0.30	14.96	15.98	97
M242C	17.28	0.71	16.09	18.48	64
M261A	15.81	0.61	14.78	16.83	45

continued

Appendix table B.7—Softwood transparency status summary statistics (continued)

Ecoregion section code[a]	Softwood transparency	Std. error	90% confidence interval Lower	Upper	Plots
	percent				*no.*
M261B	17.88	1.17	15.80	19.97	11
M261C, M261F	37.07	3.20	30.63	43.51	10
M261D	16.33	1.13	14.39	18.27	24
M261E	18.19	0.64	17.13	19.26	53
M261G	14.21	0.88	12.69	15.72	21
M262A, 261A	20.13	2.75	13.66	26.60	6
M262B	19.57	1.51	16.35	22.79	5
M331A, M331J	12.83	0.69	11.63	14.04	19
M331B	13.28	0.22	11.92	14.64	5
M331D	13.46	0.59	12.43	14.48	34
M331E	11.64	1.16	9.61	13.68	16
M331F	11.28	1.09	9.37	13.20	12
M331G	13.70	0.68	12.55	14.85	38
M331H	11.65	1.09	9.75	13.55	15
M331I	14.33	0.44	13.58	15.07	48
M332A	14.16	0.42	13.46	14.86	51
M332E	13.21	2.40	8.55	17.86	7
M332F	13.85	1.07	11.89	15.81	10
M332G	15.55	0.92	13.98	17.12	44
M333A	19.49	1.24	17.39	21.58	39
M333D	14.82	0.73	13.57	16.07	26
M334A	13.77	0.49	10.66	16.89	2
M341A	10.93	0.57	9.95	11.91	22
M341B	14.36	1.21	12.11	16.62	15
M341C	13.14	0.41	12.44	13.85	27

[a] Plots from ecoregion sections appearing together in the table were aggregated and analyzed as a group because there was an insufficient number of plots to analyze each section individually.

Appendix table B.8—Softwood transparency change summary statistics

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Softwood transparency annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.*	- - - - - - -	
212A	0.17	56	-0.65	0.5211	-0.11	11	68	0.327
212B	0.17	143	1.74	0.0832	0.29	27	171	0.359
212C	0.14	37	5.01	0.0000	0.68	7	45	0.328
212D	0.19	99	3.11	0.0025	0.60	18	118	0.390
212E, 212F, 212G	0.30	13	-0.31	0.7626	-0.09	11	25	0.635
212H	0.20	125	6.35	0.0000	1.27	58	184	0.528
212J	0.18	75	7.70	0.0000	1.41	39	115	0.355
212K	0.32	24	5.54	0.0000	1.77	17	42	0.314
212L	0.24	63	2.54	0.0137	0.60	60	124	0.337
212M	0.37	38	2.57	0.0144	0.95	35	74	0.096
212N	0.45	46	2.30	0.0262	1.03	46	93	0.566
221A, 221B	0.41	135	0.84	0.4025	0.35	24	160	0.318
221C, 221D	0.27	44	3.78	0.0005	1.03	9	54	0.545
221E, 221F	0.96	14	-2.51	0.0248	-2.42	11	26	0.675
222E, 222F	0.81	3	-3.24	0.0480	-2.63	4	8	0.927
222H, 222I, 222J	0.31	7	6.68	0.0003	2.05	4	12	0.690
222K, 222L	0.57	11	-0.29	0.7754	-0.17	6	18	0.485
222M	0.59	3	3.55	0.0382	2.09	5	9	0.393
231A	0.10	374	6.84	0.0000	0.71	154	529	0.411
231B	0.12	172	5.15	0.0000	0.64	46	219	0.283
231C	0.56	54	1.36	0.1787	0.76	13	68	0.239
231D	0.11	39	5.52	0.0000	0.60	9	49	0.274
232A	0.15	92	3.63	0.0005	0.56	28	121	0.388
232B	0.10	250	8.94	0.0000	0.86	85	336	0.507
232C, 232G	0.17	54	7.12	0.0000	1.21	48	103	0.570
242A	0.49	13	2.56	0.0236	1.26	26	40	0.529
263A	0.51	13	-2.49	0.0271	-1.28	12	27	0.819
313A	2.51	1	1.02	0.4951	2.55	2	5	0.346
331A	0.34	3	3.53	0.0385	1.22	5	9	0.384

continued

Appendix table B.8—Softwood transparency change summary statistics (continued)

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Softwood transparency annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.* - - - - - - -		
331F, 331G	0.63	5	-0.69	0.5220	-0.44	7	13	0.610
331I	0.38	10	2.90	0.0157	1.10	12	24	0.423
341B, 341C	0.31	2	-2.82	0.1061	-0.86	5	9	0.918
341F	3.60	2	0.48	0.6811	1.71	3	6	0.978
342A, 342E, 342F, 342G	0.34	9	-0.14	0.8904	-0.05	10	20	0.514
342B, 342C	0.67	12	1.98	0.0708	1.32	16	30	0.702
342D	0.72	2	4.22	0.0517	3.03	2	5	0.637
342H, 342I	0.73	5	1.87	0.1204	1.37	10	16	0.862
M212A	0.11	294	3.43	0.0007	0.38	55	350	0.345
M212B	0.20	85	3.43	0.0009	0.67	17	103	0.278
M212C	0.24	70	-0.57	0.5707	-0.14	14	85	0.174
M221A	0.47	46	2.06	0.0455	0.97	20	67	0.048
M221D	0.21	61	4.62	0.0000	0.98	32	94	0.336
M242A, M242B	0.20	62	4.53	0.0000	0.91	97	160	0.406
M242C	0.40	42	3.55	0.0010	1.43	64	107	0.547
M261A	0.32	41	-1.89	0.0656	-0.60	45	88	0.227
M261B	0.52	12	-1.81	0.0958	-0.94	11	25	0.658
M261C, M261F	0.67	5	-0.35	0.7382	-0.24	10	17	0.930
M261D	0.31	23	-1.41	0.1706	-0.43	24	49	0.669
M261E	0.26	67	-2.56	0.0129	-0.65	52	121	0.752
M261G	0.74	18	-1.48	0.1556	-1.09	21	41	0.657
M262A, 261A	1.75	3	-1.65	0.1982	-2.88	6	11	0.828
M262B	1.02	4	1.16	0.3092	1.18	5	11	0.872
M331A, M331J	0.47	15	-1.73	0.1039	-0.81	19	35	0.015
M331B	0.25	1	4.87	0.1289	1.24	5	7	0.632
M331D	0.59	16	2.03	0.0596	1.20	21	38	0.417
M331F	0.23	15	-2.12	0.0513	-0.49	12	29	0.818

continued

Appendix table B.8—Softwood transparency change summary statistics (continued)

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Softwood transparency annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.*	- - - - - - -	
M331G	0.25	47	2.80	0.0073	0.70	38	87	0.511
M331H	0.27	16	-1.64	0.1196	-0.44	15	33	0.382
M331I	0.19	55	0.38	0.7033	0.07	48	105	0.574
M332A	0.14	52	1.64	0.1068	0.23	51	104	0.619
M332E	0.72	6	-0.36	0.7336	-0.26	7	14	0.744
M332F	0.33	9	0.44	0.6726	0.14	10	20	0.408
M332G	0.47	25	1.51	0.1432	0.71	44	70	0.582
M333A	0.83	34	1.31	0.1988	1.08	39	74	0.286
M333D	0.27	26	0.01	0.9906	0.00	26	53	0.331
M334A	1.16	1	-0.78	0.5768	-0.91	2	4	0.586
M341B	0.48	8	-0.02	0.9844	-0.01	7	17	0.295

[a] Plots from ecoregion sections appearing together in the table were aggregated and analyzed as a group because there was an insufficient number of plots to analyze each section.
[b] H_0: annual change in softwood transparency equals zero.
[c] Change values represent the average annual change in the indicator value over the period from initial measurement to 1999. Each of the five condition classes for softwood transparency were based on significant changes where $p < 0.33$. All values that were not significant at this level were considered to be no change.
[d] Each observation represents one visit to a plot.

Appendix table B.9—Softwood dieback status summary statistics

Ecoregion section code[a]	Softwood dieback	Standard error	90% confidence interval Lower	90% confidence interval Upper	Plots
	percent				*no.*
212A	7.42	1.72	4.54	10.30	11
212B	8.91	2.11	5.41	12.41	27
212C	18.83	5.81	9.04	28.63	7
212D	8.53	1.28	6.41	10.65	18
212E, 212F, 212G	5.52	1.26	3.30	7.75	29
212H	3.95	1.32	1.76	6.15	58
212J	4.81	0.89	3.33	6.30	39
212K	8.62	4.55	0.83	16.41	17
212L	2.00	0.56	1.07	2.93	60
212M	3.62	1.13	1.72	5.52	35
212N	4.44	1.02	2.74	6.15	46
221A, 221B	8.96	2.18	5.36	12.56	28
221C, 221D	6.58	2.16	2.95	10.21	9
221E, 221F	3.08	0.95	1.40	4.76	11
221H	1.73	0.94	-0.03	3.48	9
221I, 221J	4.66	2.05	1.02	8.31	13
222A	1.00	0.38	0.35	1.65	25
222C	7.60	5.71	-4.56	19.76	5
222E, 222F	2.78	1.83	-1.52	7.07	6
222H, 222I, 222J	0.76	0.63	-0.43	1.96	7
222K, 222L	5.29	2.59	0.64	9.93	6
222M	0.74	1.66	-3.17	4.64	5
231A	1.55	0.24	1.15	1.94	154
231B	2.07	0.89	0.59	3.54	47
231C	4.00	0.76	2.72	5.28	13
231D	2.80	1.00	1.12	4.49	9
232A	2.05	1.25	-0.02	4.12	28

continued

Appendix table B.9—Softwood dieback status summary statistics (continued)

Ecoregion section code[a]	Softwood dieback	Standard error	90% confidence interval Lower	Upper	Plots
	percent				*no.*
232B	2.27	0.62	1.25	3.29	85
232C, 232G	1.24	0.38	0.60	1.87	48
242A	0.75	0.31	0.20	1.29	26
251C	0.31	0.31	-1.66	2.29	2
263A	2.74	0.94	1.09	4.38	12
313A	6.76	0.93	4.05	9.48	23
331A	2.36	0.70	0.72	4.00	5
331F, 331G	2.05	0.74	0.57	3.54	7
331I	3.28	1.18	1.16	5.40	12
341A	5.64	2.13	1.78	9.50	11
341B, 341C	7.44	1.48	3.94	10.93	23
341D, 341E	4.32	1.23	2.06	6.58	10
341F	5.47	0.70	3.44	7.50	20
341G	2.94	0.78	1.42	4.47	7
342A, 342E, 342F, 342G	6.18	0.99	4.37	7.99	10
342B, 342C	6.84	2.53	2.43	11.25	26
342D	5.14	4.51	-8.01	18.30	2
342H, 342I	2.76	1.98	-1.24	6.75	10
M212A	5.24	0.56	4.32	6.16	55
M212B	2.87	0.80	1.53	4.20	17
M212C	4.12	1.06	2.35	5.89	15
M212D, M212E	3.18	0.77	1.86	4.51	21
M221A	3.29	0.88	1.82	4.77	21
M221D	3.97	1.44	1.57	6.37	32
M242A, M242B	2.24	0.35	1.66	2.82	97
M242C	3.60	0.70	2.42	4.78	64
M261A	2.03	0.46	1.25	2.80	45

continued

Appendix table B.9—Softwood dieback status summary statistics (continued)

Ecoregion section code[a]	Softwood dieback	Standard error	90% confidence interval Lower	Upper	Plots
	percent				*no.*
M261B	-0.39	0.45	-1.19	0.41	11
M261C, M261F	1.96	1.11	-0.20	4.12	10
M261D	2.78	0.64	1.69	3.87	24
M261E	2.79	0.57	1.84	3.75	53
M261G	6.27	3.87	-0.41	12.96	21
M262A, 261A	6.55	3.24	-0.36	13.46	6
M262B	4.35	3.13	-1.95	10.65	5
M331A, M331J	5.02	0.89	3.46	6.59	19
M331B	9.75	1.47	0.47	19.03	5
M331D	5.18	1.77	2.09	8.27	34
M331E	3.21	0.95	1.54	4.88	16
M331F	0.34	0.42	-0.39	1.07	12
M331G	3.38	0.58	2.41	4.34	38
M331H	4.32	1.81	1.16	7.47	15
M331I	3.63	0.56	2.69	4.56	48
M332A	4.49	1.63	1.76	7.21	51
M332E	6.06	1.61	2.94	9.19	7
M332F	3.85	2.00	0.18	7.52	10
M332G	4.13	0.97	2.47	5.79	44
M333A	0.78	0.36	0.16	1.39	39
M333D	3.82	0.72	2.58	5.05	26
M334A	1.74	1.25	-6.15	9.63	2
M341A	4.64	1.29	2.42	6.85	22
M341B	6.26	1.51	3.50	9.02	15
M341C	5.56	0.62	4.50	6.62	27

[a] Plots from ecoregion sections appearing together in the table were aggregated and analyzed as a group because there was an insufficient number of plots to analyze each section individually.

Appendix table B.10—Softwood dieback change summary statistics

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Softwood dieback annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.*	- - - - - - -	
212A	0.17	56	3.21	0.0022	0.56	11	68	0.597
212B	0.30	143	2.66	0.0088	0.80	27	171	0.600
212C	0.74	37	2.14	0.0390	1.58	7	45	0.463
212D	0.16	99	4.99	0.0000	0.78	18	118	0.557
212E, 212F, 212G	0.47	13	1.81	0.0928	0.85	11	25	0.518
212H	0.17	125	-1.33	0.1850	-0.22	58	184	0.888
212J	0.18	75	1.74	0.0863	0.31	39	115	0.555
212K	0.90	24	1.27	0.2151	1.15	17	42	0.621
212L	0.24	63	-2.65	0.0100	-0.63	60	124	0.230
212M	0.18	38	-1.16	0.2548	-0.21	35	74	0.761
212N	0.27	46	1.18	0.2426	0.32	46	93	0.467
221A, 221B	0.33	135	2.37	0.0191	0.79	24	160	0.367
221C, 221D	0.27	44	1.03	0.3103	0.27	9	54	0.415
221E, 221F	0.38	14	1.54	0.1461	0.58	11	26	0.064
222E, 222F	0.34	3	-1.39	0.2597	-0.47	4	8	0.570
222H, 222I, 222J	0.18	7	-1.41	0.2002	-0.26	4	12	0.103
222K, 222L	0.40	11	0.19	0.8542	0.08	6	18	0.798
222M	0.20	3	-7.87	0.0043	-1.58	5	9	0.490
231A	0.05	374	-2.88	0.0042	-0.15	154	529	0.405
231B	0.09	172	-2.51	0.0130	-0.22	46	219	0.487
231C	0.09	54	0.45	0.6523	0.04	13	68	0.353
231D	0.17	39	-0.17	0.8693	-0.03	9	49	0.236
232A	0.23	92	0.08	0.9399	0.02	28	121	0.145
232B	0.09	250	0.41	0.6831	0.04	85	336	0.409
232C, 232G	0.09	54	-0.04	0.9673	0.00	48	103	0.103
242A	0.46	13	-2.19	0.0477	-1.00	26	40	0.042
263A	0.21	14	-0.65	0.5282	-0.14	12	27	0.740

continued

Appendix table B.10—Softwood dieback change summary statistics (continued)

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Softwood dieback annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.*	- - - - - - -	
313A	1.69	2	-0.66	0.5763	-1.12	2	5	0.153
331A	0.18	3	-0.07	0.9470	-0.01	5	9	0.898
331F, 331G	0.71	5	-2.47	0.0567	-1.75	7	13	0.088
331I	0.48	11	-0.87	0.4006	-0.42	12	24	0.329
341B, 341C	0.17	3	-0.28	0.7959	-0.05	5	9	0.004
341F	0.50	2	0.91	0.4605	0.46	3	6	0.513
342A, 342E, 342F, 342G	0.28	9	-2.98	0.0156	-0.83	10	20	0.783
342B, 342C	1.22	13	1.13	0.2802	1.38	16	30	0.584
342D	0.10	2	-24.96	0.0016	-2.53	2	5	0.990
342H, 342I	1.17	5	-0.15	0.8843	-0.18	10	16	0.606
M212A	0.09	294	2.12	0.0346	0.20	55	350	0.341
M212B	0.13	85	-0.23	0.8199	-0.03	17	103	0.211
M212C	0.17	70	-1.66	0.1006	-0.28	14	85	0.369
M221A	0.28	46	-0.99	0.3265	-0.28	20	67	0.004
M221D	0.19	61	-0.05	0.9590	-0.01	32	94	0.344
M242A, M242B	0.23	62	-1.98	0.0519	-0.47	97	160	0.659
M242C	0.31	42	0.01	0.9935	0.00	64	107	0.873
M261A	0.11	42	0.71	0.4825	0.08	45	88	0.495
M261B	0.55	13	-1.65	0.1232	-0.91	11	25	0.517
M261C, M261F	0.26	6	-0.06	0.9508	-0.02	10	17	0.284
M261D	0.15	24	1.39	0.1785	0.21	24	49	0.510
M261E	0.09	68	2.45	0.0167	0.22	52	121	0.336
M261G	0.08	19	2.69	0.0144	0.23	21	41	0.995
M262A, 261A	0.61	4	1.21	0.2935	0.74	6	11	0.107
M262B	0.26	5	-0.65	0.5416	-0.17	5	11	0.973

continued

Appendix table B.10—Softwood dieback change summary statistics (continued)

Ecoregion section code[a]	Std. error	Degrees of freedom	*t*-value[b]	Probability of > *t*	Softwood dieback annual change[c]	Plots	Observations[d]	r^2
					percent	- - - - - - - *no.*	- - - - - - -	
M331A, M331J	0.55	15	-0.30	0.7681	-0.16	19	35	0.670
M331B	0.90	1	2.10	0.2824	1.89	5	7	0.423
M331D	0.81	16	1.03	0.3184	0.84	21	38	0.937
M331F	0.25	16	-2.80	0.0127	-0.71	12	29	0.654
M331G	0.13	48	-1.70	0.0962	-0.22	38	87	0.598
M331H	0.29	17	1.15	0.2654	0.34	15	33	0.510
M331I	0.09	56	1.69	0.0973	0.16	48	105	0.584
M332A	0.24	52	-1.99	0.0518	-0.48	51	104	0.971
M332E	0.74	6	-1.83	0.1165	-1.35	7	14	0.900
M332F	0.50	9	-1.92	0.0872	-0.95	10	20	0.702
M332G	0.27	25	0.06	0.9549	0.02	44	70	0.950
M333A	0.42	34	-3.03	0.0046	-1.27	39	74	0.040
M333D	0.33	26	0.65	0.5220	0.21	26	53	0.286
M334A	0.24	1	0.54	0.6864	0.13	2	4	0.914
M341B	0.27	9	0.57	0.5812	0.15	7	17	0.780

[a] Plots from ecoregion sections appearing together in the table were aggregated and analyzed as a group because there was an insufficient number of plots to analyze each section.
[b] H_0: annual change in softwood transparency equals zero.
[c] Change values represent the average annual change in the indicator value over the period from initial measurement to 1999. Each of the five condition classes for softwood dieback were based on significant changes where $p < 0.33$. All values that were not significant at this level were considered to be no change.
[d] Each observation represents one visit to a plot.

Appendix table B.11—Hardwood damage summary statistics

Ecoregion section code	Plots	Plots with damage		Plots with significant damage		Trees damaged	Analyzing only plots with some recorded damage: Damage severity index Mean	Min.	Max.	Std. dev.	Trees damaged on each plot Mean	Min.	Max.	Std. dev.
	- - - - no.	*- - -*	*percent*	*no.*	*- - - - - - percent-*	*- - - - -*					*- - - - - - - - - - percent-*			*- - - - - - - - -*
212A	9	8	88.89	1	11.111	10.987	7.117	0.423	17.087	5.772	12.54	1.21	27.56	8.56
212B	26	21	80.77	6	23.077	11.250	11.163	1.081	41.667	10.702	17.68	2.58	48.48	13.54
212C	6	4	66.67	2	33.333	15.828	15.553	0.369	25.833	11.235	26.31	0.74	43.54	18.27
212D	18	17	94.44	1	5.556	12.306	6.670	0.266	15.000	4.388	16.58	0.97	45.00	12.95
212E	9	9	100.00	2	22.222	15.524	9.470	2.200	22.552	7.578	16.97	4.00	32.29	9.19
212F	46	38	82.61	6	13.043	16.191	8.776	0.335	32.089	7.675	19.13	0.89	63.38	14.96
212G	18	16	88.89	4	22.222	17.312	10.871	2.374	37.123	10.756	22.29	8.06	62.00	18.43
212H	77	66	85.71	7	9.091	10.185	7.128	0.023	50.410	8.717	15.50	0.27	63.43	13.78
212J	73	70	95.89	21	28.767	19.633	13.089	0.064	51.039	12.567	26.01	0.76	100.00	20.47
212K	26	24	92.31	3	11.538	13.045	7.945	0.120	22.146	6.125	17.57	0.24	41.71	12.66
212L	60	54	90.00	10	16.667	18.566	9.285	0.960	33.333	7.439	21.02	1.92	66.67	14.90
212M	39	32	82.05	6	15.385	13.331	8.175	0.372	26.692	6.506	18.20	0.74	50.00	14.02
212N	72	64	88.89	11	15.278	13.598	7.925	0.357	25.970	6.597	18.81	1.75	71.43	15.69
221A	45	40	88.89	4	8.889	13.479	8.070	0.662	62.791	10.448	15.51	1.30	67.44	13.78
221B	8	8	100.00	2	25.000	20.144	10.215	3.709	21.250	6.232	23.23	7.79	40.30	11.11
221C	9	7	77.78	4	44.444	24.748	19.883	4.494	31.500	11.670	34.98	6.74	60.00	19.26
221D	13	12	92.31	3	23.077	21.086	15.170	1.392	49.454	16.555	24.77	3.16	58.72	18.99
221E	44	40	90.91	8	18.182	15.833	8.951	0.182	36.692	8.308	17.75	1.45	56.92	13.07
221F	6	6	100.00	2	33.333	25.391	14.719	7.000	26.471	9.029	26.93	13.33	52.94	14.74
221H	18	18	100.00	9	50.000	30.011	20.043	2.273	52.324	14.905	36.64	3.45	100.00	26.91
221I	9	9	100.00	5	55.556	36.459	21.821	1.748	42.708	15.981	31.93	4.20	68.24	24.16
221J	11	10	90.91	5	45.455	32.437	19.853	10.471	41.827	10.573	36.43	21.43	57.14	13.49
222A	88	85	96.59	21	23.864	22.559	10.565	0.194	39.756	9.568	27.07	1.11	91.76	21.39
222C	16	16	100.00	10	62.500	33.317	20.030	2.783	35.714	10.736	33.72	4.35	74.56	21.29
222D	9	9	100.00	3	33.333	17.225	18.074	2.364	60.000	19.386	24.90	3.54	66.67	21.62
222E	36	35	97.22	17	47.222	25.284	18.469	1.063	66.667	16.198	31.31	1.99	80.65	19.22
222F	7	7	100.00	3	42.857	30.210	11.379	1.625	22.550	8.825	20.34	3.33	56.29	21.54
222G	9	9	100.00	3	33.333	27.529	11.073	1.887	18.750	5.355	26.61	3.77	53.22	14.93
222H	11	10	90.91	1	9.091	16.064	7.352	1.770	18.997	4.823	15.55	3.54	35.11	9.27
222I	10	5	50.00	0	0.000	15.794	5.913	0.517	12.409	4.654	15.60	3.45	28.05	11.50

continued

Appendix table B.11—Hardwood damage summary statistics (continued)

Ecoregion section code	Plots	Plots with damage		Plots with significant damage		Trees damaged	Analyzing only plots with some recorded damage: Damage severity index: Mean	Min.	Max.	Std. dev.	Trees damaged on each plot: Mean	Min.	Max.	Std. dev.
	no.	*no.*	*percent*	*no.*	*percent*	*percent*					*percent*	*percent*	*percent*	*percent*
222J	25	21	84.00	8	32.000	18.235	10.981	0.488	31.481	9.597	19.63	0.98	54.71	15.67
222K	15	12	80.00	4	26.667	25.531	15.632	0.000	52.632	17.366	32.96	3.08	93.98	30.86
222L	20	20	100.00	7	35.000	21.177	14.724	0.267	48.485	13.301	29.85	1.07	81.82	25.20
222M, 222N	44	41	93.18	6	13.636	14.908	7.805	0.221	35.196	7.179	16.61	0.88	68.63	14.30
231A	164	137	83.54	21	12.805	13.863	7.743	0.060	72.414	10.483	16.93	0.50	89.66	18.54
231B	59	51	86.44	10	16.949	13.843	9.232	0.263	55.000	10.415	21.36	0.91	100.00	20.70
231C	18	16	88.89	4	22.222	18.785	11.566	0.265	46.791	12.091	20.42	0.68	66.84	17.67
231D	9	8	88.89	2	22.222	18.084	10.360	4.171	25.692	7.580	25.13	6.86	53.85	17.23
232A	47	46	97.87	13	27.660	23.463	11.955	0.478	43.000	9.310	26.07	0.96	66.67	17.78
232B	75	58	77.33	19	25.333	14.823	11.528	0.268	47.500	10.525	26.83	0.70	97.53	23.90
232C, 232G	46	37	80.43	8	17.391	14.614	9.479	0.402	34.572	8.765	19.96	0.80	54.61	14.53
242A	17	12	70.59	5	29.412	10.026	14.272	0.463	50.000	16.345	27.79	1.85	100.00	31.46
251A, 251B	6	6	100.00	2	33.333	20.488	10.225	0.500	24.419	9.149	22.81	1.67	43.02	14.64
251C, 251E	29	25	86.21	5	17.241	11.422	8.815	0.100	36.522	9.228	22.12	1.44	100.00	25.03
251D	16	14	87.50	5	31.250	15.592	11.939	0.556	33.333	9.845	21.83	1.11	50.00	16.28
263A	7	7	100.00	1	14.286	8.434	14.590	2.358	63.750	21.978	22.50	5.66	100.00	34.33
341A, 341B, 341D, 341F, 341G	5	4	80.00	1	20.000	37.658	14.475	4.151	33.092	12.918	43.50	26.42	66.67	17.04
342B, 342C	10	9	90.00	4	40.000	24.533	20.326	0.132	75.000	25.662	35.17	1.32	100.00	32.50
M212A	60	55	91.67	11	18.333	16.302	9.440	0.349	26.635	6.311	20.39	0.41	51.92	12.23
M212B	20	18	90.00	8	40.000	20.922	16.373	3.197	43.333	12.115	30.32	6.29	72.00	19.56
M212C	19	17	89.47	8	42.105	23.518	15.556	1.607	38.943	10.468	26.97	2.14	61.79	17.96
M212D	34	33	97.06	12	35.294	23.154	12.983	0.758	62.554	11.893	25.65	1.52	89.57	19.41
M212E	9	9	100.00	3	33.333	30.382	15.355	5.966	31.208	8.594	28.05	16.74	61.74	14.06
M221A	76	69	90.79	11	14.474	15.972	9.679	0.258	65.347	12.149	20.29	0.94	81.82	17.23
M221B	27	25	92.59	9	33.333	15.578	12.522	0.629	56.980	12.916	20.11	1.26	54.10	16.33
M221C	17	17	100.00	4	23.529	17.007	11.617	0.604	39.722	12.927	22.18	3.21	62.50	21.15
M221D	61	58	95.08	15	24.590	18.924	9.490	0.177	26.301	6.941	20.03	0.59	49.66	13.04
M242A, M242B	31	19	61.29	3	9.677	6.053	8.330	0.368	63.750	14.289	21.29	0.74	100.00	26.30

continued

Appendix table B.11—Hardwood damage summary statistics (continued)

Ecoregion section code	Plots	Plots with damage		Plots with significant damage		Trees damaged	Analyzing only plots with some recorded damage: Damage severity index: Mean	Min.	Max.	Std. dev.	Trees damaged on each plot: Mean	Min.	Max.	Std. dev.
	---- *no.* ---		*percent*	*no.*	------ *percent* ------						---------- *percent* ---------			
M261A	34	32	94.12	6	17.647	11.942	11.796	0.000	127.500	23.068	22.75	0.44	100.00	23.58
M261B	14	14	100.00	3	21.429	14.472	10.719	1.022	35.000	9.043	19.18	1.86	41.18	12.38
M261C	6	3	50.00	1	16.667	22.449	11.853	2.515	27.778	13.859	37.00	18.34	48.21	16.27
M261D, M261G	7	7	100.00	2	28.571	31.773	12.860	4.685	30.000	9.478	39.87	8.39	57.14	16.25
M261E	15	11	73.33	3	20.000	14.869	13.528	0.394	60.000	17.820	35.09	1.43	100.00	33.62
M261F	21	19	90.48	7	33.333	16.591	13.408	0.386	41.176	12.164	30.40	0.77	86.67	26.61
M262A, M262B	16	14	87.50	7	43.750	25.289	18.263	0.411	57.778	18.867	36.29	1.27	100.00	31.90
M331D	5	5	100.00	3	60.000	35.233	17.068	5.821	31.892	10.897	45.69	11.94	100.00	36.10
M331F, M331G	19	18	94.74	16	84.211	48.559	28.664	1.628	47.404	13.959	54.94	13.95	100.00	22.39
M331H, M331I	24	24	100.00	13	54.167	30.069	17.387	1.528	55.455	14.171	34.45	3.70	92.59	19.26
M332A, M332G	6	4	66.67	2	33.333	25.000	16.053	11.111	20.333	4.685	55.30	11.11	80.00	31.76
M332E, M332F	6	6	100.00	1	16.667	7.122	10.076	0.699	39.167	14.762	14.07	2.47	58.33	21.76
M333A	7	5	71.43	2	28.571	32.696	16.961	1.667	49.661	21.282	37.03	3.70	96.61	39.58
M333D	6	4	66.67	0	0.000	5.645	4.784	2.469	9.167	3.153	30.40	4.94	66.67	26.84
M341A	5	5	100.00	2	40.000	13.889	11.230	3.462	15.909	5.029	16.25	7.69	27.27	7.71

Appendix table B.12—Softwood damage summary statistics

Ecoregion section code	Plots	Plots with damage		Plots with significant damage		Trees damaged	Analyzing only plots with some recorded damage: Damage severity index				Analyzing only plots with some recorded damage: Trees damaged on each plot			
							Mean	Min.	Max.	Std. dev.	Mean	Min.	Max.	Std. dev.
	- - - - *no.* - - -		*percent*	*no.*	- - - - - - *percent* - - - - - -						- - - - - - - - - - *percent* - - - - - - - - - -			
212A	10	9	90.00	1	10.000	3.340	5.268	0.070	21.970	6.999	13.90	0.12	81.82	25.94
212B	27	15	55.56	3	11.111	3.941	6.596	0.032	30.000	8.815	14.75	0.63	100.00	25.00
212C	7	7	100.00	1	14.286	3.232	7.145	0.062	34.884	12.392	16.06	0.25	76.74	27.17
212D	17	14	82.35	0	0.000	7.349	3.621	0.134	11.243	3.440	10.51	0.67	36.36	10.31
212E, 212F, 212G	29	16	55.17	1	3.448	5.368	5.619	0.060	30.000	7.161	20.60	0.68	83.33	21.04
212H	54	37	68.52	3	5.556	10.950	4.948	0.114	26.222	6.604	13.66	0.97	72.53	16.10
212J	33	22	66.67	1	3.030	11.778	9.790	0.449	121.613	25.175	17.01	2.83	87.10	18.20
212K	15	12	80.00	2	13.333	11.811	11.976	0.806	71.667	19.585	27.74	3.23	100.00	27.68
212L	59	44	74.58	2	3.390	5.799	3.299	0.157	20.000	4.381	10.11	0.84	100.00	15.17
212M	34	29	85.29	2	5.882	10.293	4.171	0.082	23.750	5.705	12.89	0.55	67.71	15.12
212N	45	33	73.33	4	8.889	9.894	7.492	0.222	42.222	10.295	21.67	0.74	100.00	23.06
221A, 221B	28	14	50.00	2	7.143	6.637	4.486	0.000	18.750	5.649	14.27	0.63	37.50	13.34
221C, 221D	9	6	66.67	0	0.000	7.281	3.024	1.316	5.165	1.566	10.96	1.83	20.66	7.48
221E, 221F	11	2	18.18	0	0.000	1.932	3.925	1.600	6.250	3.288	6.17	4.00	8.33	3.06
221H	9	6	66.67	0	0.000	3.155	2.000	0.229	5.490	1.921	6.01	1.53	15.69	5.72
221I, 221J	13	9	69.23	2	15.385	12.617	14.254	0.263	72.500	23.730	32.07	2.50	100.00	34.42
222A	25	15	60.00	3	12.000	7.588	6.493	0.250	26.047	9.002	24.54	2.33	100.00	29.85
222C	5	3	60.00	1	20.000	5.618	20.118	0.353	47.500	24.479	39.67	2.35	100.00	52.73
222E, 222F	6	3	50.00	1	16.667	29.210	18.019	4.000	43.390	22.012	40.66	20.00	68.64	25.14
222H, 222I, 222J	7	2	28.57	0	0.000	2.469	0.398	0.259	0.538	0.197	3.01	1.72	4.30	1.82
222K, 222L	6	2	33.33	0	0.000	4.787	6.653	3.306	10.000	4.734	19.97	6.61	33.33	18.90
222M	5	5	100.00	1	20.000	16.703	9.004	2.500	16.250	5.603	16.76	10.43	25.00	5.74
231A	135	79	58.52	7	5.185	7.388	6.295	0.155	28.667	6.319	17.49	0.51	60.00	15.17
231B	42	22	52.38	4	9.524	11.814	8.521	0.857	21.506	6.186	24.39	3.33	100.00	21.81
231C	10	3	30.00	0	0.000	1.983	2.633	0.513	6.250	3.148	12.70	9.09	18.75	5.27
231D	8	3	37.50	0	0.000	4.390	4.714	1.020	7.407	3.309	15.14	2.04	28.57	13.27
232A	26	11	42.31	1	3.846	2.044	4.081	0.467	15.000	4.553	14.93	1.87	50.00	14.79
232B	74	50	67.57	6	8.108	11.035	6.765	0.076	31.250	6.458	17.16	1.25	50.00	12.61

continued

Appendix table B.12—Softwood damage summary statistics (continued)

Ecoregion section code	Plots	Plots with damage		Plots with significant damage		Trees damaged	Analyzing only plots with some recorded damage: Damage severity index Mean	Min.	Max.	Std. dev.	Trees damaged on each plot Mean	Min.	Max.	Std. dev.
	- - - - no. - - -		percent	no.	- - - - - - percent- - - - - -						- - - - - - - - - - percent- - - - - - - - -			
232C, 232G	47	31	65.96	2	4.255	10.202	6.395	0.233	28.333	6.260	14.54	1.23	33.33	10.65
242A	26	18	69.23	0	0.000	6.356	2.169	0.103	7.647	2.012	7.96	1.14	26.47	6.30
263A	6	6	100.00	1	16.667	15.319	6.626	0.370	15.000	5.917	15.02	3.70	34.48	12.05
331A	6	5	83.33	0	0.000	16.902	5.022	3.472	7.665	1.663	16.02	8.33	22.16	5.11
331F, 331G	7	4	57.14	3	42.857	38.141	20.760	7.093	31.667	10.307	54.67	17.21	100.00	34.11
331I	10	8	80.00	1	10.000	25.595	10.911	0.465	44.259	14.137	29.43	4.65	74.07	23.52
341B, 341C	9	9	100.00	4	44.444	36.245	13.539	0.526	33.333	12.304	43.03	2.63	92.59	31.62
341D, 341E	12	8	66.67	0	0.000	18.425	5.226	0.227	14.000	4.953	22.29	1.14	57.14	18.48
341F	12	9	75.00	2	16.667	13.644	9.840	2.961	38.125	11.473	17.82	5.76	37.50	8.96
341G	7	5	71.43	1	14.286	27.952	10.551	1.429	19.065	6.815	25.62	14.29	50.32	14.30
342A, 342E, 342F, 342G	11	9	81.82	4	36.364	31.739	22.620	0.625	74.000	29.094	34.97	8.92	90.00	26.61
342B, 342C	27	17	62.96	3	11.111	8.809	7.704	0.581	31.000	8.894	17.80	2.33	42.86	12.99
342H, 342I	10	6	60.00	2	20.000	12.816	9.363	1.389	23.182	9.287	24.94	5.56	65.33	23.45
M212A	53	36	67.92	1	1.887	4.660	3.733	0.217	18.333	4.457	14.53	0.70	92.59	23.57
M212B	17	12	70.59	1	5.882	8.224	4.723	0.436	17.600	5.316	12.20	2.01	48.08	13.23
M212C	14	7	50.00	0	0.000	9.440	3.114	0.286	5.882	2.095	12.77	0.98	29.41	9.50
M212D, M212E	24	14	58.33	1	4.167	14.739	4.568	0.000	15.800	4.278	17.57	2.30	54.67	14.77
M221A	19	9	47.37	1	5.263	8.601	5.984	0.917	21.875	7.108	15.55	1.83	48.21	13.72
M221D	32	14	43.75	2	6.250	8.673	9.436	0.375	42.000	12.524	27.20	2.16	100.00	34.41
M242A, M242B	96	78	81.25	8	8.333	10.011	6.154	0.104	43.571	7.518	15.53	0.90	57.14	14.41
M242C	63	56	88.89	11	17.460	24.924	11.710	0.025	81.475	17.007	26.22	0.25	83.33	21.01
M261A	47	30	63.83	2	4.255	10.645	4.996	0.159	22.222	5.193	14.59	1.32	34.40	11.56
M261B	12	6	50.00	1	8.333	6.912	9.834	0.190	32.500	12.250	20.20	1.90	50.00	16.62
M261C, M261F	10	3	30.00	1	10.000	18.056	7.748	0.370	21.875	12.238	19.55	7.41	31.25	11.93
M261D	18	15	83.33	1	5.556	12.464	6.704	0.333	44.848	11.099	21.14	3.13	100.00	25.94
M261E	52	39	75.00	5	9.615	10.813	7.352	0.112	32.037	9.062	18.16	0.45	51.85	16.20
M261G	25	14	56.00	3	12.000	12.584	14.726	0.606	90.000	25.525	32.44	4.04	100.00	33.72
M262A, 261A	7	5	71.43	2	28.571	28.889	12.523	1.364	25.000	9.929	49.15	9.09	70.00	24.23

continued

Appendix table B.12—Softwood damage summary statistics (continued)

Ecoregion section code	Plots	Plots with damage		Plots with significant damage		Trees damaged	Analyzing only plots with some recorded damage: Damage severity index Mean	Min.	Max.	Std. dev.	Trees damaged on each plot Mean	Min.	Max.	Std. dev.
	no.	no.	percent	no.	percent	percent					percent	percent	percent	percent
M331A, M331B, M331J	23	19	82.61	4	17.391	25.105	10.046	0.500	27.447	8.121	28.24	2.47	100.00	23.63
M331D	21	17	80.95	3	14.286	22.984	10.055	1.371	38.333	9.626	25.20	3.17	67.44	18.31
M331F	10	8	80.00	1	10.000	22.423	5.425	1.579	17.931	5.483	24.47	5.33	65.52	20.32
M331G	29	24	82.76	3	10.345	21.290	7.080	0.222	29.694	7.690	23.38	3.03	59.18	17.74
M331H	24	21	87.50	4	16.667	26.500	9.534	0.625	64.286	13.678	27.09	3.64	87.10	21.65
M331I	35	32	91.43	5	14.286	21.161	10.695	0.292	88.852	17.447	22.47	1.17	86.89	20.48
M332A	51	48	94.12	4	7.843	19.477	10.919	0.428	130.000	20.382	24.94	2.63	100.00	22.93
M332E	7	7	100.00	1	14.286	20.000	9.283	0.438	29.697	9.920	26.52	2.92	53.03	16.38
M332F	10	7	70.00	2	20.000	19.339	10.445	1.029	26.364	9.423	23.39	5.88	49.09	14.78
M332G	42	35	83.33	3	7.143	19.425	7.769	0.128	73.750	12.423	23.00	1.28	75.00	19.88
M333A	39	30	76.92	2	5.128	11.047	5.463	0.335	40.093	7.857	13.77	1.12	41.67	10.96
M333D	26	23	88.46	1	3.846	7.145	4.319	0.315	23.214	5.212	8.03	0.62	23.77	6.89
M341A	22	18	81.82	2	9.091	22.646	9.799	0.242	38.475	8.736	25.39	1.61	56.52	15.57
M341B	9	9	100.00	4	44.444	35.701	23.628	1.037	60.000	21.472	41.45	5.93	100.00	31.41

Appendix table B.13—Tree mortality summary statistics

Ecoregion section code	Plots	Plots with mortality	Obser.	Mortality	Growth	MRATIO	Std. error of MRATIO	DDLD ratio Mean	DDLD ratio Minimum	DDLD ratio Maximum	DDLD ratio Std. error	Plot mortality volume Mean	Plot mortality volume Minimum	Plot mortality volume Maximum
	- - - - no. - - - -			- - ft³ per ac per yr - -								- - - - ft³ per acre - - - -		
212A	12	9	39	36.55	99.51	0.367	0.1315	1.217	0.523	2.530	0.6116	425.8	32.8	1041.9
212B	29	23	100	31.06	83.36	0.373	0.0987	0.916	0.287	1.868	0.4343	290.5	19.5	1467.5
212C, 212D	26	24	93	32.78	78.41	0.418	0.0838	0.798	0.180	1.802	0.3517	282.8	16.6	866.9
212E, 212F, 212G	15	8	38	37.94	86.91	0.437	0.1453	1.634	0.331	3.312	1.0545	254.8	42.4	530.7
212H	77	52	181	40.77	62.84	0.649	0.1946	1.172	0.207	4.920	1.0694	259.8	2.9	2485.3
212J	70	44	161	28.07	70.26	0.400	0.0946	0.827	0.156	2.070	0.4857	174.5	6.6	1019.6
212K	13	8	28	27.47	56.32	0.488	0.1663	0.707	0.295	1.449	0.3835	143.9	35.4	341.0
212L	13	7	28	44.98	45.37	0.991	0.3026	1.126	0.452	1.916	0.3143	238.4	73.0	415.6
212M	5	1	13	23.59	61.86	0.381	0.3516	3.458	3.458	3.458	0.0000	536.4	536.4	536.4
212N	16	7	34	47.39	65.86	0.720	0.2970	0.637	0.408	1.085	0.1294	271.2	13.3	688.5
221A	44	40	157	23.91	63.59	0.376	0.0569	0.800	0.171	2.148	0.4688	214.5	5.9	601.2
221E, 221F	38	24	125	30.08	84.01	0.358	0.0873	0.940	0.191	2.790	0.7178	172.5	12.8	1337.2
222D	5	3	11	105.39	67.45	1.562	0.6746	0.872	0.273	1.263	0.5272	306.1	14.8	506.7
222E, 222F	13	5	32	34.36	160.77	0.214	0.0789	0.652	0.296	1.299	0.3913	224.9	13.2	450.8
222G	5	3	10	11.04	88.57	0.125	0.0627	1.034	0.217	1.658	0.7395	27.5	14.7	39.0
222H	8	7	16	98.57	106.40	0.926	0.5542	1.088	0.257	3.151	1.0066	231.8	12.2	1089.0
222I, 222J	23	16	52	22.67	73.29	0.309	0.1053	0.877	0.176	1.695	0.4829	109.2	4.4	410.7
222K	12	4	26	14.07	57.90	0.243	0.1319	1.498	0.788	2.206	0.5795	168.6	64.6	296.9
222L	11	4	22	20.57	46.76	0.440	0.3651	0.899	0.266	1.741	0.6588	184.8	10.3	439.0
222M, 222N	11	5	27	16.64	56.05	0.297	0.1697	0.909	0.528	1.602	0.2990	152.5	24.8	266.3
231A	139	105	376	32.57	127.34	0.256	0.0426	0.780	0.056	3.734	0.5909	259.6	3.7	1928.6
231B	65	56	190	22.09	126.28	0.175	0.0292	0.747	0.115	2.254	0.5315	173.1	5.9	798.6
231C	34	31	100	48.98	83.96	0.583	0.1509	0.794	0.167	2.578	0.5289	352.4	8.7	2783.0
232A	18	16	54	44.13	137.24	0.322	0.1336	0.571	0.227	1.275	0.2878	317.5	7.4	1755.8
232B	88	57	240	24.37	130.52	0.187	0.0492	0.662	0.166	2.077	0.3644	206.0	4.4	1667.5
232C, 232G	29	15	73	26.93	98.05	0.275	0.1394	1.174	0.224	4.744	1.2586	198.3	4.9	1008.3
242A	16	1	35	11.79	150.59	0.078	0.0757	0.942	0.942	0.942	0.0000	219.9	219.9	219.9

continued

Appendix table B.13—Tree mortality summary statistics (continued)

Ecoregion section code	Plots	Plots with mortality	Obser.	Mortality	Growth	MRATIO	Std. error of MRATIO	DDLD ratio Mean	DDLD ratio Minimum	DDLD ratio Maximum	DDLD ratio Std. error	Plot mortality volume Mean	Plot mortality volume Minimum	Plot mortality volume Maximum
	- - - - - - - - - no.	- - - - - - - -		- - ft³ per ac per yr - -								- - - - - - - - ft³ per acre- - - - - -		
251C, 251D	13	4	27	74.51	75.99	0.981	0.4840	0.765	0.505	0.939	0.1932	359.4	118.4	578.0
263A	9	4	22	8.35	177.36	0.047	0.0239	0.900	0.229	2.026	0.7795	67.0	2.5	90.7
313A	5	1	13	1.02	11.71	0.087	0.0460	0.026	0.026	0.026	0.0000	8.5	8.5	8.5
331I	9	3	19	5.45	25.92	0.210	0.1785	0.234	0.019	0.572	0.2965	51.8	6.6	139.5
341B, 341C	7	2	17	1.40	12.08	0.116	0.1052	0.405	0.250	0.560	0.2188	26.1	25.6	26.5
342B, 342C	8	7	18	22.62	25.83	0.876	0.4420	0.950	0.428	1.978	0.4819	105.4	6.8	266.3
342H, 342I	6	1	12	6.52	15.38	0.424	0.4267	1.049	1.049	1.049	0.0000	48.9	48.9	48.9
M212A	70	63	250	41.43	71.43	0.580	0.0949	0.973	0.221	2.699	0.5943	362.2	15.4	2390.3
M212B	20	17	79	16.46	76.54	0.215	0.0486	0.874	0.197	3.392	0.8070	165.7	16.0	712.1
M212C	17	17	57	35.85	83.05	0.432	0.1116	1.272	0.191	4.252	0.9978	309.4	10.2	1532.5
M221A	48	38	145	34.13	71.42	0.478	0.1013	0.841	0.248	2.546	0.5469	228.5	4.5	899.5
M221B	19	9	65	19.95	73.75	0.271	0.1617	0.909	0.220	1.906	0.5739	170.6	6.7	592.4
M221C	16	10	58	14.53	69.85	0.208	0.0674	0.583	0.231	1.512	0.4696	98.7	28.0	196.6
M221D	32	17	84	34.75	109.32	0.318	0.1062	0.869	0.197	2.565	0.6222	273.6	21.6	1086.9
M242A, M242B	56	19	119	37.08	137.12	0.270	0.1237	0.849	0.325	3.371	0.6965	171.7	10.0	1283.3
M242C	39	10	83	33.14	51.94	0.638	0.3518	0.623	0.250	1.067	0.2692	181.5	2.2	962.6
M261A	40	21	93	44.22	80.87	0.547	0.2854	1.023	0.300	3.181	0.6691	329.2	9.3	3070.2
M261B	15	7	33	110.41	82.80	1.333	1.0989	1.704	0.243	7.018	2.4564	659.5	1.8	4049.1
M261C, M261F	25	10	56	4.10	34.43	0.119	0.0532	0.728	0.136	1.506	0.4618	51.6	2.2	123.2
M261D	15	7	32	10.01	96.54	0.104	0.0681	1.020	0.281	2.000	0.6334	143.1	1.5	386.6
M261E	52	18	124	32.09	74.82	0.429	0.1869	0.913	0.114	3.037	0.7370	425.4	5.3	2688.9
M261G	21	3	46	6.00	27.29	0.220	0.1541	1.044	0.386	1.443	0.5743	104.1	50.3	172.6
M262A	10	2	22	2.43	38.05	0.064	0.0670	1.997	0.902	3.092	1.5487	67.7	2.0	133.4
M262B	6	1	13	0.93	23.81	0.039	0.0388	0.304	0.304	0.304	0.0000	27.5	27.5	27.5
M331A, M331J	12	1	28	3.23	33.62	0.096	0.0959	0.863	0.863	0.863	0.0000	67.8	67.8	67.8
M331D	17	3	39	1.94	38.57	0.050	0.0387	0.737	0.286	1.112	0.4182	25.0	15.6	40.2
M331F	12	3	29	3.14	30.24	0.104	0.0742	0.286	0.034	0.749	0.4015	39.6	11.6	88.8
M331G	33	20	75	9.98	29.91	0.334	0.1217	0.933	0.053	3.129	0.7236	62.4	2.1	301.6

continued

Appendix table B.13—Tree mortality summary statistics (continued)

Ecoregion section code	Plots	Plots with mortality	Obser.	Mortality	Growth	MRATIO	Std. error of MRATIO	DDLD ratio Mean	DDLD ratio Minimum	DDLD ratio Maximum	DDLD ratio Std. error	Plot mortality volume Mean	Plot mortality volume Minimum	Plot mortality volume Maximum
	- - - - - - - - - *no.*	- - - - - - - -		- - *ft³ per ac per yr* - -								- - - - - - - - *ft³ per acre*	- - - - - - -	
M331H	37	20	88	16.94	45.43	0.373	0.0935	0.739	0.000	1.428	0.3383	112.1	6.1	289.9
M331I	32	15	72	5.13	34.48	0.149	0.0470	0.865	0.018	1.671	0.4958	47.0	2.4	143.6
M332A	48	15	104	33.89	52.53	0.645	0.2820	1.050	0.317	1.640	0.3645	216.2	10.7	991.0
M332E	7	1	16	2.80	32.70	0.086	0.0833	0.540	0.540	0.540	0.0000	32.3	32.3	32.3
M332F	9	2	19	18.44	27.99	0.659	0.4451	1.059	0.680	1.437	0.5355	159.5	127.6	191.5
M332G	27	8	57	35.62	39.65	0.898	0.5384	1.220	0.000	2.611	0.8311	216.7	14.4	1165.9
M333A	26	9	57	16.36	71.23	0.230	0.1013	1.066	0.492	1.802	0.4473	82.7	25.3	247.3
M333D	21	12	48	46.65	125.89	0.371	0.1995	1.428	0.287	4.652	1.2720	203.8	2.8	990.6
M341B	9	5	20	3.24	17.66	0.183	0.0990	0.651	0.000	1.829	0.8522	26.8	4.2	79.5

MRATIO = annual mortality volume to gross volume growth; DDLD = ratio of the average dead-tree diameter to the average live-tree diameter.

Appendix table B.14—Multivariate analysis loadings of each original indicator on each component after rotation

Indicator	Rotated factor pattern [a]								
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
Wet hydrogen deposition	0.922	0.152	-0.076	0.099	-0.152	0.029	-0.036	-0.078	0.020
Wet ammonium deposition	0.832	-0.053	0.123	-0.005	0.100	0.040	-0.123	0.253	-0.331
Wet nitrate deposition	0.947	0.065	-0.016	0.098	-0.073	0.049	-0.058	0.058	-0.156
Rainfall pH	-0.935	-0.130	0.114	-0.123	0.061	0.037	-0.010	-0.012	0.124
Wet sulfate deposition	0.966	0.119	-0.042	0.059	-0.074	0.010	-0.046	0.007	-0.049
Percent forest	0.078	0.962	-0.061	0.078	-0.105	0.071	0.024	-0.089	-0.062
Area-weighted average forest patch size	0.001	0.928	-0.202	0.096	-0.086	0.090	0.006	-0.123	-0.043
Forest connectivity	0.160	0.937	-0.011	-0.002	-0.073	0.001	0.035	-0.019	-0.089
Average forest patch size	0.170	0.502	-0.508	0.107	-0.126	0.187	-0.104	-0.089	-0.042
Number of forest patches	0.107	-0.457	0.776	-0.199	-0.075	0.002	-0.044	0.068	0.078
Forest edge	0.020	0.107	0.930	-0.113	-0.180	0.031	0.076	-0.005	0.029
Landcover texture	0.420	0.354	-0.732	0.074	0.174	-0.002	-0.098	0.136	-0.149
Hardwood dieback	-0.258	-0.078	-0.338	0.564	0.068	0.037	-0.394	0.130	0.123
Hardwood dieback change	0.148	0.099	-0.018	0.680	0.142	-0.061	-0.277	0.096	0.167
Softwood dieback	-0.017	0.044	-0.191	0.799	-0.070	-0.003	0.069	-0.026	-0.158
Softwood dieback change	0.223	0.064	-0.039	0.773	-0.063	0.065	0.200	-0.034	0.073
Hardwood foliar transparency	-0.419	-0.054	0.084	-0.011	0.725	0.154	-0.003	0.301	0.088
Hardwood foliar transparency change	-0.125	-0.049	-0.178	0.037	0.884	-0.029	-0.063	0.078	0.103
Softwood foliar transparency change	0.123	-0.252	-0.152	-0.094	0.752	0.000	-0.091	-0.324	-0.292
Softwood foliar transparency	0.415	0.039	0.519	-0.086	0.151	-0.047	-0.386	0.006	-0.298
Fire condition class 3 (percent)	-0.468	0.293	0.122	-0.018	-0.027	0.463	-0.357	0.066	-0.195
DDLD	0.078	0.248	-0.070	-0.085	-0.041	0.681	-0.116	0.216	0.009
MRATIO	0.064	-0.111	-0.007	0.104	0.105	0.688	0.079	-0.148	0.108
Growth	0.300	0.639	-0.040	-0.262	0.151	-0.274	-0.303	0.073	0.237
Carbon sequestration	0.251	0.217	-0.022	-0.499	0.384	-0.432	-0.128	0.163	0.216

continued

Appendix table B.14—Multivariate analysis loadings of each original indicator on each component after rotation (continued)

Indicator	Rotated factor pattern [a]								
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
Ozone bioindicator	0.696	0.005	-0.095	-0.071	-0.170	-0.018	0.016	-0.019	0.367
Species richness	0.669	0.322	0.131	-0.061	0.204	-0.229	-0.121	-0.179	-0.009
Softwood damage	-0.624	-0.089	-0.092	0.226	0.021	-0.297	0.002	-0.247	-0.158
Hardwood damage	-0.150	-0.012	0.063	-0.001	-0.075	-0.031	0.868	0.081	-0.018
99 insect and pathogen (percent)	0.066	-0.265	0.011	0.052	0.079	0.008	0.055	0.813	-0.103
99 drought	0.661	-0.137	0.135	0.064	-0.015	-0.034	-0.018	-0.430	0.374
Drought deviation	-0.235	-0.322	0.257	0.099	0.107	0.229	-0.057	-0.305	0.611
Eigen value [b]	7.86	4.63	3.07	2.82	1.84	1.72	1.42	1.12	1.03
Total sample variance explained (percent)	24.6	14.5	9.6	8.8	5.8	5.4	4.4	3.5	3.2
Cumulative sample variance explained (percent)	24.6	39.0	48.6	57.4	63.2	68.6	73.0	76.5	79.7

MRATIO = annual mortality volume to gross volume growth.
[a] Numbers in boxes are indicators with highest loadings for each factor and are basis of interpreting factors.
[b] Only significant factors are shown. Criterion for determining significance was an Eigen value > 1 (Johnson and Wichern 1982).

APPENDIX C

Summary of 1999 Forest Health Monitoring Quality Assurance Report

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Introduction

The Forest Health Monitoring (FHM) Program is a cooperative multiagency effort designed to monitor, evaluate, and report on long-term changes and trends in the health of the Nation's forest ecosystems (FHM Strategic Plan 1994). Its major purpose is to provide scientifically sound information that meets the policy and program management needs of the FHM partners. The program's goal is to produce complete, accurate, and unbiased forest health information of known quality. To accomplish this goal, a number of quality assurance (QA) procedures have been implemented in the FHM Program.

A plan was developed for QA implementation in 1999 that detailed the specific roles and responsibilities of various FHM personnel for QA activities during the 1999 field season.[1] The QA protocols used in 1999 were a synthesis of past QA activities but primarily were based on results of analysis of the 1998 FHM QA data.[2] As in 1998, the core FHM QA program in 1999 was a combination of training, auditing, remeasurement protocols, and debriefings. QA procedures were standardized on a national scale to provide comparable datasets representing the five FHM regions.

Each region provided documentation on the extent of training, debriefing, and QA data collection activities that were implemented during the 1999 field season. Core variables for the crowns, damage, soils, ozone, and mensuration indicators were assessed for precision, bias, and measurement quality objective (MQO) achievement using data derived from regional expert team plot remeasurement data.

These analyses used data derived from complete remeasurements of plots by a regionally experienced team of foresters (QA crews or auditors). It should be noted that the QA crews who conducted the FHM Program typically had attended pretraining sessions (interregional calibration and seasonal refreshers) and had numerous field seasons' experience before being selected as a regional QA crew. However, no statement is made in these analyses as to which crew was correct; rather, the absolute magnitude of differences

[1] Pollard, J.E.; Smith, W.D.; Palmer, C.J. 1999. Forest health monitoring 1999 plot component quality assurance implementation plan. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program. 17 p. + attachments. On file with: U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program, P.O. Box 12254, Research Triangle Park, NC 27709.

[2] Pollard, J.E.; Smith, W.D. 1999. Forest health monitoring 1998 plot component quality assurance report. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program. 31 p. Vol. 1. On file with: U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program, P.O. Box 12254, Research Triangle Park, NC 27709.

between the field crews and QA crews is used as the basis for performance evaluation.

The system of uncertainty estimation used in the FHM Program was termed cold checks. This system was a blind remeasurement system in which the field crews do not know which of their regular seasonal plots will be remeasured as a performance evaluation plot. The QA crews did not have crew data available to them on the plot, so they did not know what the target values were for the plots during remeasurement. A subset of regional field plots that was identified by regional QA personnel as being representative of plots within the region was chosen for cold-check remeasurements. Results of the remeasurement were not used to change the original crew data but were exclusively used for estimation of measurement uncertainty, as will be described next.

Crowns Indicator Analysis Methods

QA measurements were collected during cold-check sampling in the Northeast, Lake States, South, West Coast, and Interior West regions. The following indicator variables, with the assigned database variable name in parentheses, were evaluated using the SAS system of programs for statistical analysis (SAS 1999): foliar transparency (FOLT_ERR), crown dieback (CDIE_ERR), crown density (CDEN_ERR), crown ratio (CRAT_ERR), crown width (CRW_ERR), and crown width 90° (CR90_ERR). Cold-check data were analyzed by aggregation of all trees observed within a given region, as well as aggregation of trees within a given plot from each of the five regions. Sample sizes for aggregated trees within a region were generally high, ranging from 28 to 340 for a given tree category (softwoods or hardwoods). The sample size used for the analysis of plot-level performance, however, was much lower than the regional aggregate, with sample sizes ranging from 3 to 13.

Details of statistical treatment of crown data are presented in the 1999 FHM QA Report.[3] The following analyses are presented in appendix A of that report: basic statistical tables presenting the mean differences between auditors and crews, standard error of the difference, and minimum and maximum values of differences for all crown variables. Each is presented by

[3] 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, Forest Health Monitoring Program. [Number of pages unknown]. Vol. 1. On file with: U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program, P.O. Box 12254, Research Triangle Park, NC 27709.

species group. The mean differences were tested to determine if they were significantly different from zero; i.e., biased, using a Student's t-test. Significance of biases are presented in the first page of output tables for a region under the Prob > |t| column. Minimum and maximum differences are also presented. Basic statistics tables are followed by control chart plots of individual measurements, by species number, of the crew–QA crew differences in relation to the MQOs. The MQOs are presented as horizontal lines on the plots. Cumulative frequencies of errors then are tabulated for all analysis variables for all trees and hardwood and softwood species groups (softwoods = numbers 1 to 400, and hardwoods = numbers 401 to 1,000). These statistical analyses allow evaluation of crew attainment of the numerical MQOs established for the FHM Program.[4] A brief summary of crown QA data follows.

Crowns Indicator Results/Conclusions

For all trees measured within a region, absolute mean differences between QA crews and field crews for all indicator variables ranged from 5.61 to -5.64. The pattern of significance of these differences was variable within indicator variables, by tree species grouping, and within regions. For example, transparency showed significant negative differences in hardwoods for both the Northeast and Lake States regions but showed negative differences in the Northeast and positive differences in the Lake States regions for softwoods (appendix table C.1). The significance of these differences was substantially reduced in the within-plot aggregations, probably as a function of small sample sizes of the number of plots (appendix table C.2).

The relevance of these observed measurement differences can be viewed in light of the MQOs established for the program. The MQOs established for the crown variables were for 90 percent of the measurements to be ±10 percent. In other words, 90 percent of the differences between field crew measurements and QA crew measurements should have been no more than ±10 percent. Crew performance was near or above specified MQO levels for transparency and dieback, with one exception in the South (appendix table C.3). Performance in measuring crown density was variable both by region and species group. Generally, however,

[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: U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program, P.O. Box 12254, Research Triangle Park, NC 27709.

crews performed better for this indicator variable on hardwoods than on softwoods. Performance on crown ratio measurement was generally lower for hardwoods than for softwoods, although there appeared to be a substantial problem with this indicator variable in the Lake States for both species subgroups. Measurement of crown widths was substantially better for softwoods than for hardwoods, with the exception of the West Coast region.

Damage Indicator Analysis Methods

Preliminary results are presented here, based on initial analyses. Final results for this indicator are published in the 1999 FHM QA Report (see footnote 3). QA measurements were collected during cold-check sampling in the Northeast, Lake States, South, West Coast, and Interior West. Regional aggregations of data were analyzed for the following damage indicator variables: total number of trees, number of undamaged trees observed by auditors and field crews, percent agreement on number of undamaged trees, number of damaged trees observed by auditors and field crews, percent agreement on number of damaged trees, total number of damages observed by auditors and field crews, percent agreement on total observed damages, and damage index.

Details of statistical treatment of damage data are presented in the 1999 FHM QA Report (see footnote 3). The following analyses are presented in appendix B of that report. A table is presented showing the number of damaged and undamaged trees observed by auditors and field crews, as well as agreement figures for the two crews, the total number of damages observed, and agreement in the observations. Distribution of the damage index was plotted against tree species in a control chart format with MQOs for the index plotted as ± horizontal lines on the plot. Following the control chart, frequency of error in the index between QA crew and crew measurements were presented in cumulative frequency tables for hardwoods and softwoods. Types of damage observed were tabulated for auditors and crews, and are displayed side by side to allow comparison of individual damage calls by each crew type. Location and severity of individual damage are included in the tabulations to help determine comparability of the two crews' results. A brief summary of damage QA data is presented in the next section.

Damage Indicator Results/Conclusions

Generally, crew performance was within the established 90 percent MQOs for identification and enumeration of undamaged trees. There was a distinct difference between auditors and crews in identification of undamaged hardwood trees in the Interior West (appendix table C.5). Performance in identification of damaged trees generally was poor but variable for both hardwoods and softwoods (appendix tables C.4 and C.5), ranging from 41.7 to 100 percent MQO compliance. This was also the case for individual damage identification as well as the calculated damage index (appendix tables C.4 and C.5). The damage indicator lead provided levels of damage assignment that are considered threshold-level effects. When analysis took into account these thresholds, individual damage assignments were much closer to the auditor's observations (appendix tables C.4 and C.5). This indicates that the crews tend to identify fewer damages than the auditors when the damage is slight or difficult to identify. The concept of thresholds and how this relates to MQOs within the FHM Program needs to be investigated more fully by the indicator advisor.

Mensuration Indicator Analysis Methods

QA samples were collected for the mensuration indicator as described earlier for crowns and damage. A limited number of variables were evaluated for mensuration QA. Mensuration data collection involved observation of a large number of forest attributes that are often used in combination, or in complex calculations. The analysis presented next is not exhaustive, but is intended to illustrate the types of QA analyses that can be performed on mensuration variables. The measurements included the tree location variables of distance and azimuth (AZ_ERR and DIST_ERR), tree identification (SPEC_ERR), tree tally error variables (MISSTREE and XTRATREE), tree diameters (DBH_ERR and DRC_ERR), seedling counts (SEED_ERR), and understory percent cover (MOSS_ERR, FERN_ERR, HERB_ERR, SHRB_ERR, and SEED_ERR).

Details of statistical treatment of mensuration data are presented in the 1999 FHM QA Report (see footnote 3). The following analyses are presented in appendix C of that report. Basic statistical tables about microplots and subplots present the mean differences between auditor and crew data, standard error of the differences, and minimum and maximum values of differences for diameter at breast height (d.b.h.), diameter at root collar, azimuth, distance, and tree height. The authors used a Student's t-test to determine if mean differences were significantly different from zero; i.e., biased. These tables are followed by tabulations of misidentified tree species and missed and extra tree observations. Basic statistical tables are followed by control chart plots of individual difference measurements by microplot and subplot in relation to the MQOs, which are shown as horizontal lines on the plots. Cumulative frequencies of absolute errors were tabulated for all analysis variables for microplots and subplots. These statistical analyses allow comparison of performance to the FHM Program's established MQOs. Seedling and understory vegetation variables were also evaluated for plots. The error in seedling counts (SEED_ERR) are plotted by species in a control chart and tabulated in frequency distributions for hardwood and softwood species groups. Basic statistical tables are presented for understory vegetation measured in percent ground cover (MOSS_ERR, FERN_ERR, HERB_ERR, SHRB_ERR, and SEED_ERR) as well as frequency distributions of the absolute value of the error. A brief summary of mensuration QA data is presented in the next section.

Mensuration Indicator Results/Conclusions

The QA crews did not measure tree heights during the 1999 field season, so they could not be evaluated for data quality. Generally, distance, azimuth, and d.b.h. of trees had low absolute mean values for differences between field crews and auditors. This indicated that those variables were generally being measured with acceptable quality. Values for differences on microplots (appendix table C.6), however, displayed a much higher proportion of substantial differences than the means for subplot aggregations for all regions (appendix table C.7). On the other hand, the absolute number of species misidentifications, missed trees, and extra trees observed on subplots was higher than on microplots, as would be expected with the higher number of trees observed in the aggregated subplots datasets.

Excepting the West Coast region, hardwood seedling counts displayed higher differences between auditors and crews than the softwood seedling counts (appendix table C.8). The increased difference between auditors and crews was reflected in improved MQO compliance for softwoods as opposed to hardwoods (appendix table C.9). Differences between crews and auditors were substantially higher for percent cover of herbs and shrubs, as compared to mosses, ferns, and seedlings (appendix table C.8). This pattern also was reflected in improved MQO compliance for the more consistent percent cover variables (appendix table C.9).

Soils Indicator Analysis Methods

QA samples were collected for the soils indicator as described earlier for crowns, damage, and mensuration. The following variables were evaluated for the soils indicator: litter layer thickness (LTHK_ERR), forest floor thickness (FTHK_ERR), depth to restrictive horizon (DSUB_ERR), A texture (ATXT_ERR), underlying texture (UTXT_ERR), percent bare soil (PSOILERR), percent litter cover (PLIT_ERR), percent plant cover (PLANTERR), litter and ground depth (DEPTHERR), litter decomposition (DCOMPERR), and slope length (SLPLNERR).

Details of statistical treatment of soils data are presented in the 1999 FHM QA Report (see footnote 3). The following analyses are presented in appendix D of that report. Basic statistical tables present the mean differences between auditor and field crew data, standard error of the differences, and minimum and maximum values of differences for all soils variables. The authors used a Student's t-test to determine if mean differences were significantly different from zero; i.e., biased. Basic statistical tables are followed by plots of individual measurements of these differences in relation to the MQOs, which are shown as horizontal lines on the plots. Cumulative frequencies of errors were tabulated for all analysis variables. The statistical analyses allow comparison of crew performance to the FHM Program's established MQOs. A brief summary of soils QA data is presented in the next section.

Soils Indicator Results/Conclusions

In 1999, performance of crews in collecting soils indicator variables was highly improved over the performance in 1998 (see footnote 2). Changes to soils variable collection protocols appeared to be quite effective in improving the indicator's precision. Remeasurement data did reflect some potential difficulties in reliably measuring some of the indicator variables in some regions. Field crews seemed to have the most difficulty in obtaining data comparable to the auditors for depth to the DSUB_ERR and PLANTERR. In addition, mean differences between auditors and crews were substantial for FTHK_ERR and DEPTHERR in the Lake States and South regions (appendix table C.10).

Field crew performance in achieving specified MQOs for the soils indicator was variable for indicator parameters (appendix table C.11). For example, LTHK_ERR, DECOMPERR, and PSOILERR appeared to be highly reproducible in most regions. On the other hand, PLIT_ERR, PLANTERR, DEPTHERR, and SLPLNERR were generally well below specified MQOs. There appears to be a regional difference in MQO compliance with soil texture variables.

Ozone Indicator Analysis Methods

Data from the 1999 field sampling effort were organized into two regions, the Lake States and the Northeast. Detailed results of all analyses are presented in appendix E of "Forest Health Monitoring 1999 Plot Component Quality Assurance Report."[5] Analyses were performed for each species of bioindicator plant for the amount of injury and severity of injury ratings assigned by crews compared to equivalent ratings assigned by the auditors. The total number of plants or stems found for evaluation at each plot or hexagon as well as the number of injured stems and the bioindicator index values for both the field crews and the auditors were evaluated.

The differences between crew types were calculated for number of plants evaluated, number of injured plants found, individual species index for a given plot, ratio of total plants to injured plants, and significance of the differences between injured to uninjured plant ratios for the two crews. Composite evaluations also are presented for all stems evaluated within a region for each species. Plots are presented

[5] 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, Forest Health Monitoring Program. [Number of pages unknown]. Vol. 1. On file with: James Pollard, FIA Quality Assurance Coordinator and Program Director - Fisheries and Aquatic Sciences at the University of Nevada, Las Vegas-HRC, 4505 S. Maryland Parkway, Las Vegas, NV 89154-4009.

showing the percentage difference between field crew and auditors' observations of the number of stems of each species chosen for a given plot. These plots demonstrate the degree of MQO compliance with the $\pm$10 percent target established for this indicator variable.

The summary plot index for ozone effects (all species indices combined for a plot) was calculated for each plot, and the number of species included in the composite index was displayed for each crew type. The two crews' overall agreement of injury assessment on each plot was calculated as the difference in the plot index.

The distribution of injury ratings for field crews and auditors is displayed as tabled matrices for amount and severity observations. The matrices are organized by region and species. They detail the injury or severity rating for each species within a region for field crews and auditors. In addition, for each species within a region, the distributions of crew observations versus auditor observations were tested for statistical differences using the Wilcoxon-Mann-Whitney two-sample test for differences. This test is a nonparametric rank sum procedure appropriate for datasets with unequal sample sizes (Steel and others 1997), as well as for distributions that are highly skewed (SAS 1999). Summary statistics for these tests are presented in the next section following the distribution matrices for each region.

Ozone Indicator Results/Conclusions

There were 4 hexagons in the Lake States and 10 hexagons in New England with available paired field crew versus auditor data. In the 1999 field season, the target number of stems for evaluation on a bioindicator plot was 30 individual plants (stems) of 3 ozone-sensitive species (see footnote 4). The actual number of species and individuals of ozone-sensitive plants found on each ozone site varied by plot and crew type, ranging from 10 to 31 individual plants and 1 to 5 species per plot. Auditors tended to collect the targeted 30 individuals of a given species more often than field crews, but not consistently. This can be seen in appendix table C.12, which displays total number of plants evaluated on all sites within a region.

The individual species index was calculated for each species at each plot for both crew types. The value of this index was near or < 1 for most species, with the most common value being zero for both crew types. Blackberry was a striking exception to this pattern, with the crew values on some plots much higher than the auditor values. This pattern was reflected in the composite plot index (appendix table C.13), where large differences (> 5) in values between crews could be entirely accounted for by differences in observations of blackberry stems. When the difference between two indices is > 5, there is an indication that crew performance on that plot could affect interpretation of the ozone effect evaluation. This guidance is based on the estimation by the indicator advisor that an index value of 5 is high enough to be a threshold indicator of ozone damage. Based on these guidelines, the plots in hexagons B (in the Lake States) and I (in the Northeast) would be suspect for interpretation of ozone damage.

Between field crews and auditors, the differences in number of injured plants found at sites were fairly consistent, with one major exception. Field crews tended to find higher blackberry ozone damage than the auditors. The pattern was evident and almost entirely consistent in both the Lake States and Northeast regional datasets, as well as in the plot and individual index data presented earlier. The results of the Wilcoxon rank sum tests on the amount and severity of injury support this observation. Blackberry data consistently had a significantly different distribution of injury amount and severity between field crews and auditors. In addition, the data showed a weak pattern indicating that auditors found a higher incidence of injury in black cherry than field crews. Because the sample size for this observation was small, this conclusion is tentative.

During the 1998 field season, 18 plots were audited for the ozone indicator. In the QA report for that year, a similar set of analyses were performed on those data (see footnote 2). In that report, blackberry and black cherry were also identified as having a high incidence of discrepancies between auditors and crew observations. Given the consistency of results between the 2 years' data, we recommend that serious consideration of reevaluating these species in the ozone indicator protocols and/or additional training development.

Appendix table C.1—Absolute mean differences between auditors and crews for all trees within a region for crown variables measured on softwoods and hardwoods

Crown condition	North-east	Lake States	South	Interior West	West Coast	Mean of regions	Weighted mean
Hardwoods[a]							
Transparency	**-3.32**	**-3.84**	**0.91**	-0.45	0.53	-1.234	-2.27
Crown dieback	**-0.59**	**-0.58**	**-1.46**	**-2.69**	-0.13	-1.09	-0.92
Crown density	-1.03	-0.24	0.98	**-3.88**	**1.45**	-0.544	-0.71
Crown ratio	**-1.4**	**-4.09**	**5.61**	**-3.49**	**-2.5**	-1.174	-1.40
Crown width	**1.29**	0.48	**-1.51**	**0.52**	2.91	0.738	0.71
Softwoods[b]							
Transparency	**-2.89**	**3.93**	**1.13**	**1.37**	**-0.41**	0.626	0.06
Crown dieback	0.33	**-0.71**	**1.25**	**-0.47**	**0.71**	0.222	0.13
Crown density	**-4.44**	2.86	0.56	-0.46	**1.21**	-0.054	-1.06
Crown ratio	-2.56	**-5.64**	**-1.31**	**-2.05**	**-1.75**	-2.662	-3.05
Crown width	-0.7	**-2.04**	-0.41	**0.37**	**2.21**	-0.114	-0.68

Differences in bold type are significant at 0.10 probability.

[a] Number of trees in the Northeast: 247; Lake States: 147; South: 82; Interior West: 67; and West Coast: 38.

[b] Number of trees in Northeast: 45; Lake States: 28; South: 80; Interior West: 340; and West Coast: 302.

Appendix table C.2—Absolute mean differences between auditors and crews within plots in each region for crown variables measured on softwoods and hardwoods

Crown condition	North-east	Lake States	South	Interior West	West Coast	Mean of regions	Weighted mean
Hardwoods[a]							
Transparency	**-3.66**	**-3.83**	1.05	1.37	0	-1.014	-1.82
Crown dieback	-0.44	-0.54	**-1.14**	-2.26	-0.33	-0.942	-0.73
Crown density	-0.03	-0.39	0.31	-6.71	2.11	-0.942	-0.32
Crown ratio	-0.5	-4.24	4.71	-5.17	-0.5	-1.14	-0.66
Crown width	1.33	0.64	-1.08	0.15	5.1	1.228	1.23
Softwoods[b]							
Transparency	-3.88	2.3	-0.22	**1.51**	-0.68	-0.194	-1.12
Crown dieback	0.4	-0.27	0.84	-0.4	**0.84**	0.282	0.35
Crown density	**-3.5**	-2	0.19	-1.41	0.65	-1.214	-1.74
Crown ratio	**-3.87**	**-4.93**	-0.2	0.06	**-1.48**	-2.084	-2.68
Crown width	-0.54	-0.7	-0.54	-0.2	1.94	-0.008	-0.16

Differences in bold type are significant at 0.10 probability.

[a] Number of plots in the Northeast: 13; Lake States: 6; South: 6; Interior West: 3; and West Coast: 5.

[b] Number of plots in Northeast: 7; Lake States: 3; South: 6; Interior West: 10; and West Coast: 11.

Appendix table C.3—Percentage of measurements that were within MQOs for all trees measured within each region

Crown condition	North-east	Lake States	South	Interior West	West Coast	MQO
Hardwoods[a]						
Transparency	92.3	92.5	100	97.0	100	90% ± 10%
Crown dieback	98.0	100	**74.4**	94.0	100	90% ± 10%
Crown density	**79.4**	**81.0**	97.6	91.0	94.7	90% ± 10%
Crown ratio	**79.8**	**67.3**	**69.5**	**83.6**	92.1	90% ± 10%
Crown width	**72.5**	**76.2**	**75.6**	**85.1**	**86.8**	90% ± 5 feet
Softwoods[b]						
Transparency	88.9	96.4	100	99.4	98.7	90% ± 10%
Crown dieback	100	100	90.0	98.2	98.3	90% ± 10%
Crown density	**74.3**	**71.4**	100	**79.4**	92.7	90% ± 10%
Crown ratio	**84.4**	**32.1**	90.0	**85.0**	90.1	90% ± 10%
Crown width	91.1	96.4	98.8	97.9	**73.2**	90% ± 5 feet

MQO = measurement quality objective.

Numbers in bold type are substantially below the MQO for that variable.

[a] Number of trees in the Northeast: 247; Lake States: 147; South: 82; Interior West: 67; and West Coast: 38.

[b] Number of trees in Northeast: 45; Lake States: 28; South: 80; Interior West: 340; and West Coast: 302.

Source: Pollard, J.E.; Smith, W.D. 1999. Forest health monitoring 1998 plot component quality assurance report. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program. 31 p. Vol. 1. On file with: U.S. Department of Agriculture, Forest Service, Forest Health Monitoring Program, P.O. Box 12254, Research Triangle Park, NC 27709.

Appendix table C.4—Summary of softwood damage observation performance by region[a]

Indicator variable	North-east	Lake States	South	West Coast	Interior West
Undamaged trees - auditor	45	25	49	218	241
Undamaged - trees field crew	41	24	49	209	213
Agreement (%) (MQO = 90%)	91.1	96	100	95.9	88.4
Damaged trees - auditor	3	12	33	47	143
Damaged trees - field crew	1	7	8	7	56
Agreement (%) (MQO = 90%)	66.7	41.7	75.8	85.1	60.8
Total individual damages (no.)	4	13	46	64	213
Classification agreement (%) (85%)	50	38.5	60.9	71.9	48.4
Damage index % MQO compliance	85.7	92.3	42.4	75.0	64.9

MQO = measurement quality objective.
[a] Number of trees sampled in the Northeast: 48; Lake States: 37; South: 82; West Coast: 265; and Interior West: 384.

Appendix table C.5—Summary of hardwood damage observation performance by region[a]

Indicator variable	North-east	Lake States	South	West Coast	Interior West
With no damage (no.)	218	193	82	13	48
Undamaged correct (no.)	197	174	78	13	22
Undamaged correct (%) (90%)	90.4	90.2	95.1	100	45.8
Damaged trees (no.)	71	40	25	0	33
Damages missed (no.)	13	11	10	0	10
Damages correct (%) (90%)	81.7	72.5	60	100	69.7
Extra damages (no.)	21	19	4	0	26
Total damages (no.)	86	51	35	0	46
Missed damages (no.)	20	19	15	0	22
Missed at threshold (no.)	0	2	1	0	2
Correctly classified (%) (85%)	76.7	62.7	57.1	100	52.2
Extra damages (no.)	31	33	7	0	46
Extra at threshold (no.)	6	5	2	0	4

[a] Number of trees sampled in the Northeast: 289; Lake States: 233; South: 107; West Coast: 13; and Interior West: 81.

Appendix table C.6—Absolute difference between auditor and crew measurements for mean microplot values of distance, azimuth, d.b.h., d.r.c., species identifications, missed trees, and extra trees observed on plots[a]

Plot values	North-east	Lake States	South	West Coast	Interior West
Variable					
Distance	-3.31	0.74	8.02	-0.06	11.70
Azimuth	-0.10	-1.52	-0.91	0.0	-1.90
d.b.h.	-0.04	-0.20	-0.20	0.02	-0.49
d.r.c.	NM	NM	NM	NM	-4.23
Species	6	2	5	0	5
Missed trees	1	9	12	2	4
Extra trees	5	0	10	0	0

d.b.h. = diameter at breast height; d.r.c. = diameter at root collar; NM = not measured.
[a] Number of trees sampled in the Northeast: 64 – 67; Lake States: 95 – 116; South: 44 – 69; West Coast: 15 – 17; and Interior West: 37 – 51.

Appendix table C.7—Absolute difference between auditor and crew measurements for mean subplot values of distance, azimuth, d.b.h., d.r.c., species identifications, missed trees, and extra trees observed on plots[a]

Plot values	North-east	Lake States	South	West Coast	Interior West
Variable					
Distance	-0.04	0.36	-2.10	0.18	-1.93
Azimuth	1.69	0.01	-0.09	0.02	0.00
d.b.h.	-0.03	0.09	-0.07	-0.01	0.02
d.r.c.	NM	NM	NM	NM	-0.40
Species	16	7	16	6	10
Missed trees	3	7	33	12	23
Extra trees	8	2	50	9	7

d.b.h. = diameter at breast height; d.r.c. = diameter at root collar; NM = not measured.
[a] Number of trees sampled in the Northeast: 281 – 325; Lake States: 160 – 194; South: 175 – 270; West Coast: 277 – 348; and Interior West: 276 – 452. D.r.c. number of trees was 126.

Appendix table C.8—Absolute difference between auditor and crew measurements for mean subplot values of seedling counts for hardwoods and softwoods as well as percent cover for mosses, ferns, herbs, shrubs, and seedlings observed on plots

Variable	North-east	Lake States	South	West Coast	Interior West
Seedling counts - hardwoods	5.34	6.00	4.51	0.25	5.00
Seedling counts - softwoods	2.00	2.00	1.83	0.25	1.00
Cover moss (%)	1.80	2.81	3.55	3.08	6.67
Cover fern (%)	2.41	2.00	0.34	1.26	0.00
Cover herb (%)	10.80	10.04	13.92	4.61	6.91
Cover shrubs (%)	10.02	9.04	8.42	7.50	3.35
Cover seedlings (%)	5.26	3.77	3.47	0.39	0.37

Appendix table C.9—Percent MQO compliance for mensuration variables[a]

Variable	North-east	Lake States	South	West Coast	Interior West	MQO
Distance	**87.6**	**88.1**	**86.1**	95.1	**76.3**	90% ± 1 foot
Azimuth	98.1	100	96.3	98.2	87.7	90% ± 10 degrees
d.b.h.	96.8	98.1	**84**	**73.3**	**80.4**	90% ± 5%
d.r.c.	NM	NM	NM	NM	**44.4**	85% 0.2 foot
Species	94.9	96.2	91.5	98.2	97.7	90% to species
Missed trees	99.1	96.4	87.8	**76.1**	94.9	85% agreement
Extra trees	97.6	99.0	**81.5**	98.0	98.5	85% agreement
Seedling counts - hardwoods	**48.7**	**52.0**	**48.7**	100.0	**37.5**	75% ± 2
Seedling counts - softwoods	100.0	100.0	75.0	100.0	87.5	75% ± 2
Cover moss (%)	100.0	100.0	94.7	97.4	88.3	90% ± 20%
Cover fern (%)	100.0	100.0	100.0	100.0	100.0	90% ± 20%
Cover herb (%)	89.1	**80.8**	79.0	97.4	93.0	90% ± 20%
Cover shrubs (%)	**82.6**	88.5	86.8	94.7	97.7	90% ± 20%
Cover seedlings (%)	97.8	100.0	100.0	100.0	100.0	90% ± 20%

MQO = measurement quality objective; d.b.h. = diameter at breast height; d.r.c. = diameter at root collar; NM = not measured.
Numbers in bold type are substantially below the MQO for that variable.
[a] Number of trees sampled in Northeast: 281 – 325; Lake States: 160 – 194; South: 175 – 270; West Coast: 277 – 348; and Interior West: 126 – 452.

Appendix table C.10—Mean absolute difference between auditor and crew measurements for soil indicator variables[a]

Variable	North-east	Lake States	South	West Coast	Interior West	MQO
LTHK_ERR	-0.68	0.02	0.02	1.24	0.1	90% ± 2
FTHK_ERR	-1.6	7.4	7.4	1.65	-0.4	90% ± 2
DSUB_ERR	-7	12.93	12.93	11.03	-0.4	90% ± 2
ATXT_ERR	0.23	0.73	0.73	0.78	-0.87	90% ± 7
UTXT_ERR	0.4	1	1	0.81	-1.13	90% ± 7
PSOILERR	3.95	-0.43	-0.43	-1.34	-4.95	90% ± 7
PLIT_ERR	-5.13	0.88	0.88	6.77	1.35	90% ± 7
PLANTERR	-5.71	4.55	4.55	4.21	-5.95	90% ± 7
DEPTHERR	-2.64	11.65	11.65	1.48	-0.2	90% ± 10
DCOMPERR	0.08	0.01	0.01	-0.04	0.18	90% ± 1
SLPLNERR	-20.43	-24.78	-24.78	-1.25	-6.6	90% ± 1

MQO = measurement quality objective; LTHK_ERR = litter layer thickness; FTHK_ERR = forest floor thickness; DSUB_ERR = depth to restrictive horizon; ATXT_ERR = A texture; UTXT_ERR = underlying texture; PSOILERR = percent bare soil; PLIT_ERR = percent litter cover; PLANTERR = percent plant cover; DEPTHERR = litter and ground depth; DCOMPERR = litter decomposition; SLPLNERR = slope length.

[a] Number of plots in the Northeast: 10; Lake States: 5; South: 7; West Coast: 8; and Interior West: 5.

Appendix table C.11—Percent MQO compliance for the soil indicator variables in all regions[a]

Variable	North-east	Lake States	South	West Coast	Interior West	MQO
LTHK_ERR	**50**	100	100	88	100	90% ± 2
FTHK_ERR	**80**	**60**	86	**63**	**80**	90% ± 2
DSUB_ERR	**50**	**40**	**43**	**38**	**60**	90% ± 2
PSOILERR	**70**	100	88	90	**80**	90% ± 7
PLIT_ERR	**70**	**60**	**50**	**70**	**60**	90% ± 7
PLANTERR	**30**	**20**	**63**	**70**	**60**	90% ± 7
DEPTHERR	**70**	**60**	**75**	**70**	100	90% ± 7
DCOMPERR	100	100	100	100	100	90% ± 7
SLPLNERR	**40**	**40**	**25**	90	**60**	90% ± 10
ATXT_ERR	88	**80**	95	**69**	**67**	90% ± 1
UTXT_ERR	88	**77**	84	**66**	**67**	90% ± 1

MQO = measurement quality objective; LTHK_ERR = litter layer thickness; FTHK_ERR = forest floor thickness; DSUB_ERR = depth to restrictive horizon; PSOILERR = percent bare soil; PLIT_ERR = percent litter cover; PLANTERR = percent plant cover; DEPTHERR = litter and ground depth; DCOMPERR = litter decomposition; SLPLNERR = slope length; ATXT_ERR = A texture; UTXT_ERR = underlying texture.

Variables out of compliance by 10 percent or more are in bold type.

[a] Number of plots in the Northeast: 10; Lake States: 5; South: 7; West Coast: 8; and Interior West: 5.

Appendix table C.12—Total number of stems found in each region for all plots with paired field versus auditor data

Species	Crew	Auditor	Difference
Lake States			
Big leaf aster	30	30	0
Common and tall milkweed	74	119	-45
Spreading dogbane	67	27	0
Black cherry	68	60	0
Blackberry	55	91	-36
Sassafras	16	30	-14
Northeast			
Big leaf aster	30	30	0
Common and tall milkweed	92	125	-33
Spreading dogbane	103	118	-15
White ash	64	42	0
Sweetgum	33	60	-27
Yellow-poplar	70	100	-30
Black cherry	84	78	0
Blackberry	89	152	-63
Sassafras	60	60	0

Appendix table C.13—Differences between plot index for crews and auditors

Hexagon	Crew	Auditor	Difference
Lake States			
A	0.27389	0.09500	0.17889
B	7.65381	0.11861	7.5352
C	0.00893	0.13632	-0.12739
D	0.00000	0.00000	0.00000
Northeast			
E	0.0296	0.05487	-0.025
F	0.0000	0.0000	0.0000
G	0.0498	2.19421	-2.1444
H	0.0000	0.0000	0.0000
I	93.5204	0.0000	93.5204
J	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000
L	0.0000	0.0000	0.0000
M	0.0000	0.0000	0.0000
N	2.6483	0.0000	2.6483

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The Forest Health Monitoring (FHM) Program's annual national report uses FHM data, as well as data from a variety of other programs, to provide an overview of forest health based on the criteria and indicators of sustainable forestry framework of the Santiago Declaration. It presents information about the status of and trends in various forest health indicators nationwide and uses statistically valid analysis methods applicable to large-scale ecological assessments. Five main sections correspond to the Santiago criteria: Biological Diversity, Productive Capacity, Health and Vitality, Conservation of Soil, and Carbon Cycling. A variety of indicators contribute information about the status of each forest ecosystem considered. Many indicators use data collected from ground plots. Such indicators include species diversity (tree and lichens), bioindicator species (lichens and vascular plants sensitive to ozone), changes in trees (crown condition, damage, and mortality), physical and chemical soil characteristics, and above ground and belowground carbon pools. Additional information about forest health status and change is derived from data that are used to measure forest extent; data about insects and pathogens; and remotely sensed and/or ground-based data about forest fragmentation, fire, and air pollution. A sixth section presents and discusses a multivariate analysis of the indicators. The technique provides a composite picture of forest health, based on statistically significant principal components.

Keywords: Assessment, bioindicators, carbon, criteria and indicators, diversity, fragmentation, mortality.

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