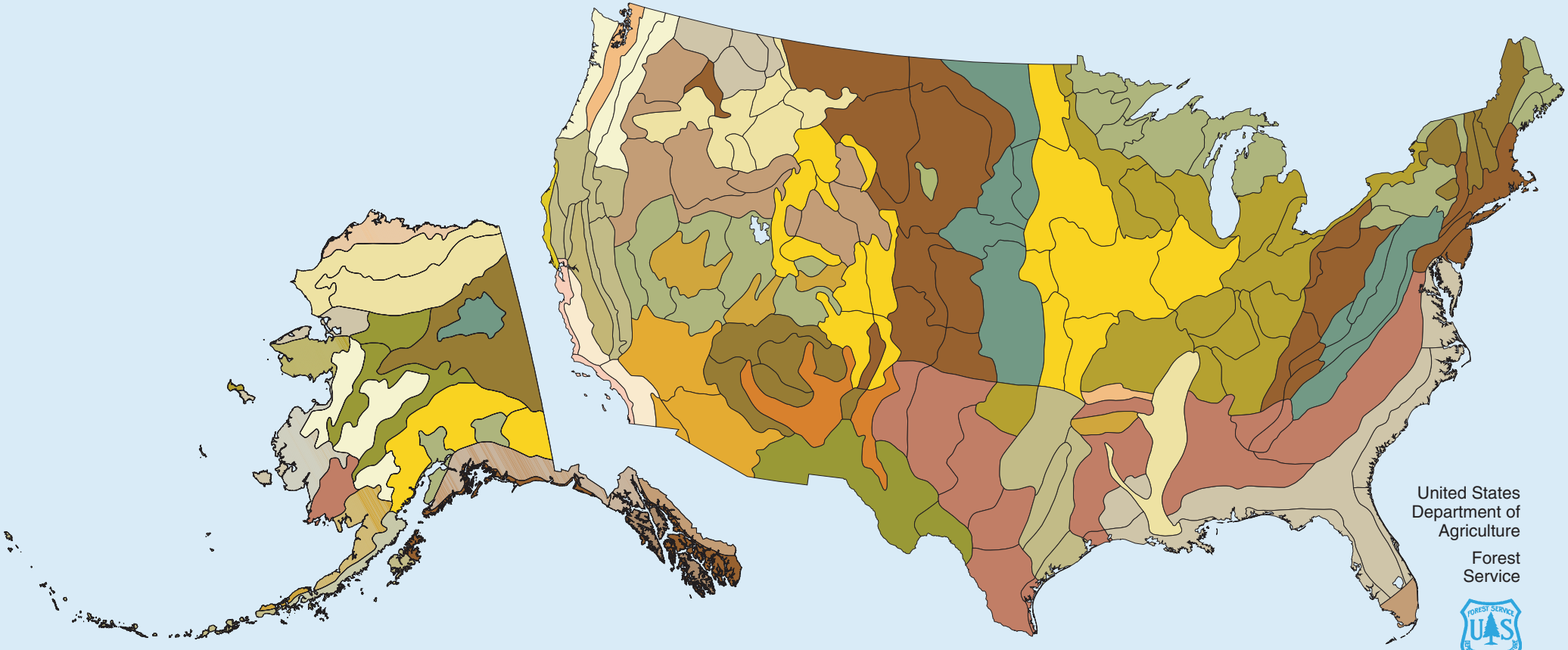
Forest Health Monitoring 2005 National Technical Report

Editors Mark J. Ambrose Barbara L. Conkling



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

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

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Editors

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Abstract

The Forest Health Monitoring program's annual national technical report presents results of forest health analyses from a national perspective using data from a variety of sources. The report is organized according to the Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests of the Santiago Declaration. The results of several analyses of forest fragmentation are synthesized to evaluate fragmentation in U.S. forests. Drought in 2004 is presented, and drought over the decade 1995-2004 is compared with the historical average. Areas of intense forest fire activity during the 2004 fire season are identified. Ozone bioindicator data are used to create an interpolated ozone map of the United States, and the possible impact on sensitive tree species is examined. Aerial survey data are used to identify hotspots of insect and disease activity based on the relative exposure to defoliation- and mortality-causing agents. Data from the Forest Inventory and Analysis down woody materials indicator are analyzed to produce preliminary per-acre estimates of amounts of woody debris and carbon pools stored in down woody materials. Data from the Forest Inventory and Analysis soil quality indicator are analyzed to provide preliminary information about erosion and soil compaction, soil pH, and effective cation exchange capacity, and to produce preliminary per-hectare estimates of soil carbon.

Keywords—Criteria and indicators, down woody materials, drought, fire, forest soils, fragmentation, ozone bioindicator.

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Chapter 1. Introduction

Mark J. Ambrose

This annual technical report is a product of the Forest Health Monitoring (FHM) program. The report provides information about a variety of issues relating to forest health at the national scale. Previous FHM national reports have had a dual focus of presenting analyses of the latest available data and showcasing innovative techniques for analyzing forest health data. This more streamlined report, in contrast, focuses on the latest analytical results. The report is organized using the Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Anon. 1995, Montreal Process Working Group 1999) as a general reporting framework.

While FHM is committed to reporting annually on the state of U.S. forests, there are not always enough new data available to warrant reporting on each indicator every year. In this report, indicators are included if a substantial amount of new data has become available since they were last reported by FHM or if significant progress has been made in analytical techniques such that the data can be used to provide new insights into the health of U.S. forests. Indicators were also included if information from earlier analyses could be synthesized in a way that provided better understanding of forest health issues.

The Forest Health Monitoring Program

The FHM program is a national effort to determine on an annual basis the status of, and changes and trends in, indicators of forest condition. The U.S. Department of Agriculture Forest Service cooperates with State forestry and agricultural agencies to conduct FHM activities. Other Federal agencies and universities also participate. The FHM program has five major activities (Tkacz 2003):

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

In addition to FHM's national reporting, each of the five FHM regions also produces reports. The regions, in cooperation with their respective States, produce Forest Health Highlights (available on the FHM web site at www.fhm.fs.fed.us) and other State reports such as Keyes and others (2003), Laustsen and others (2003), Neitlich and others (2003), and Steinman (2004). FHM also produces reports on monitoring techniques and analytical methods, such as Smith and Conkling (2004).

Data Sources

The FHM program strives to use a variety of data collected by the various branches of the Forest Service as well as data from other sources. A major data source is the Forest Service's Forest Inventory and Analysis (FIA) program. The FIA program's phase 2 consists of plots measured at regular intervals to collect data associated with traditional forest inventories. FIA's phase 3 plots are a subset of the phase 2 plots. On phase 3 plots additional data are collected on many of the forest health indicators that were previously measured as part of the FHM detection monitoring ground plot system[1] (Palmer and others 1991).

For this report, Forest Service data sources were FIA periodic inventory and annualized phase 2 survey data (1990-2003);[2] FIA phase 3 data—ozone bioindicator (1999-2002), down woody material (2001-2003), and soils (2001-2003); and Forest Health Protection (FHP) aerial survey data (2003).[3] Other data sources were National Oceanic and Atmospheric Administration—Palmer Drought Severity Index (1895 through 2004) (National Climate Data Center 1994), Moderate Resolution Imaging Spectroradiometer (MODIS) fire data for 2004 (U.S. Department of Agriculture Forest Service, Remote Sensing Application Center 2004), and National Interagency Coordination Center (2004) data on forest area burned in 2004.

About the Report

In this report we used the Santiago Declaration and accompanying Criteria and Indicators (Anon. 1995, Montreal Process Working Group 1999) that were adopted by the Forest Service as a forest sustainability assessment framework (U.S. Department of Agriculture Forest Service 2004, Smith and others 2001). The seven criteria are:

[1] 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: Forest Health Monitoring Program National Office, 3041 Cornwallis Rd., Research Triangle Park, NC 27709.

[2] U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis. National Office, 1601 North Kent Street, Suite 400, Arlington, VA 22209. http://fia.fs.fed.us/tools-data/data/ [Date accessed: September 1, 2005].

[3] U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. Unpublished database. On file with: FHP/FHTET, 2150 Centre Ave., Bldg. A, Suite 331, Fort Collins, CO 80526-1891.

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.

A complete evaluation of all the sustainability criteria is not appropriate here. We focus on the elements of these criteria that are most directly related to issues of forest health.

Bailey's ecoregion sections (Bailey 1995) were used as the assessment unit for analysis (fig. 1.1) when the spatial scale of the available data made such analyses appropriate and when the indicator being analyzed may reasonably have been expected to show some pattern relating to ecological regions. Bailey's system is a national, hierarchical system of ecological units that classifies the United States into ecoregion domains, divisions, provinces, sections, subsections, land type associations, and land types (McNab and Avers 1994). Ecoregion sections typically contain thousands of square miles. Areas within an ecoregion section are expected to be similar in their geology and lithology, regional climate, soils, potential natural vegetation, and potential natural communities (Cleland and others 1997). Bailey's ecoregion sections provide a common framework for an ecologically based assessment.

Figure 1.1—Bailey's ecoregion provinces and ecoregion sections for the continental United States (Bailey 1995, McNab and Avers 1994). Ecoregion sections within each ecoregion province are shown in the same color.

Alaska Ecoregion Provinces

- Ahklun Mountains Tundra—Meadow Province (M126)
- Alaska Range Humid Tayga—Tundra—Meadow Province (M135)
- Aleutian Oceanic Meadow—Heath Province (M127)
- Arctic Tundra Province (124)
- Bering Tundra (Northern) Province (125)
- Bering Tundra (Southern) Province (126)
- Brooks Range Tundra—Polar Desert Province (M121)
- Coastal Trough Humid Tayga Province (135)
- Pacific Coastal Mountains Forest—Meadow Province (M244)
- Pacific Gulf Coastal Forest—Meadow Province (M245)
- Seward Peninsula Tundra—Meadow Province (M125)
- Upper Yukon Tayga Province (139)
- Upper Yukon Tayga—Meadow Province (M139)
- Yukon Intermontane Plateaus Tayga Province (131)
- Yukon Intermontane Plateaus Tayga—Meadow Province (M131)

Eastern ecoregion provinces

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

Western ecoregion provinces

- American Semi-Desert and Desert (322)
- Arizona—New Mexico Mountains Semi-Desert—Open Woodland—Coniferous Forest—Alpine Meadow (M313)
- Black Hills Coniferous Forest (M334)
- California Coastal 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)

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CRITERION 1—

Chapter 2. Forest Fragmentation

Kurt H. Riitters

What Is Forest Fragmentation, and Why Is It Important?

Forest fragmentation refers to a loss of forest and the division of the remaining forest into smaller blocks. Fragmentation is of concern primarily because of its impact on the conservation of biological diversity. Forest fragmentation can affect the amount and quality of habitat for many wildlife species (Fahrig 2003, Roundtable on Sustainable Forests 2000). Fragmented forests may consist of patches of forest too small to maintain viable populations of certain species. Fragmentation is also an issue because the resulting smaller blocks of forest may not be viable units for forest management (Roundtable on Sustainable Forests 2000).

So, How Fragmented Are the Forests?

Forest Health Monitoring (FHM) has conducted several national assessments of forest fragmentation for the conterminous States. The results have appeared in the series of national technical reports produced by FHM (e.g., Conkling and others 2005); in the report entitled "State of the Nation's Ecosystems," which was produced by the H.J. Heinz III Center for Science, Economics, and the Environment (2002); in the "National Report on Sustainable Forests—2003" by the U.S. Department of Agriculture Forest Service (2004); and in other outlets. Preparations are now underway to utilize newer landcover maps based on satellite imagery that will enable national updates and analysis of fragmentation changes over time. It is now appropriate to summarize an answer to the motivating question, "How fragmented are U.S. forests?"

The landcover maps used in the assessments reported here were derived from 1992 satellite imagery (Vogelmann and others 2001) with a spatial resolution of 0.09 ha per parcel of land, an area about the size of a baseball diamond infield. Of the 8.6 billion parcels of land evaluated, 2.8 billion were classified as forest. Some of the assessments also used detailed road maps (Geographic Data Technology 2002) that identify approximately 10 million km of roads of all sizes. The road maps were superimposed on the landcover maps when analyzing "road-caused" fragmentation (Riitters and others 2004b).

Two general approaches were used to analyze the landcover and road data. These can be described briefly as follows. One approach (Riitters and others 2004a) used classical procedures to assess forest patch size, forest edge, distance between forest patches, and other fragmentation indices within approximately 140,000 non-overlapping, 56.25 km^2 analysis units, each containing 62,500 land parcels. The other approach (Riitters and others 2002) used an innovative multiple-scale procedure to evaluate each forest parcel separately, in terms of the fragmentation experienced in the surrounding landscape, for five landscape sizes from 2.25 ha to 5314 ha. The assessments typically combined all classes of forest into one class and ignored fragmentation by water, snow, ice, talus slopes, bare rock, sand, and clay.

This section is a synthesis of information contained in eight published manuscripts (Riitters and others 2000, 2002, 2003, 2004a, 2004b, 2006; Riitters and Wickham 2003; Riitters and Coulston 2005), which will not be cited again in this section in order to maintain readability. Considering first the gross distribution of forest area, there is at least some forest land cover nearly everywhere in the lower 48 States. Forest is the dominant landcover for one-third of all land area, and three-fourths of all forest area is found in these forest-dominated landscapes. Fifteen percent of forest is located in landscapes dominated by shrubs and grasses, and the remainder occurs in landscapes dominated by agricultural and urban land uses. There is a marked distinction between regions that are mostly forested and those that are not, and these regions more or less correspond to ecological regions defined by biophysical constraints. At the same time, the fragmentation or spatial pattern of forest is not correlated with ecological regions because patterns are created by human activities that do not typically follow biophysical constraints. The gross distribution of forest area is a regional-scale phenomenon, and the spatial pattern of forest is a local-scale phenomenon.

Considering the spatial arrangement of forest land, most forest land is near other forest land, over very large regions. The perimeter of a typical forest "patch" (contiguous clump of forest parcels) is only about 100 m from the perimeter of its nearest neighbor patch except where there is not much forest, in which case that distance is

200 to 300 m. At the same time, fragmentation is so common that one-half of all forest is within about 100 m of forest edge, and < 1 percent is > 1 km from forest edge. About half of all fragmentation is associated with the physical separation of distinct forest patches, and half is associated with small (< 7-ha) perforations in otherwise continuous forest cover. A typical location has between 10 and 40 percent as much edge as it could possibly have, for the amount of forest present.

Overall, at least half of the fragmentation is associated with human land uses. Almost all fragmentation in the East is clearly anthropogenic. Partitioning natural vs. anthropogenic causal factors is problematic in the West because landcover is not an accurate guide to actual land use, but generally speaking most of the western fragmentation is associated with semi-natural landcover types such as grassland and shrubland. In both the East and West, the largest reserves of intact forest are contained in public forests on land that is not suited for agriculture or urban development (fig. 2.1). In a global context, the Eastern United States contains the last major reserve of relatively intact deciduous broadleaf forest, and this region is expected to experience significant urbanization with consequent fragmentation over the next 50 years.

Landcover maps derived from satellite imagery do not adequately portray the extensive road network that many believe is critical information when assessing forest fragmentation (fig. 2.2). Taking into account some 10 million km of major and minor roads, 20 percent of all forest land is within 125 m of a road, and the proportion increases rapidly with distance, such that 80 percent of forest land is within 1000 m of a road, and only 3 percent is > 5 km from a road. Ecological impacts from roads may be the rule rather than the exception in most of the conterminous United States. Roads are so pervasive that fragmentation associated with roads is clearly a significant contributor to overall fragmentation, even if roads are not directly the proximate cause of fragmentation, for example, where nonforest landcover types are between the road and the forest. In heavily forested landscapes containing large shares of public forest land where small roads traverse undeveloped landscapes,

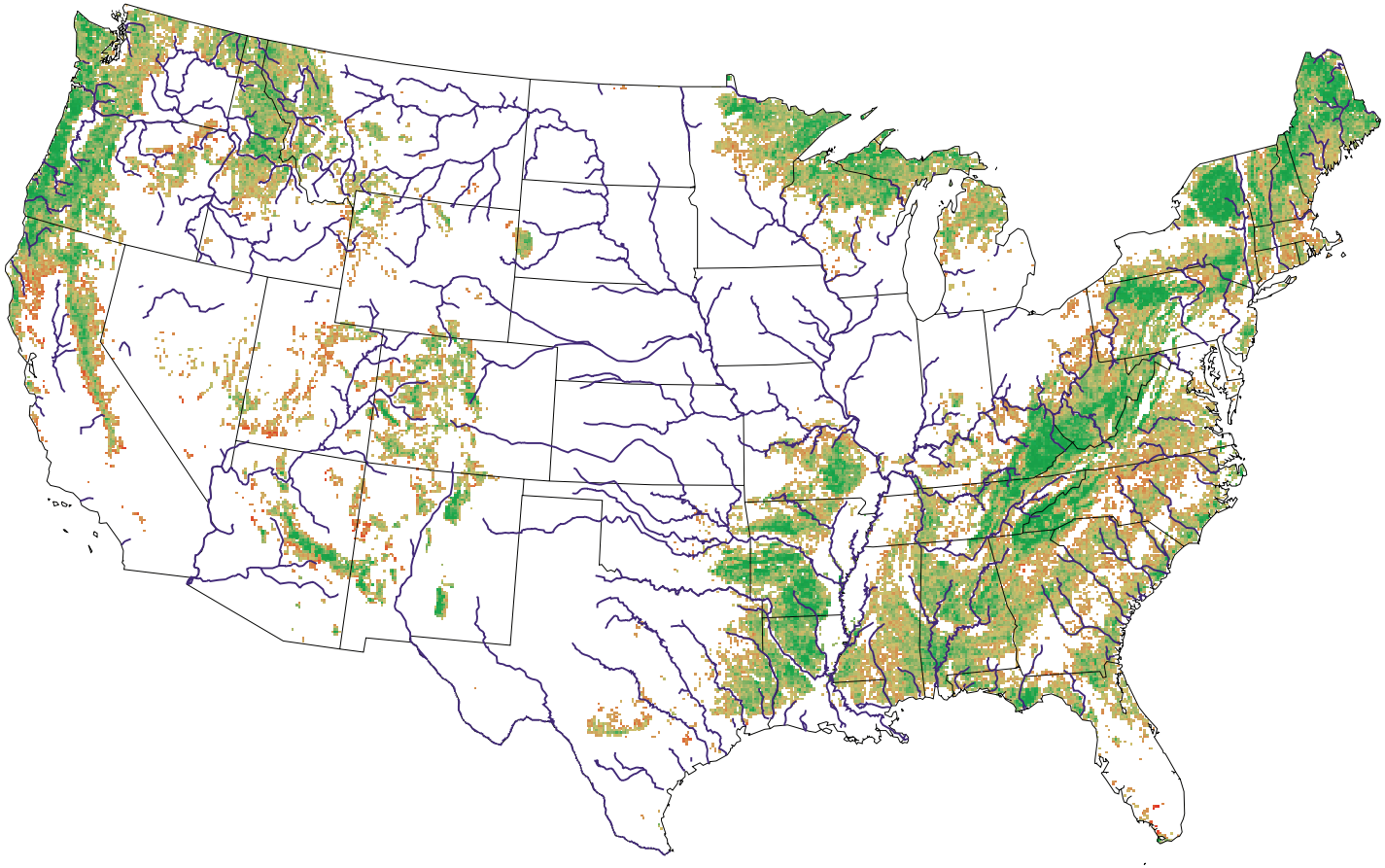

Figure 2.1—Forest land fragmentation from national landcover maps. This map shows the relative amount of "interior" forest at a 7-ha scale shaded from low (red) to high (green) for areas containing > 60 percent forest overall. The large green areas contain the major reserves of less fragmented forest land. (Data source: U.S. Department of Agriculture Forest Service 2004)

Figure 2.2—Panoramic view of Quinnimont and Grandview Sandbar (New River Gorge National River, West Virginia). The forest fragmentation associated with the main road is detectable on landcover maps because the adjacent nonforest parcels are large enough to be detected on satellite images. The "subpixel" canopy gaps created by the unpaved road along the far shore of the river are too small to be detected. The national road map identifies even more roads than are visible in this photograph. (Photograph by Frank Sellers, courtesy of the National Park Service)

fragmentation from roads accounts for over half of the total fragmentation. While roads increase total fragmentation, they do not change the relative geographic distribution of intact forest. With or without roads, the largest reserves of intact forest are on the Oregon-Washington coast; in northern Minnesota, New York, and Maine; and in the Northern Rocky, Ouachita, Ozark, and Appalachian Mountains.

National fragmentation assessments satisfy national reporting requirements, but they do not identify specific places where ecological impacts are likely or the particular forest types that are at risk. The location of perforated forest is of special concern because it represents emergent "holes" in otherwise intact forest cover that are expected to grow and coalesce with additional loss of forest. In the East, hotspots of perforated forest are widely distributed and cover 20 percent of the total area of

10 forest-dominated ecological provinces, but anthropogenic hotspots are concentrated in the Piedmont and upper Great Lakes regions. More than 90 percent of the forest edge in hotspots was attributed to anthropogenic landcover in the central latitudes, but in northern and southern latitudes it was more often associated with semi-natural landcover such as herbaceous wetlands. Nationwide, hotspots of different types of fragmentation tend to dominate in different ecological provinces. In the East, hotspots of "edge" and "patch" fragmentation dominate the less forested regions, such as the outer Coastal Plain and the Ohio River Valley. In the West, hotspots of edge fragmentation were more common in the northern ecological provinces, whereas hotspots of perforated and patch forest were concentrated in the southern ecological provinces. These geographic patterns of fragmentation imply that management and interpretation of forest fragmentation must be tailored to local conditions.

In summary, over the past 5 years the FHM program has provided unprecedented assessments of the fragmentation status of forest land in a consistent national framework. In comparison to pristine conditions, the forests of the conterminous States are heavily fragmented by human activities. But in comparison to the high development in Europe, for example, the forests are still in relatively good condition. More attention must be given to interpreting the findings of these assessments, which have created a unique opportunity to study the impacts of fragmentation on ecological endpoints such as biodiversity and water quality over extremely large regions. Such work is necessary because ecology at that scale is important, perhaps more important than local concern over individual species or water supplies, yet ecological understanding of dynamics at that scale is at best meager. Our ability to quantify and assess fragmentation in physical terms has outpaced our ability to interpret the findings in ecological terms. In the future, FHM will continue to assess and report the status of and trends in forest fragmentation, and will continue to assist ecologists and forest managers in understanding and making use of the data.

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CRITERION 3—

Chapter 3. Drought Occurrence

John W. Coulston

Why Is Drought Important?

Drought is an important forest disturbance that occurs regularly in the Western United States and irregularly in the Eastern United States (Dale and others 2001). Moderate drought stress tends to slow plant growth while severe drought stress can also reduce photosynthesis (Kareiva and others 1993). Drought can also interact with other disturbances, such as fire, insects, and diseases, that may lead to tree mortality and can exacerbate ecosystem stress.

Methods

The National Climate Data Center (NCDC) calculates the Palmer Drought Severity Index (PDSI) monthly by climate division for the conterminous United States. The NCDC archive contains monthly estimates of PDSI from 1895 to present (National Climate Data Center 1994). Using the PDSI, the average number of months of moderate, severe, or extreme drought was calculated for each ecoregion section of the conterminous United States for each year from 1895 through 2004 (for details about the method used, see Conkling and others 2005).

Both the 2004 drought occurrence and the 1995-2004 drought deviation were examined for each ecoregion section. Drought deviation compares drought occurrence in the current decade to the historical average (Conkling and others 2005). The frequency of drought from 1895 through 2004 served as a historical account or reference point for each ecoregion section. For example, if 396 months of drought were recorded in an ecoregion section from 1895 through 2004, then approximately 36 months of drought would be expected on a 120-month (10-year) basis. The historical account was then compared to the current decade. If the expected number of months with drought conditions was 36, and 48 months of drought were recorded in the current decade, then the drought deviation was 48 – 36 = 12. This technique simply compared the number of months of drought in the current decade with the expected value. There was no analysis of either the number of sequential months of drought or any possible temporal autocorrelation in drought occurrence, both of which may be important when assessing drought impacts.

What Do the Data Show?

In the Eastern United States, 2004 was a relatively wet year, with all ecoregion sections experiencing < 2 months of drought (fig. 3.1). The Western United States was considerably more droughty in 2004. Forests in section M332D–Belt Mountains experienced 12 months of drought. The scattered forests in sections 331G–Powder River Basin, 342G–Green River Basin, 322B–Sonoran Desert, and 342F–Central Basin and Hills experienced 11 months of drought in 2004.

The past decade (1995-2004) was more droughty than expected for several ecoregion sections in the Western United States (fig. 3.2). Forested areas in section 313C–Tonto Transition experienced 43 more months of drought than was expected based on long-term averages. The ecoregion sections in the American Semi-Desert and Desert Province (322) had a drought deviation of > 36 months. Forests in section M332D–Belt Mountains had a drought deviation of 33 months during the past decade (1995-2004). Section M331A–Yellowstone Highlands had a drought deviation of 32 months.

Most ecoregion sections in the Eastern United States experienced the expected amount or less than the expected amount of drought during the past decade (1995-2004). However, there were a few exceptions. The forested areas of section 232G–Florida Coastal Lowlands (Eastern) experienced 19 more months of drought than expected. Forested areas in section M221D–Blue Ridge Mountains experienced an additional 13 months of drought, and forests in section 221C–Upper Atlantic Coastal Plain experienced an additional 10 months of drought.

Drought stress plays a major role in ecosystem dynamics, influencing insect populations, uptake of ozone in plants, and fire occurrence. Over the past decade, ecoregion sections in the Western United States experienced drought conditions more often than ecoregion sections in the Eastern United States. The large-scale influence of drought stress on ecosystems is unknown, but continuous monitoring of drought conditions can help elucidate the relationships between drought and other disturbances at a national scale.

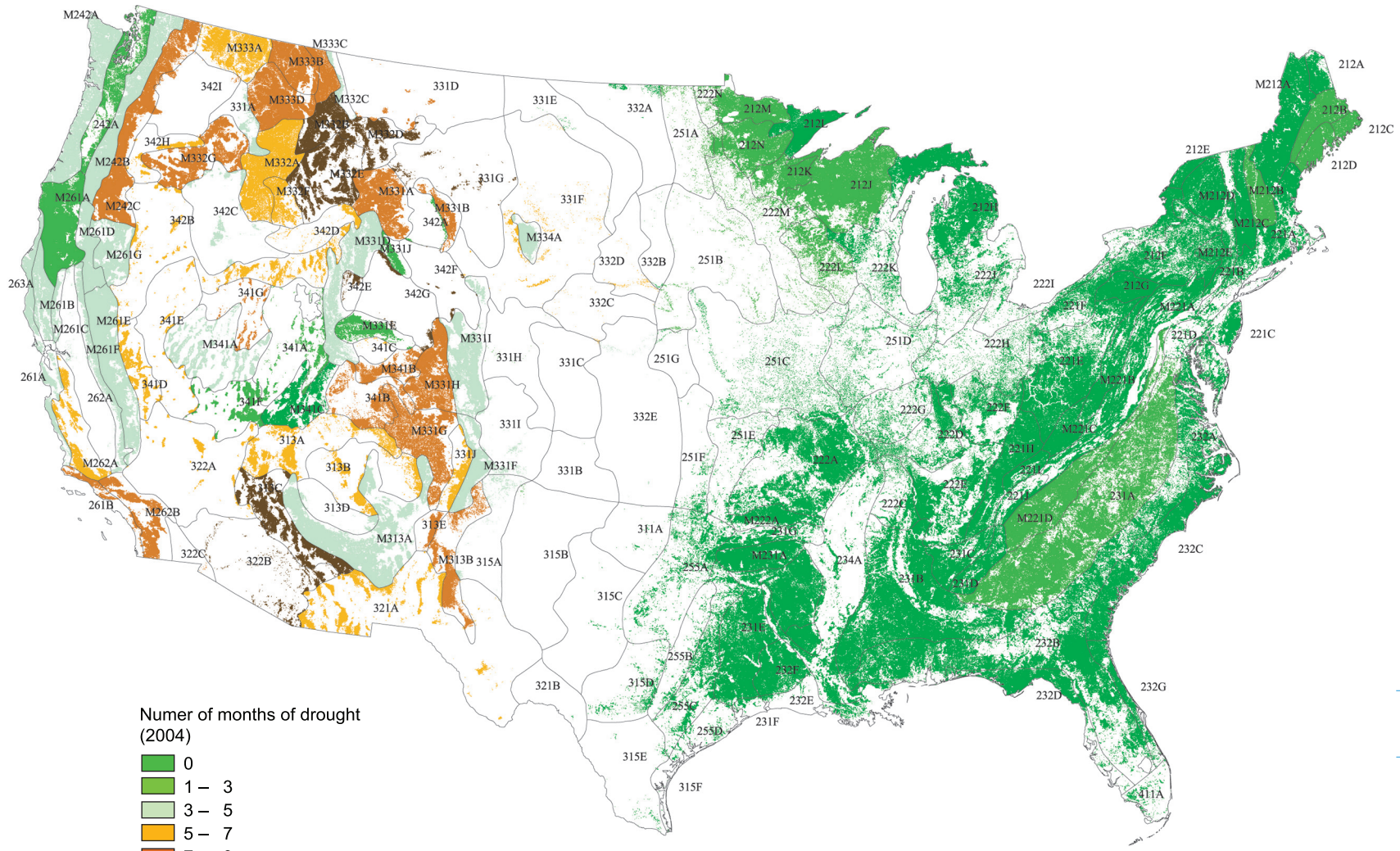

Figure 3.1—The average number of months of drought for forested areas of each ecoregion section (Bailey 1995, McNab and Avers 1994) in 2004. Forest cover is derived from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery (Zhu and Evans 1994). (Data source: National Climate Data Center)

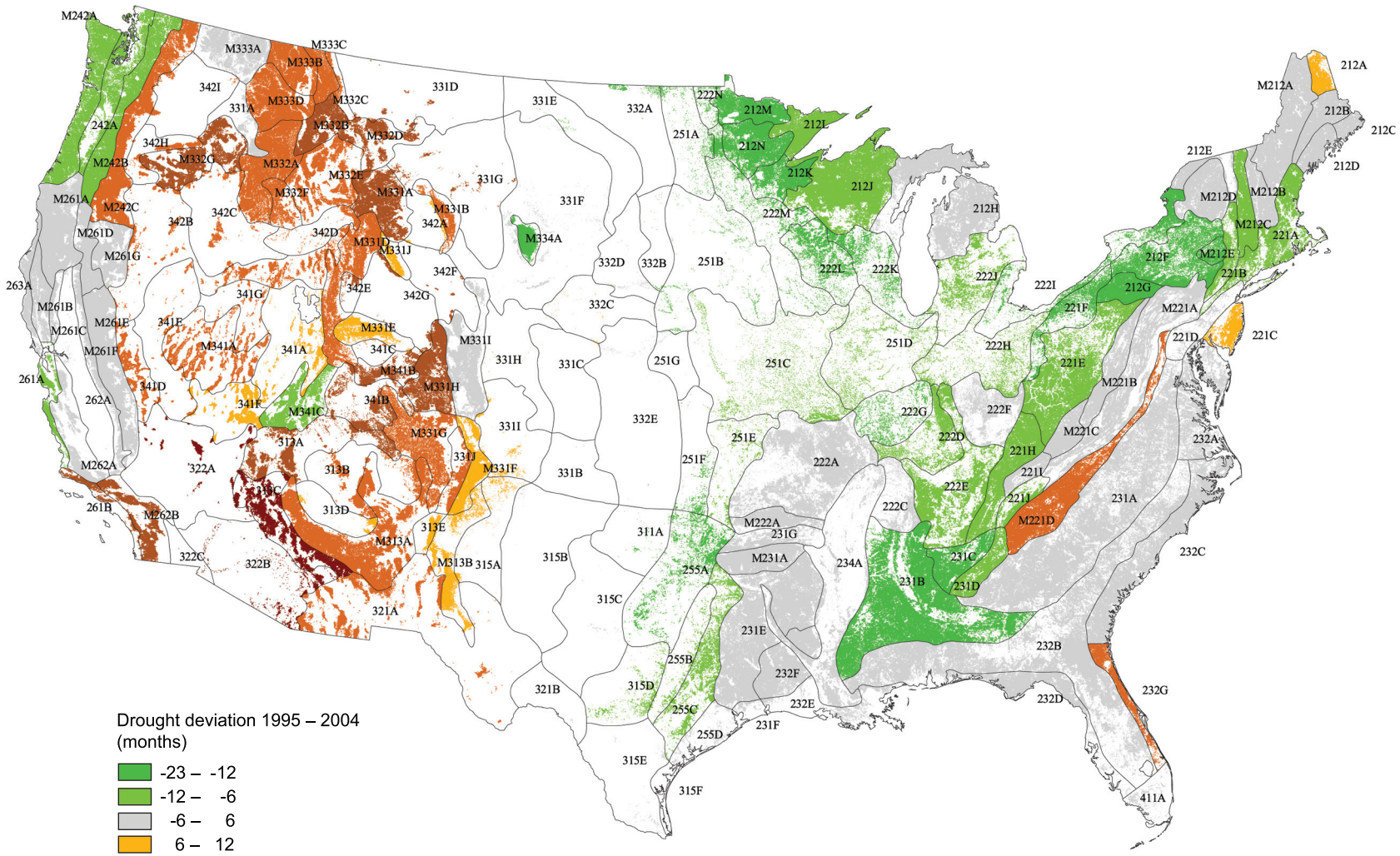

Figure 3.2—Drought deviation for the period 1995–2004 for forested areas of each ecoregion section (Bailey 1995, McNab and Avers 1994). Forest cover is derived from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery (Zhu and Evans 1994). (Data source: National Climate Data Center)

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CRITERION 3—

Chapter 4. Fire Occurrence (2004)

John W. Coulston

Why Is Fire Important?

Fire is a powerful, selective regulatory mechanism in forest ecosystems. It is a natural part of the environment, and fire-affected ecosystems depend on a particular frequency and intensity of fire. These ecosystems will remain in their natural state only if the fire regime to which they are adapted is present (Kimmins 1987). The frequency and intensity of burning depends on the buildup of fuels, weather conditions, management activities, and the occurrence of ignition sources. Fire frequency and intensity have been significantly altered on approximately 15 percent of the forested area in the conterminous United States (Schmidt and others 2002). Wildland fires in these areas can have significant economic and ecological impacts.

Methods

Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detection data for the conterminous United States for 2004 (U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center 2004) were examined to determine the proportion of forested pixels in each ecoregion section with active fires recorded. The pixel size was 1 km^2, but the MODIS sensor does not differentiate between a fire as small as 0.01 km^2 burning at very high temperatures and a 1-km^2 low-intensity fire. The entire 1-km^2 pixel may be classified as having a fire in either scenario. For this reason the MODIS fire data were not used to determine area burned. Information on area burned was obtained from the National Interagency Coordination Center (2004). MODIS data for the 2004 fire season were analyzed as suggested by Coulston and others (2005). Specifically, we examined the timing of the fire season using a cumulative distribution function and identified ecoregion sections containing a relatively high proportion of forested pixels that had fires in 2004.

What Do the Data Show?

The length and timing of each fire season can differ among years. In 2004, approximately 70 percent of the fires in forested areas recorded

by the MODIS satellites occurred between day-of-year 170 (18 June 2004) and day-of-year 246 (2 September 2004) (fig. 4.1). According to the official wildland fire statistics, the total area burned in the conterminous United States in 2004 was 5876 km², which is only 40 percent of the annual 10-year average (National Interagency Coordination Center 2004).

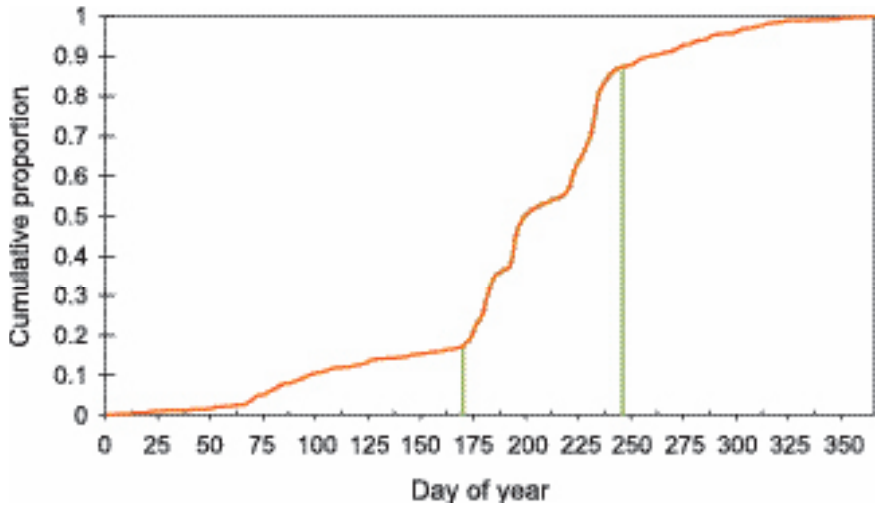

Figure 4.1—Cumulative distribution function of fire occurrence in 2004 by day-of-year. The vertical lines show the approximate start and end of the fire season. (Data source: U.S. Department of Agriculture Forest Service, Remote Sensing Application Center.)

However, Alaska had a severe fire season in which 26 895 km² burned, and this area was 82 percent of the national total for 2004 (32 771 km²). The number of forested pixels in the United States with fires recorded on them by the MODIS satellites increased from 2003 to 2004, but this increase was mostly a result of relatively high fire occurrence in sections M139A–Upper Yukon Highlands and 139A–Upper Yukon Flats in Alaska. Both the Upper Yukon Highlands and Upper Yukon Flats sections had fires recorded on > 10 percent of the forested pixels (fig. 4.2). In the conterminous United States, section 315A–Pecos Valley in New Mexico had the largest percentage (5.96 percent) of forested pixels with fires recorded by the MODIS satellites in 2004 (fig. 4.2). However, this area was not heavily forested, containing a relatively small area of forest in northeastern New Mexico and another small area of forest in south-central New Mexico. Sections 251F–Flint Hills in Oklahoma and Kansas and 255A–Cross Timbers and Prairie in Oklahoma and Texas had fires detected on 4.7 percent and 3.9 percent of the forested pixels, respectively. In Louisiana, fires were detected on 3.3 percent of the forested pixels in section 232F–Coastal Plains and Flatwoods, Western Gulf.

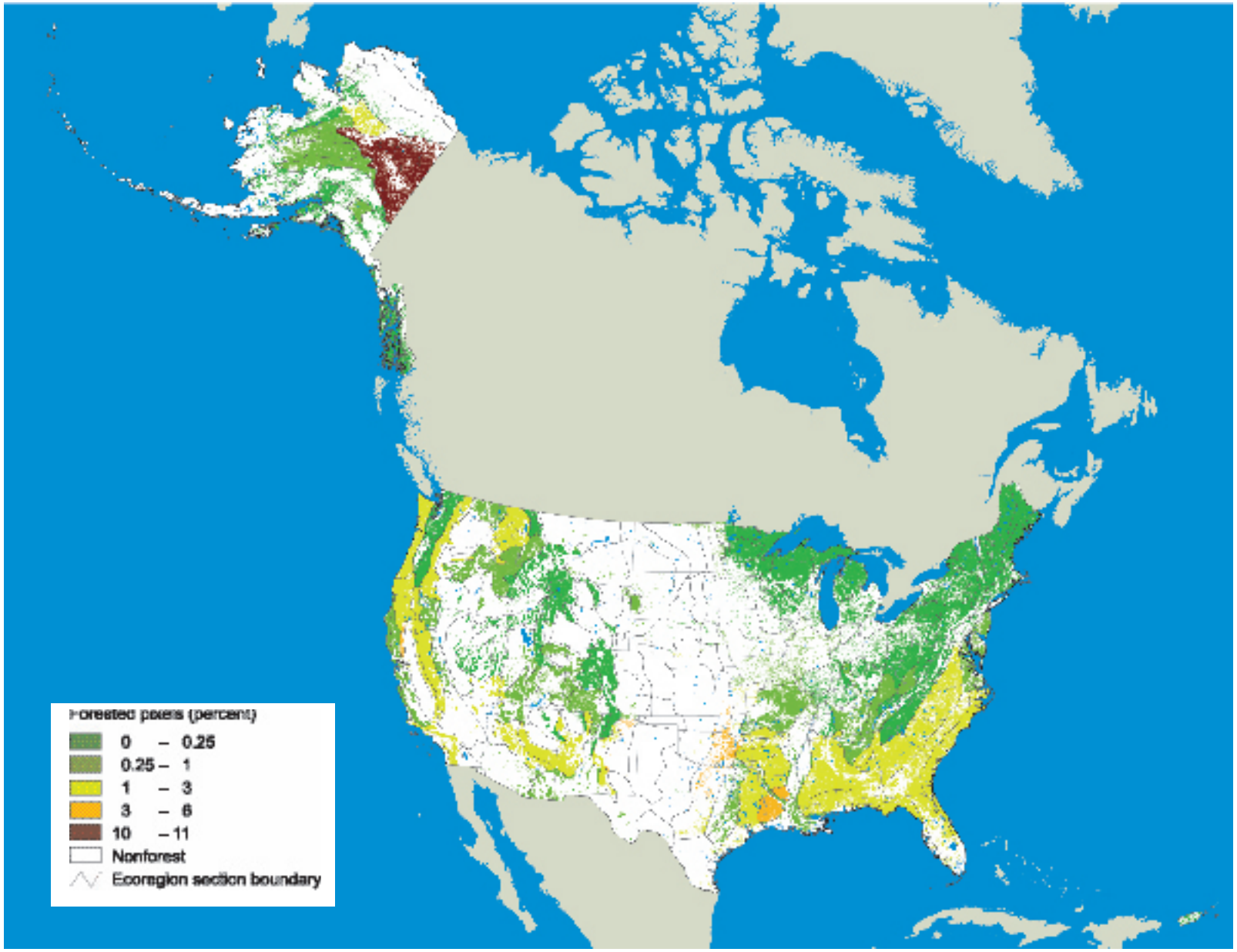

Figure 4.2—The percent of forested pixels in 2004 with fires recorded by the MODIS satellites by ecoregion section (Bailey 1995, McNab and Avers 1994). Forest cover is derived from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery (Zhu and Evans 1994). (Data source: U.S. Department of Agriculture Forest Service, Remote Sensing Application Center; Map projection: Lambert azimuthal, center of projection: 100° W, 45° N.)

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CRITERION 3—

Chapter 5. Ozone Bioindicator

John W. Coulston and
Mark J. Ambrose

Why Is Ozone Important?

Ground-level ozone occurs at phytotoxic levels in the United States (Lefohn and Pinkerton 1988). Elevated levels of ozone can cause foliar injury to several tree species, may cause growth loss, and can make trees more susceptible to insects and pathogens (Chappelka and Samuelson 1998). However, tree species have varying degrees of sensitivity to ozone, and ozone can induce foliar injury only if tree stomata are open. Thus, the overall impact of elevated ozone concentrations depends on the amount of ozone, climatic conditions such as drought, and the composition of the forest.

Methods

The protocols suggested by Coulston and others (2003) were used to calculate an ozone biosite index that describes the amount and severity of ozone injury to biomonitoring plants on ozone biomonitoring plots (1999-2002). Next, a map of potential ozone injury and risk was created using the categories in table 5.1 (Coulston and others 2003, Smith and others 2003) and inverse distance weighted interpolation of the biosite index. Forest Inventory and Analysis (FIA) phase 2 plots (using approximate locations) were then spatially intersected with the ozone injury risk

Table 5.1—Classification scheme for the Forest Inventory and Analysis biosite index

Biosite value	Bioindicator response	Assumption of risk	Possible impact	Relative air quality
0 – < 5	Little or no foliar injury	None	Visible injury to highly sensitive species, e.g. black cherry	Good
5 – < 15	Light to moderate foliar injury	Low	Visible injury to moderately sensitive species, e.g. yellow-poplar	Moderate
15 – < 25	Moderate to severe foliar injury	Moderate	Visible and invisible injury; tree-level response	Unhealthy for sensitive species
≥ 25	Severe foliar injury	High	Visible and invisible injury; ecosystem-level response	Unhealthy

map. Each tree species on the FIA phase 2 plots was then classified as either ozone sensitive, moderately ozone sensitive, insensitive to ozone, or having unknown sensitivity based on a literature review by Smith and others (in press). We used the interpolated risk map to determine the distribution of five commercially important, ozone-sensitive tree species (loblolly pine, white ash, quaking aspen, black cherry, and ponderosa pine) across ozone biosite classes. We also used the interpolated risk map together with the ozone sensitivity classifications to determine the distribution of tree species by ozone sensitivity within areas predicted to have relatively high ozone biosite index scores.

What Do the Data Show?

In general, the amount and severity of ozone injury to bioindicator plants was higher in the Eastern United States than the Western United States for the 1999 to 2002 period (fig. 5.1). Almost all of the basal area of quaking aspen and ponderosa pine was located in areas predicted to have little or no ozone injury (table 5.2). Of the tree species analyzed, black cherry had the lowest proportion (approximately 0.66) of its basal area in the little or no injury category. The proportion of black cherry in the highest risk category was 0.02. Both loblolly pine and white ash had the same proportion (0.76) of their basal areas in the little or no injury category, but their proportions in the high-risk category were 0.02 and 0, respectively.

The five commercially important species examined did not have a majority of their basal areas at high risk to ozone injury. However, this does not mean that specific “localized” areas may not be at risk. In the Northeast and South Forest Health Monitoring (FHM) regions, forests predicted to be in the high and moderate risk categories consisted of > 40 percent ozone-sensitive species (by basal area) (fig. 5.2). High- and moderate-risk areas in the North Central FHM region had about 30 percent of basal area in sensitive species, while high- and moderate-risk areas in the West Coast region had only about 6 percent of basal area in sensitive species.

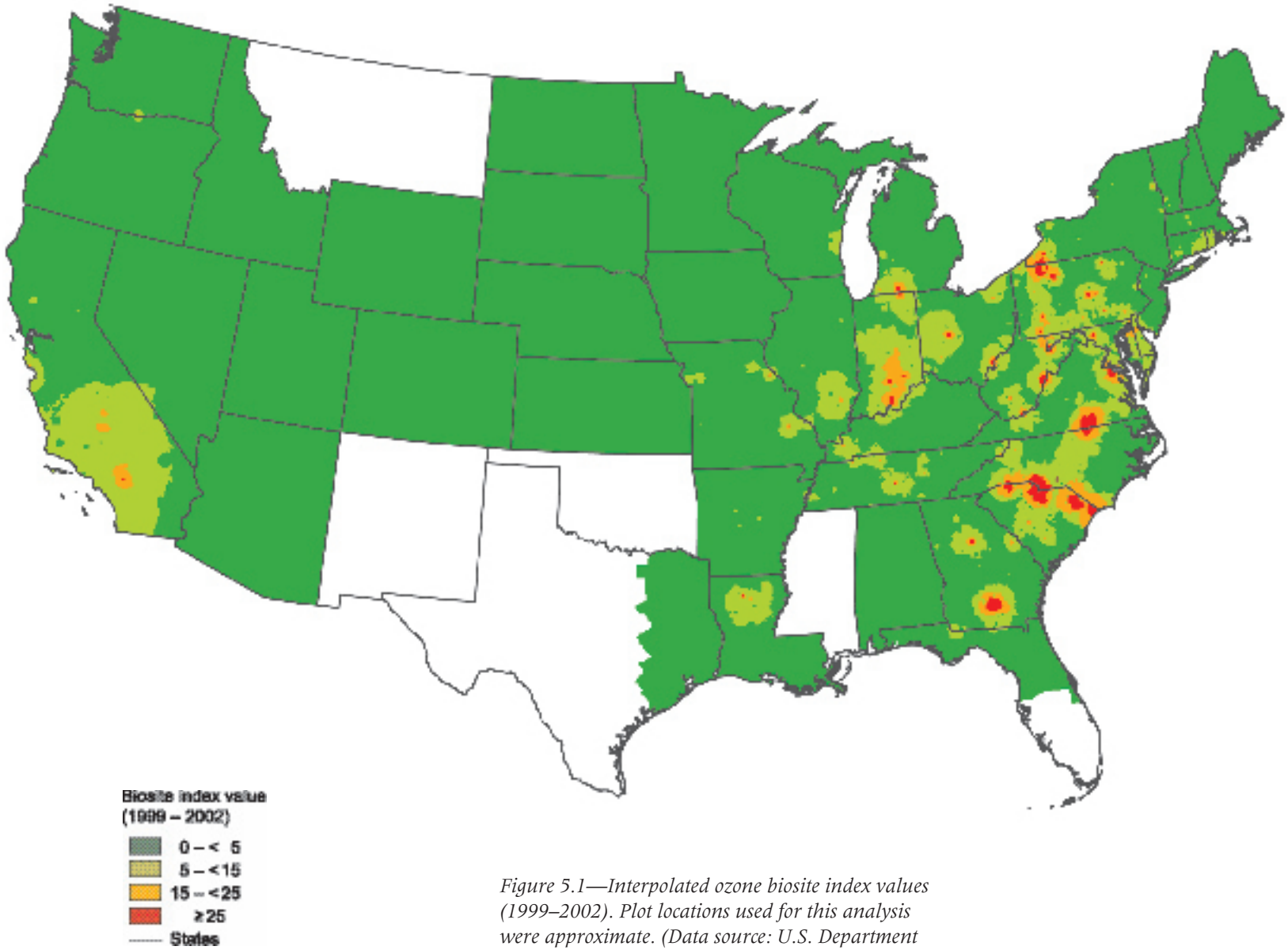

Figure 5.1—Interpolated ozone biosite index values (1999–2002). Plot locations used for this analysis were approximate. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

Table 5.2—Basal area proportion of five commercially important species in each biosite index category for the Eastern and Western United States

	Eastern United States				Western United States	
Biosite index	Loblolly pine	White ash	Quaking aspen	Black cherry	Ponderosa pine	Quaking aspen
0 – 5	0.76	0.76	0.99	0.66	0.99	1.00
5 – 15	0.18	0.21	0.01	0.25	0.01	0.00
15 – 25	0.05	0.03	0.00	0.07	0.00	0.00
≥ 25	0.02	0.00	0.00	0.02	0.00	0.00

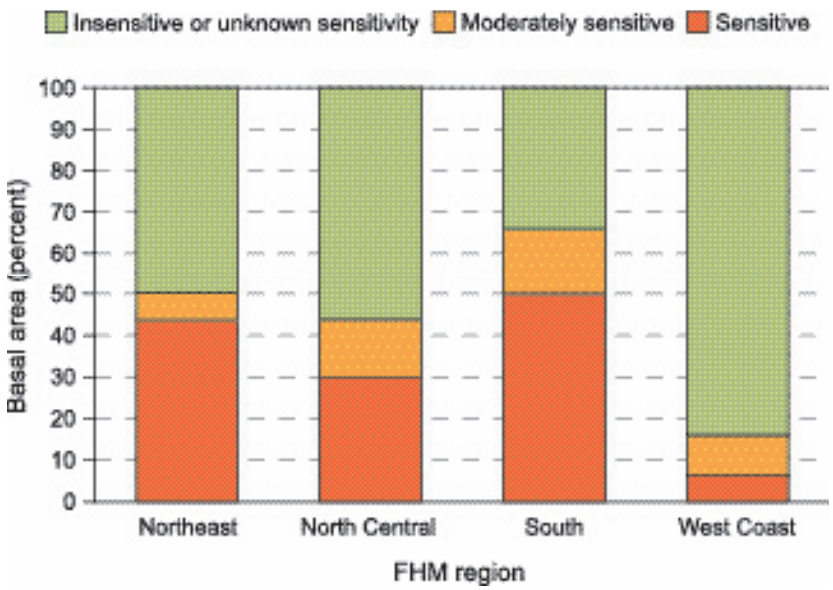

Figure 5.2—Ozone sensitivity of tree species in the high and moderate ozone risk areas of the conterminous United States by Forest Health Monitoring (FHM) region. Note: The Interior West FHM region did not have any area predicted to be in either the moderate or high ozone risk category. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

Overall, most of the forested FIA plots (86 percent) were classified in the lowest biosite index category, and tropospheric ozone does not appear to pose a large-scale threat to the five commercially important species examined. However, there are specific areas where bioindicator plant injury from ozone was severe and where there is, therefore, a higher risk of impact. For example, in the high-risk areas of the South region, sensitive or moderately sensitive tree species accounted for approximately 66 percent of the basal area. The probability of negative effects (e.g., change in species composition, reduced growth rates, and increased susceptibility to insects and pathogens) is greater in such areas.

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Appendix—Common and scientific names of cited tree species

Common name	Scientific name
Black cherry	*Prunus serotina*
Loblolly pine	*Pinus taeda*
Ponderosa pine	*Pinus ponderosa*
Quaking aspen	*Populus tremuloides*
White ash	*Fraxinus americana*

CRITERION 3—

Chapter 6. Insect and Disease Activity (2003)

John W. Coulston

Why Are Insects and Diseases Important?

Native insects and diseases are a natural part of ecosystems and are essential to the ecological balance in natural forests (Castello and others 1995). In contrast, nonnative insects and diseases can pose a particular threat because ecosystems often lack natural internal controls of these agents. The activity of both native and nonnative insects and pathogens (i.e., disease-causing microorganisms) is related to a suite of both natural and anthropogenic factors such as climate and management activities. Insects and diseases can influence patterns and processes of forested landscapes mostly through tree mortality or reduced tree vigor, which in some cases result in ecological or economic impacts, or both.

Methods

Nationally compiled Forest Health Protection (FHP) aerial survey data from 2003 were used to assess insect and disease activity at the landscape level. In the aerial surveys, areas of defoliation and mortality caused by insects and pathogens were mapped and the causal agent identified. A particular species of insect or pathogen might be identified as a defoliation-causing agent in one location and as a mortality-causing agent in another, depending on the level of damage to the forest in a particular area. In 2003, aerial surveys were conducted over a majority of the forested area of the conterminous United States (fig. 6.1). The exposure of forests to mortality- and defoliation-causing agents was assessed within each Forest Health Monitoring (FHM) region. Exposure was defined as the area in hectares with mortality- or defoliation-causing agents present. The analysis was based on relative exposure (observed vs. expected) on a county basis within each FHM region and was used to identify hotspots of activity during 2003 [e.g., see Kulldorff (1997) and Coulston and Riitters (2003)]. The observed exposure was the number of hectares in each county with activity, and the expected exposure in hectares was calculated for each region based on a Poisson model (Coulston and others 2005). Relative exposure ranges from 0 to infinity, where values < 1 represent low relative exposure and less than expected defoliation or mortality within the region. A value > 1 represents more than

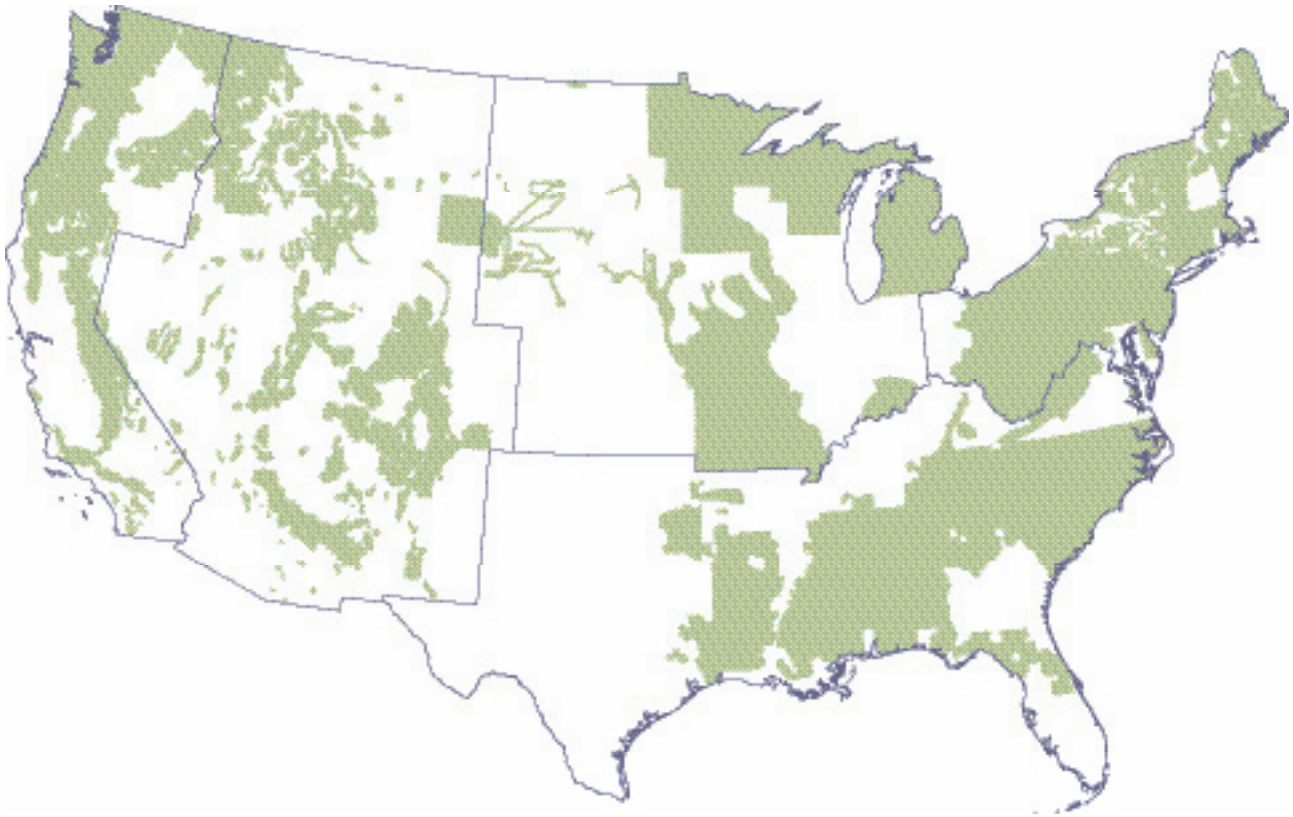


Figure 6.1—The extent of aerial surveys for insect and disease activity conducted in the conterminous United States in 2003 (shown in green). The purple lines delineate the Forest Health Monitoring program regions. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection.)

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.

What Do the Data Show?

Several forested areas in the Northeast FHM region had high relative exposures to mortality-causing agents. Portions of sections 212G–Northern Unglaciated Allegheny Plateau and M221B–Allegheny Mountains experienced more than six times the expected exposure (fig. 6.2A). Some of the reported mortality was due to beech bark disease. As a result of balsam woolly adelgid and decline,[1] much of the forested area in section M212C–Green, Taconic, Berkshire Mountains had more than twice the expected exposure to mortality-causing agents. The most intense areas of defoliation activity in the Northeast FHM region were in sections M221A–Northern Ridge and Valley and 221A–Lower New England (fig. 6.2B). Gypsy moth accounted for most of the defoliation-causing activity in the Northern Ridge and Valley section. In Lower New England, spanworm and forest tent caterpillar accounted for most of the activity.

The forest tent caterpillar was also active in the South FHM region, causing defoliation in parts of sections 232C–Atlantic Coastal Flatlands and 232B–Coastal Plains and Flatwoods, Lower, in South Carolina (fig. 6.2B). The only other agent reported as causing defoliation damage in the South FHM region in the 2003 national aerial survey data was gypsy moth (in Virginia). The forest tent caterpillar and the baldcypress leafroller caused mortality in sections 234A–Mississippi Alluvial Basin and 232E–Louisiana Coast Prairies and Marshes Section (fig. 6.2A).

Most mortality-causing insect and disease activity in the North Central FHM region was concentrated in four ecoregion sections (fig. 6.2A). Emerald ash borer caused mortality in sections 222I–Erie and Ontario Lake Plain and 222J–South-Central Great Lakes. In section 212H–Northern Great Lakes, annosus root disease, beech bark disease, and oak wilt caused mortality. Mountain pine beetle accounted for a majority of the mortality-causing activity in section M334A–Black Hills. Relative exposure to

[1] Specific causal agents were not identified in the FHP database.

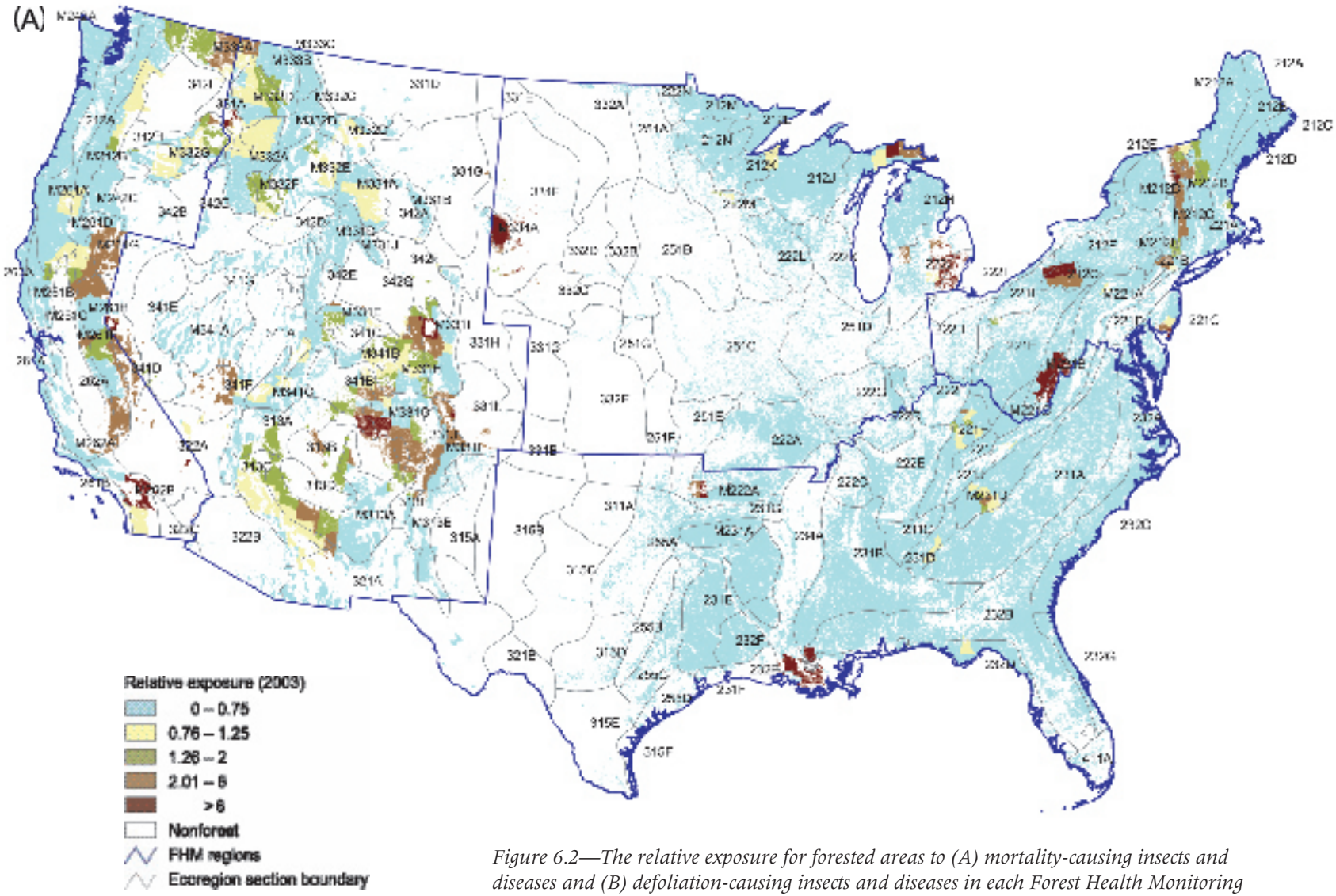
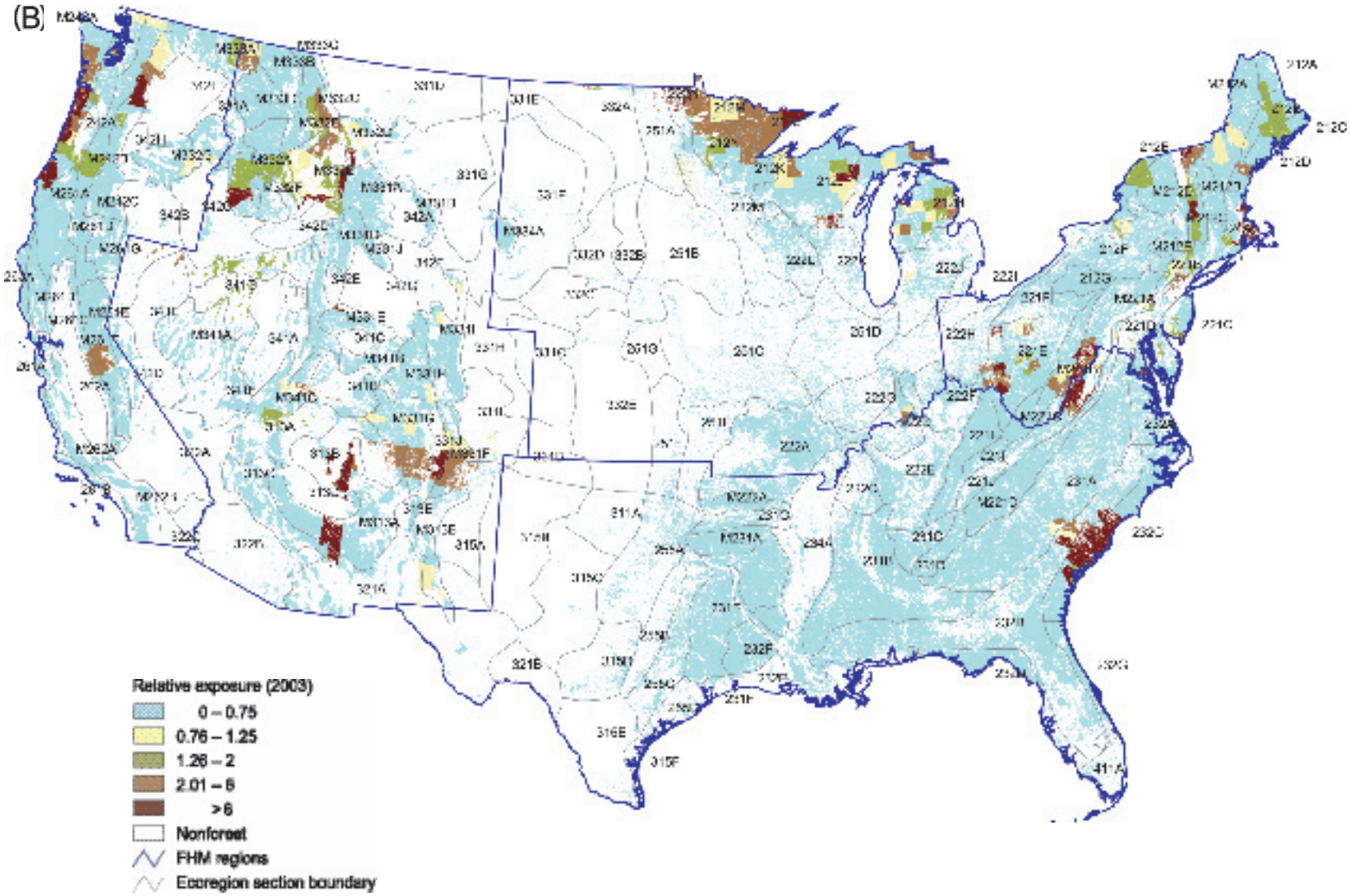


Figure 6.2—The relative exposure for forested areas to (A) mortality-causing insects and diseases and (B) defoliation-causing insects and diseases in each Forest Health Monitoring (FHM) region (2003). The gray lines delineate Bailey's ecoregion sections (Bailey 1995, McNab and Avers 1994). Forest cover is derived from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery (Zhu and Evans 1994). (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection.) *(Continued to next page)*


(B)
Relative exposure (2003)
0 – 0.75
0.76 – 1.25
1.26 – 2
2.01 – 6
>6
Nonforest
FHM regions
Ecoregion section boundary

defoliation-causing insects and diseases was high in sections 212L–Northern Superior Uplands, 212M–Northern Minnesota and Ontario, and 212N–Northern Minnesota Drift and Lake Plains (fig. 6.2B). Most of this defoliation, particularly in section 212L–Northern Superior Uplands, was caused by the forest tent caterpillar.

In 2003, there were several hotspots of mortality-causing insect and disease activity in the Interior West FHM region (fig. 6.2A). Pinyon pine mortality[2] was most intense in parts of sections 313A–Grand Canyon and M331G–South-Central Highlands. Forests in section M331I–Northern Parks and Ranges also experienced high relative exposure to mortality-causing agents. Mountain pine beetle accounted for much of this activity. There were also several hotspots of defoliation-causing insect and disease activity (fig. 6.2B). Some forested areas in section M313A–White Mountains–San Francisco Peaks–Mogollon Rim had exposure rates more than six times the expected levels. This high relative exposure was mostly due to western spruce budworm, spruce aphid, and aspen defoliation.[3] The western spruce budworm was mostly responsible for areas of high relative exposure in sections M331F–Southern Parks and Rocky Mountain Ranges, M332A–Idaho Batholith, M332D–Belt Mountains, and M332E–Beaverhead Mountains.

Parts of the West Coast FHM region had higher than expected exposure to mortality-causing insects and pathogens in 2003 (fig. 6.2A). Several areas in sections M261G–Modoc Plateau and M261E–Sierra Nevada had more than twice the expected rates of exposure to mortality-causing agents. Much of this activity was from bark beetles. In section M262B–Southern California Mountains and Valleys, multi-insect and disease damage caused mortality. Parts of section M242A–Oregon and Washington Coast Ranges had more than six times the expected exposure rate to defoliation-causing insects and diseases (fig. 6.2B). Much of the defoliation in this ecoregion section was caused by Swiss needle cast. Parts of section M242C–Eastern Cascades also had more than six times the expected exposure rate, but in this case, western spruce budworm was responsible for most of the defoliation.

[2] The specific mortality-causing agents were not identified in the FHP database.

[3] The specific causes of defoliation were not identified in the FHP database.

Overall, in 2003, 48 different species of mortality-causing agents were recorded during aerial surveys of the conterminous United States. Of these species, mountain pine beetle, Douglas-fir beetle, fir engraver, and southern pine beetle were the most frequently observed. Fifty-four different species of defoliation-causing agents were recorded in the conterminous United States during 2003. Of these defoliation-causing agents, forest tent caterpillar, Swiss needle cast, western spruce budworm, and gypsy moth were most frequently observed. Continued monitoring of forested areas is important to determine when the activity of insects and diseases that cause mortality or defoliation warrants follow-up investigation or management action.

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Appendix—Common and scientific names of cited forest pest species

Common name	Scientific name
Annosus root disease	*Heterobasidion annosum*
Baldcypress leafroller	*Archips goyerana*
Balsam woolly adelgid	*Adelges piceae*
Beech bark disease	*Nectria coccinea var. faginata*
Douglas-fir beetle	*Dendroctonus pseudotsugae*
Emerald ash borer	*Agrilus planipennis*
Fir engraver	*Scolytus ventralis*
Forest tent caterpillar	*Malacosoma disstria*
Gypsy moth	*Lymantria dispar*
Mountain pine beetle	*Dendroctonus ponderosae*
Oak wilt	*Ceratocystis fagacearum*
Southern pine beetle	*Dendroctonus frontalis*
Spruce aphid	*Elatobium abietinum*
Swiss needle cast	*Phaeocryptopus gaumannii*
Western spruce budworm	*Choristoneura occidentalis*

CRITERION 3—

Chapter 7. Down Woody Materials as an Indicator of Wildlife Habitat, Fuels, and Carbon Stocks of the United States

Christopher W. Woodall

Why Are Down Woody Materials Important?

The down woody materials (DWM) indicator is used to estimate the quantity of dead organic material (resulting from plant mortality and leaf turnover) in forest ecosystems of the United States. The DWM indicator, coupled with other components of the enhanced Forest Inventory and Analysis (FIA) program, can indicate the current status of fuels, carbon pools, and wildlife habitat of our nation's forest ecosystems. The fine and coarse woody components of the DWM indicator are specifically designed to match the components defined by the National Fire Danger Rating System. Use of the DWM indicator may increase the precision of carbon pool estimates across the United States. Additionally, the coarse woody debris (CWD) component of DWM may indicate the condition of habitat critical for numerous plants and animals.

Methods

The diversity of ecosystem attributes estimated using data from the DWM indicator requires a variety of plot-based sampling protocols: line-intersect sampling for fine woody debris (FWD) and CWD; simple random sampling for duff, litter, and fuel-bed depths; and shape and packing ratio estimation for slash piles. Briefly, CWD was sampled on each of three 24-foot horizontal distance transects radiating from each FIA subplot center at 30, 150, and 270 degrees. Down woody pieces with an intersecting transect diameter of at least 3 inches and a length of at least 3 feet were considered CWD. Data collected for every CWD piece were transect diameter, length, small-end diameter, large-end diameter, decay class, species (if it could be determined), evidence of fire, and presence of cavities. FWD (1-, 10-, and 100-hour fuels) were sampled on the 150-degree transect on each subplot. FWD pieces with transect diameters of 0.01 to 0.24 and 0.25 to 0.99 inches (1- and 10-hour fuels, respectively) were tallied separately along a 6-foot (slope distance) segment of the 150-degree transect. Pieces of FWD with transect diameters of 1.00 to 2.99 inches (100-hour fuels) were tallied on a 10-foot (slope distance) segment of the 150-degree transect (Woodall and Williams 2005).

Slight differences between the 2001 and 2002-03 DWM sample protocols are detailed in Woodall and Williams (2005). Unit-area estimates (tons per acre) for the fuel-hour classes followed Brown's (1974) estimation procedures, while CWD volume and pieces per acre estimates were based on DeVries's line-intercept estimators (DeVries 1986). Conversion of tonnage estimates (fuel loads) to carbon estimates was based on work detailed by Waddell (2002). For more background and details regarding the sampling and estimation of DWM components, see Woodall and Williams (2005). In order to produce national maps of DWM estimates, each plot was assigned to an Environmental Monitoring and Assessment Program (EMAP) hexagon (Overton and others 1990, White and others 1992). The EMAP grid, produced by the U.S. Environmental Protection Agency, is a hexagonal grid superimposed on the map of the United States.

What Data Are Available?

The national DWM inventory began in 2001, primarily in States for which the FIA annual inventory system (U.S. Department of Agriculture Forest Service 2002) had been implemented. Since 2001, as annual inventories have started in each State, so have the DWM inventories, with 41 States having an annual DWM inventory in 2003 for a total of 3,535 plots nationwide (table 7.1). As annual inventories are implemented in remaining States and as more years of DWM data are collected in current annual inventory States, the nationwide sample size will increase substantially. Because the database management and estimation algorithms are currently being developed, the current analyses for the DWM indicator should be considered preliminary until data have been thoroughly vetted and appropriately linked with the standing tree inventory (phase 2). Although 3,535 plots were sampled as of 2003, only 3,167 were included in these analyses. The data from the remaining 368 plots require further editing and validation. These data editing and management efforts are ongoing.

What Do the Data Show?

FWD are down dead woody materials with a diameter < 3 inches and can usually be attributed to branch-fall or wind-felled

Table 7.1—Preliminary number of down woody materials indicator inventory plots as of 2003

State	Number of plots	State	Number of plots
Alabama	139	Nebraska	12
Arizona	164	Nevada	21
Arkansas	109	New Hampshire	16
California	214	New Jersey	13
Colorado	167	New York	118
Connecticut	6	North Carolina	102
Florida	78	North Dakota	4
Georgia	160	Ohio	66
Idaho	44	Oklahoma	2
Illinois	44	Oregon	167
Indiana	30	Pennsylvania	225
Iowa	21	South Carolina	84
Kansas	20	South Dakota	13
Kentucky	68	Tennessee	103
Louisiana	67	Texas	73
Maine	123	Utah	181
Massachusetts	6	Vermont	8
Michigan	128	Virginia	108
Minnesota	192	Washington	140
Missouri	105	Wisconsin	92
Montana	102		

tree crowns. There are no obvious areas of exceedingly high FWD fuel loadings (> 20 tons per acre) across the nation (fig. 7.1). Upon visual inspection, the distribution of FWD fuel loadings across the nation appears to be random. The accumulation of FWD may be partly dependent on the growth form of trees, stochastic wind disturbances, and individual tree mortality in the context of stand development. Local areas of unusually high FWD accumulations may indicate blowdown events or locally limited tree mortality.

CWD are down dead woody materials with a diameter ≥ 3 inches and are usually detached large tree limbs or dead and down shrub or tree boles. There is a definite pattern of CWD fuels across the nation (fig. 7.2). The forest ecosystems of the West Coast, together with more isolated areas of the northern Great Lakes region and northern New England, have some of the highest accumulations of CWD in terms of fuel loadings (tons per acre). There are areas of very high CWD accumulations in other regions. However, they occur in patches indicating the possible effects of local-scale

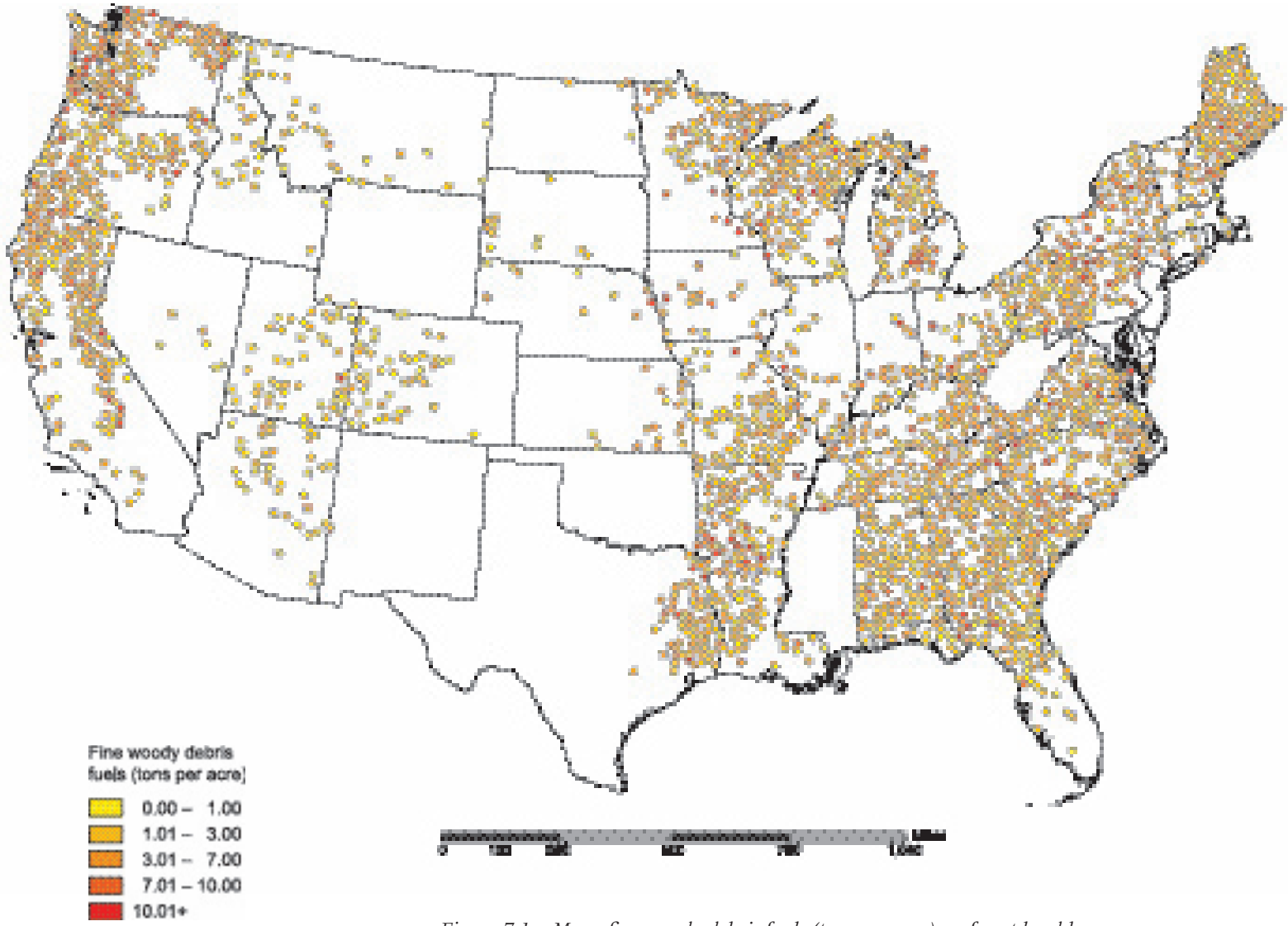

Figure 7.1—Mean fine woody debris fuels (tons per acre) on forest land by Environmental Monitoring and Assessment Program (EMAP) hexagon (Overton and others 1990, White and others 1992) based on the down woody materials indicator of the Forest Inventory and Analysis program, 2001–03. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

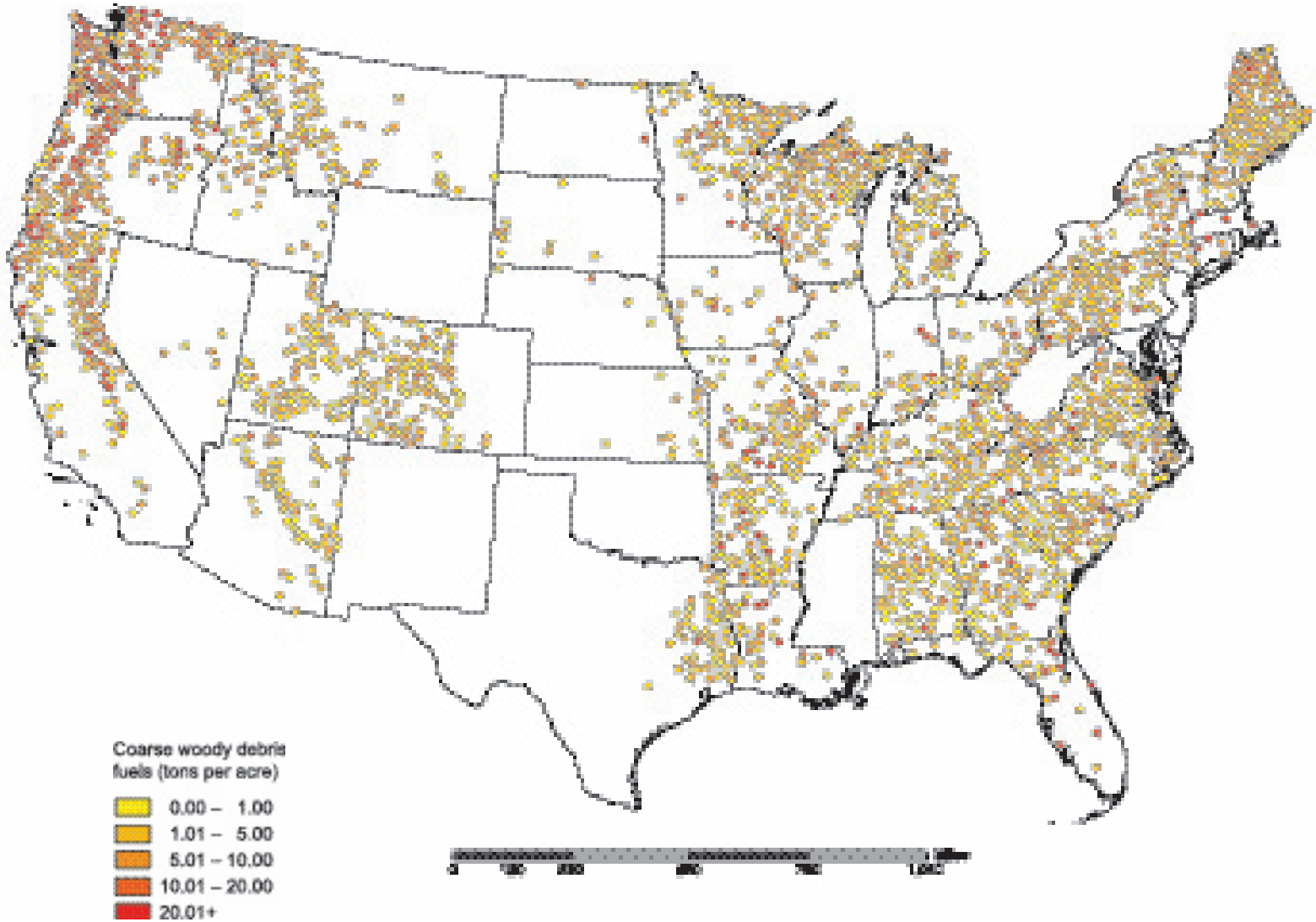

Figure 7.2—Mean coarse woody debris fuels (tons per acre) on forest land by Environmental Monitoring and Assessment Program (EMAP) hexagon (Overton and others 1990, White and others 1992) based on the down woody materials indicator of the Forest Inventory and Analysis program, 2001–03. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

wind events (i.e., tornadoes), mortality events (i.e., root diseases or pine beetle outbreaks), or microtopography (e.g., watershed drainages or mountaintops). These results indicate that the cool and rather moist regions of the United States (e.g., Maine, Oregon, and Washington) feature forests producing substantial amounts of forest biomass that eventually become down dead debris with slow decay rates. Forests in other regions have less CWD accumulation, possibly because the average site quality is lower and less biomass is produced in these regions, and possibly because decay rates are higher in areas with warmer climates.

The volume and condition of CWD can indicate the quantity and quality of wildlife habitat or of stand structural diversity across large scales. The condition of CWD habitat may be indicated by decay and size distributions. A uniform distribution of decay class proportions indicates sustainable recruitment of new CWD pieces. A size class distribution dominated by large CWD pieces indicates a more decay-resistant CWD habitat optimal for larger wildlife. CWD volume estimates, like the estimates of CWD weight, are highest in the Pacific Northwest (fig. 7.3). The distribution of CWD piece sizes varies by region of the United States, with the Pacific Northwest States having the highest mean number of CWD pieces in the largest CWD size classes (table 7.2). Forests in States in the Great Lakes region and in New England have substantially more CWD pieces in the smaller CWD size classes than do forests in the Pacific Northwest. The Rocky Mountain

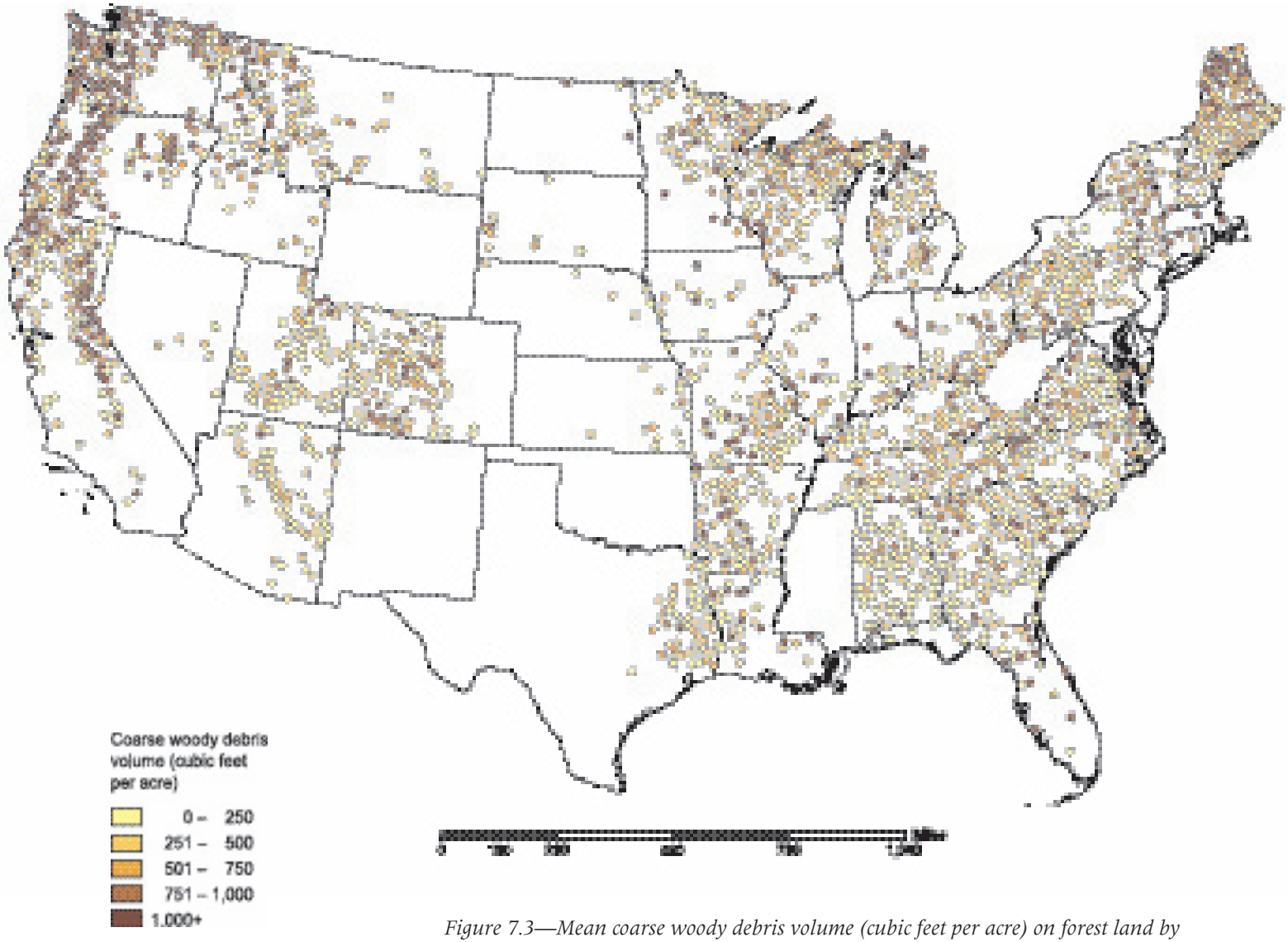

Figure 7.3—Mean coarse woody debris volume (cubic feet per acre) on forest land by Environmental Monitoring and Assessment Program (EMAP) hexagon (Overton and others 1990, White and others 1992) based on the down woody materials indicator of the Forest Inventory and Analysis program, 2001–03. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

and Southeastern forests have fewer CWD pieces per acre in all size classes. The distribution of CWD pieces by decay class is nearly Gaussian in most regions, with only minor differences by region (table 7.3). The Great Lakes and Pacific Northwest regions have higher proportions of freshly fallen CWD compared to New England, which has a higher proportion of very decayed pieces. Overall, these CWD analyses indicate substantial amounts of CWD habitat across the United States, primarily concentrated in Pacific Northwest States. Trends in the condition and recruitment of CWD pieces across the United States are less distinct, with certain regions appearing to have larger and more recently recruited pieces.

The carbon pools of CWD and FWD pieces are a substantial portion (approaching 10 percent) of the carbon sequestered in forests of the United States (O'Neill and others 2004, Smith and others 2004) (table 7.4). Climate may play an important role in the accumulation of this carbon, especially in the soil and DWM carbon pools (FWD and CWD). When all DWM inventory plots are stratified by 4-degree latitude classes, there are obvious trends in CWD and

Table 7.2—Mean number of coarse woody debris (CWD) pieces per acre by CWD diameter class for representative States of different regions of the United States (Pacific Northwest, Great Lake States, northern New England, southern Rocky Mountains, and Southeast)

State group	Number of plots	CWD transect diameter class (inches)				
		3.0 – 7.9	8.0 – 12.9	13.0 – 17.9	18.0+	Total
		pieces per acre				
OR, WA	299	191	45	18	14	268
MI, MN, WI	327	156	27	2	1	186
ME, NH, VT	147	220	27	3	1	251
AZ, CO, UT	478	57	10	2	1	70
GA, NC, SC, TN	430	73	9	2	2	86

Table 7.3—Mean number of coarse woody debris pieces per acre by decay class for representative States of different regions of the United States (Pacific Northwest, Great Lake States, northern New England, southern Rocky Mountains, and Southeast)

State group	Number of plots	Decay class[a]				
		1	2	3	4	5
		pieces per acre				
OR, WA	299	16	55	112	67	17
MI, MN, WI	327	15	49	64	40	19
ME, NH, VT	147	4	28	75	85	57
AZ, CO, UT	478	2	8	26	25	9
GA, NC, SC, TN	430	4	19	33	25	6

[a] Class 1 = least decayed; class 5 = most decayed.

FWD carbon pools (table 7.4). As latitude increases, so does the mean mass of CWD carbon per hectare in forested landscapes. Between the lowest and highest latitude classes there is a nearly 140-percent increase in CWD carbon. For FWD, there is less of a trend, with only a 23-percent increase between the lowest and highest latitude classes. Although no stronger conclusions can be drawn from a preliminary dataset and without more rigorous statistical testing, the data suggest that colder forests at more northern latitudes may have slower decay rates and sequester more DWM carbon.

Conclusions

Since 2001, the DWM inventory has been progressively accumulating data about an important indicator of fuel loadings, wildlife habitat, and carbon pools. The inventory is a work in progress with preliminary data indicating numerous forest ecosystem attributes across the nation. First, fuel loadings of larger down woody pieces, CWD, are highest in the Pacific Northwest and are also high in the Great Lake States and northern New England. Remaining areas of the United States have large amounts of CWD only at local scales, and these concentrations are most likely due to isolated windfall events. Second, the fuel loadings of smaller down woody pieces, FWD, are more randomly distributed across the United States. Third, both size class and decay class distributions of the CWD resource vary across the nation, indicating a variation in the quantity and quality of wildlife habitat. Fourth, a substantial amount of the carbon in forest ecosystems is in CWD and FWD. This carbon contribution to the overall forest carbon equation may be partially dependent on the climate of the region, i.e., whether cool temperatures and lack of moisture slow the decomposition of DWM.

Table 7.4—Mean carbon pools of coarse woody debris and fine woody debris in megagrams per hectare (Mg/ha) by latitude class for the United States

Latitude class	Number of observations	CWD	CWD std. error	FWD	FWD std. error
degrees		- - - - - - - *Carbon pools (Mg/ha)* - - - - - - -			
< 33	408	4.56	1.02	2.99	0.19
≥ 33 and < 37	706	4.70	0.71	3.21	0.15
≥ 37 and < 41	860	4.75	0.47	2.63	0.15
≥ 41 and < 45	600	8.05	1.14	4.06	0.18
≥ 45	593	10.45	1.40	3.69	0.20

CWD = Coarse woody debris; FWD = Fine woody debris.

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CRITERION 4—

Chapter 8. Physical Properties of Forest Soils

Charles H. Perry and
Michael C. Amacher

Introduction

The soil quality indicator was initially developed as a tool for assessing (1) the current and future status of forest soil resources and (2) the contribution of forest soils to the global carbon cycle. The soil quality indicator, when combined with other data collected by the Forest Inventory and Analysis (FIA) program, can indicate the current rates of soil erosion, the extent and intensity of soil compaction, the thickness and properties of the forest floor, and the chemical composition and physical properties of the top 20 cm of soil. The data are collected using a variety of methods. Area of bare soil, useful in soil erosion potential prediction models, is estimated ocularly. Ocular estimates are also made of the area of compacted soil. Forest floor and soil samples are collected in the field and sent to regional laboratories for physical and chemical processing.

The national inventory for the soil quality indicator began in 1999, but the protocols were not finalized and formally implemented at a national scale until 2001 (U.S. Department of Agriculture Forest Service 2002). The soil quality indicator is measured on a double-length phase 3 cycle. In any given State, soils are measured over a period of years, so that all phase 3 panels are measured. Over the next cycle of phase 3 measurements, soils are not measured in that State. This sampling schedule is designed to permit soil properties to respond to changing forest cover and climatic conditions before the soil profile is re-sampled. Since 2001, samples have been collected in most of the continental United States. The sample size will increase as inventories in these States are completed and additional States are inventoried. The changing sample size and refinement of the database management and estimation algorithms together suggest that the results presented here should be considered preliminary.

Why Are Physical Properties of the Soil Important?

The soil quality indicator, when combined with other data collected by the FIA program, can indicate the current rates of soil erosion, the extent and intensity of soil compaction,

and some basic physical properties of the forest floor and the top 20 cm of soil. In this report, two particular physical properties of the soil are presented: bare soil and soil compaction.

Soil erosion is the removal of soil from the land surface by agents such as wind and water. It is a natural process, and modest amounts of erosion may not affect forest health (Brady 1990, Liechty and others 2002). In contrast, accelerated erosion of mineral soil may be expected to reduce long-term forest productivity (Brady 1990, Merino and others 2004). Forest soils normally have adequate cover, such as forest floor and plant canopies, to protect them from erosion. The principal factors influencing soil erosion rates include climatic factors such as the amount and intensity of precipitation, the presence of bare soil, the soil texture, the slope of the soil surface, the length of the slope, and the occurrence of disturbances, such as fire and forest harvesting, that can alter soil properties. For this indicator, we are interested in assessing accelerated erosion due to disturbance events such as fire, forest harvesting, grazing, and recreational activities. Since the presence of bare soil can lead to accelerated soil erosion, it is the key variable for assessing soil erosion potential and is an important input variable to soil erosion potential models such as the Watershed Erosion Prediction Project (U.S. Department of Agriculture Forest Service 2005).

Soil compaction is the crushing of soil aggregates leading to the reduction of pore space in the soil structure. As a consequence of soil compaction, soil aeration and water permeability are reduced, and roots have greater difficulty penetrating compacted layers to obtain the water, oxygen, and nutrients they need for optimal plant growth and vigor (Brady 1990).

Methods

Bare soil and soil compaction measurements were completed in the field according to well-documented ocular estimation procedures.[1] Soil field observation data from 2001 and 2002 were available for these analyses (fig. 8.1). The percent bare soil and percent compacted area were estimated on each of four subplots per plot. Additional details on field measurements, laboratory processing, and estimation procedures are available[2] (O'Neill and others 2005). The distribution of values of percent cover of

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

[2] The current version of the *Forest Inventory and Analysis National Core Field Guide* is available online at http://fia.fs.fed.us/library/field-guides-methods-proc/.

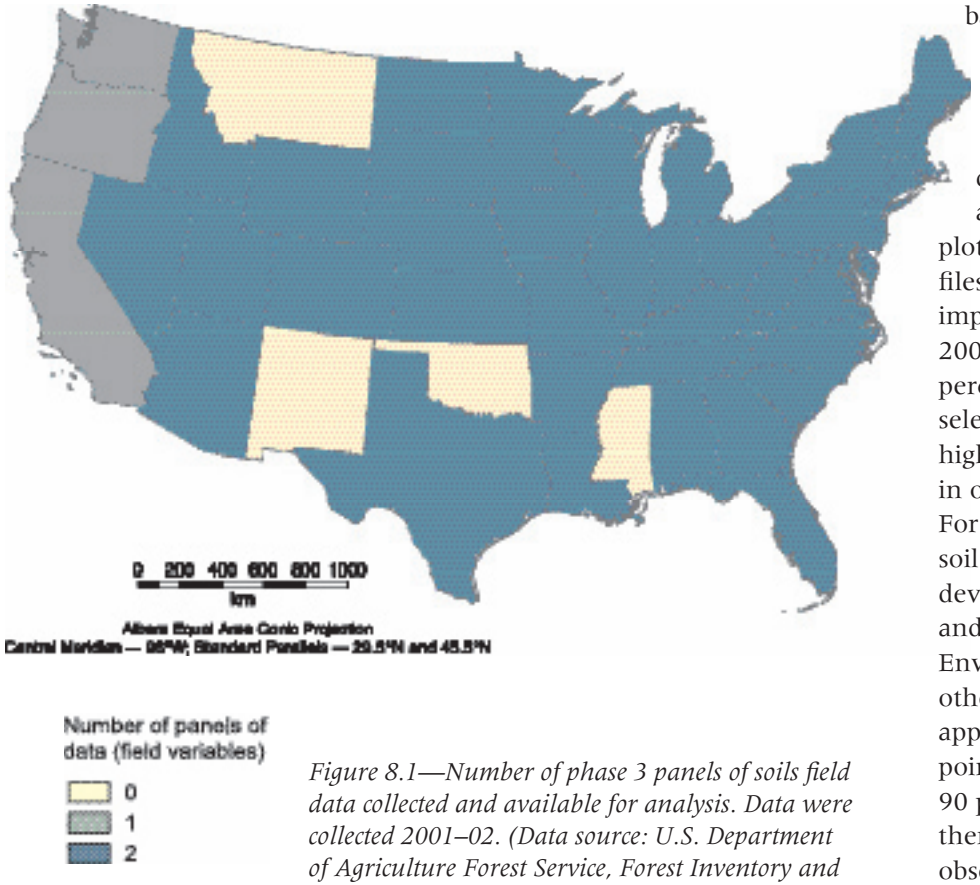


Figure 8.1—Number of phase 3 panels of soils field data collected and available for analysis. Data were collected 2001–02. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

bare soil and percent compacted area were analyzed considering each subplot estimate to be a single observation.

Numeric data were imported into R, a data analysis and graphics package (Venables and others 2005), for statistical analysis and plotting. Spatially explicit comma-delimited files were also exported from the database and imported into ArcMap (Harlow and others 2004). The maximum percent bare soil and percent compacted area on each plot were selected from the four subplot observations. The highest subplot value was reported for each plot in order to focus on areas of potential concern. For mapping purposes, the plot maxima for each soil property were then assigned to hexagons developed by the Environmental Monitoring and Assessment Program (EMAP) of the U.S. Environmental Protection Agency (White and others 1992). Each hexagon has an area of approximately 648 km^2, and hexagon center points are roughly 27 km apart. Approximately 90 percent of the hexagons had only one plot in them; the remaining 10 percent contained two observations, which were averaged.

What Do the Data Show?

Bare soil is not a common problem in the forests of the United States. The maximum observed bare soil fraction is 10 percent or less on half of the plots nationwide; the third quartile (75th percentile) is 25 percent bare soil (fig. 8.2). There are regional differences in the amount of exposed bare soil (fig. 8.3). The Northeastern United States and the Pacific Northwest (west of the Cascade Range) have little exposed soil. There are isolated pockets of bare soil in the Midwest, with a noticeable concentration in Wisconsin that requires further investigation. Bare soil is concentrated in the more arid Interior West, where lower precipitation levels lead to less plant canopy and forest floor cover.

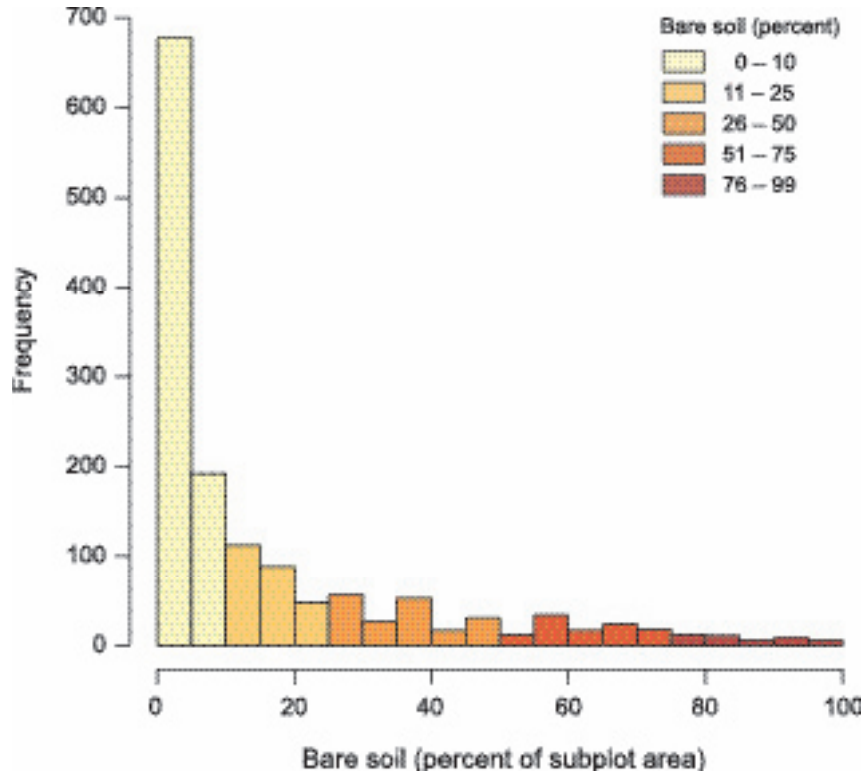


Figure 8.2—Distribution of bare soil observations (2001–02). Each observation represents the maximum percent bare soil recorded on any of four subplots on each plot. (75th percentile = 25 percent, mean = 17 percent, median = 10 percent, 25th percentile = 1 percent bare soil.) The colors represent the same bare soil percentages they represent in figure 8.3. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

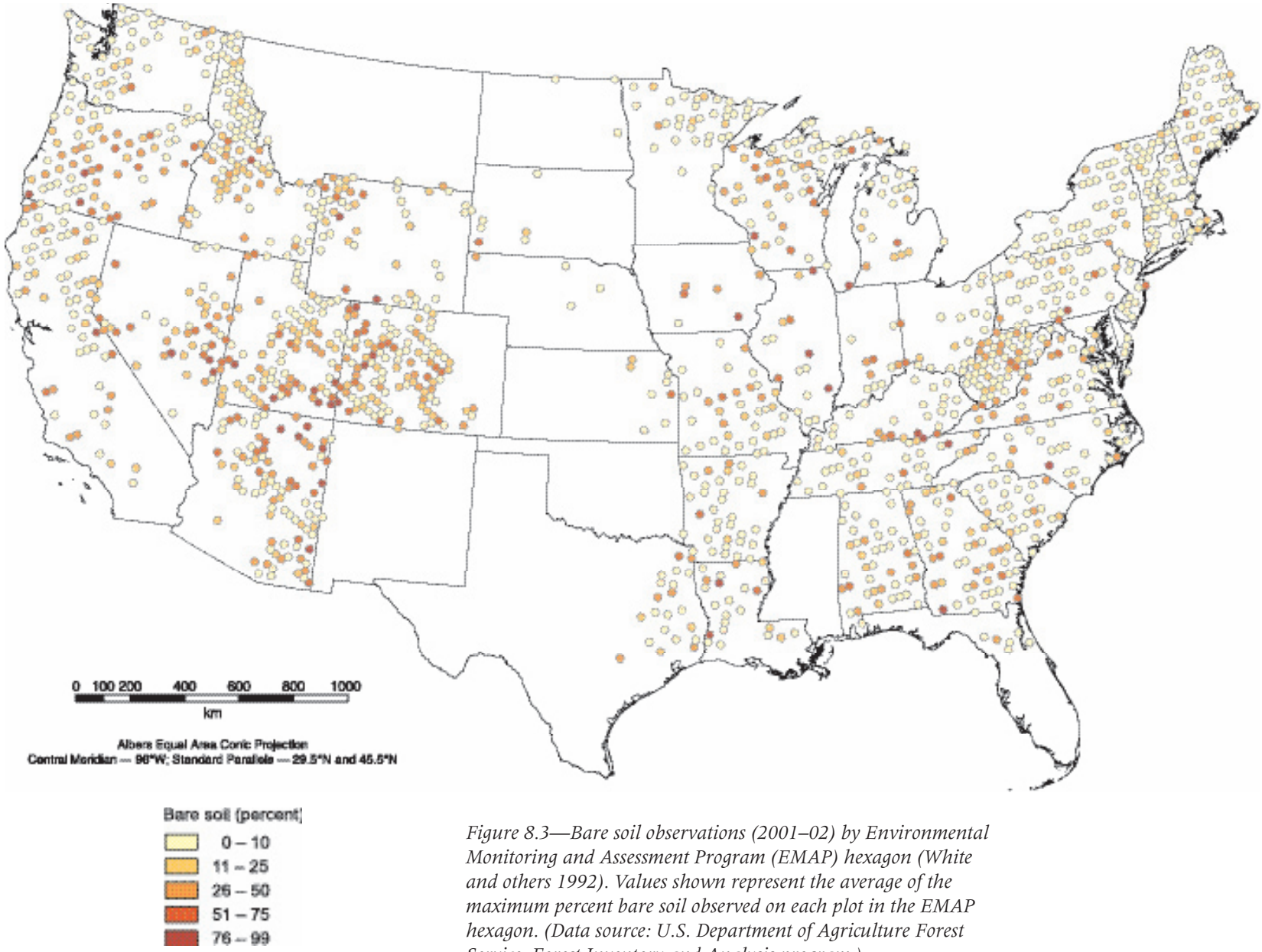


Figure 8.3—Bare soil observations (2001–02) by Environmental Monitoring and Assessment Program (EMAP) hexagon (White and others 1992). Values shown represent the average of the maximum percent bare soil observed on each plot in the EMAP hexagon. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

Like bare soil, soil compaction is not generally a problem in the forests of the United States. Half of the plots have no measurable areas of soil compaction (fig. 8.4). The 1,439 measurements are summarized into 387 EMAP hexagons for mapping purposes. Because only the maximum subplot values of percent compacted area for each plot are averaged for each EMAP hexagon, the values shown on the map (fig. 8.5) are skewed towards higher values of soil compaction. For this reason, the map identifies areas where soil compaction may be a problem rather than quantifying the extent of any such problem.

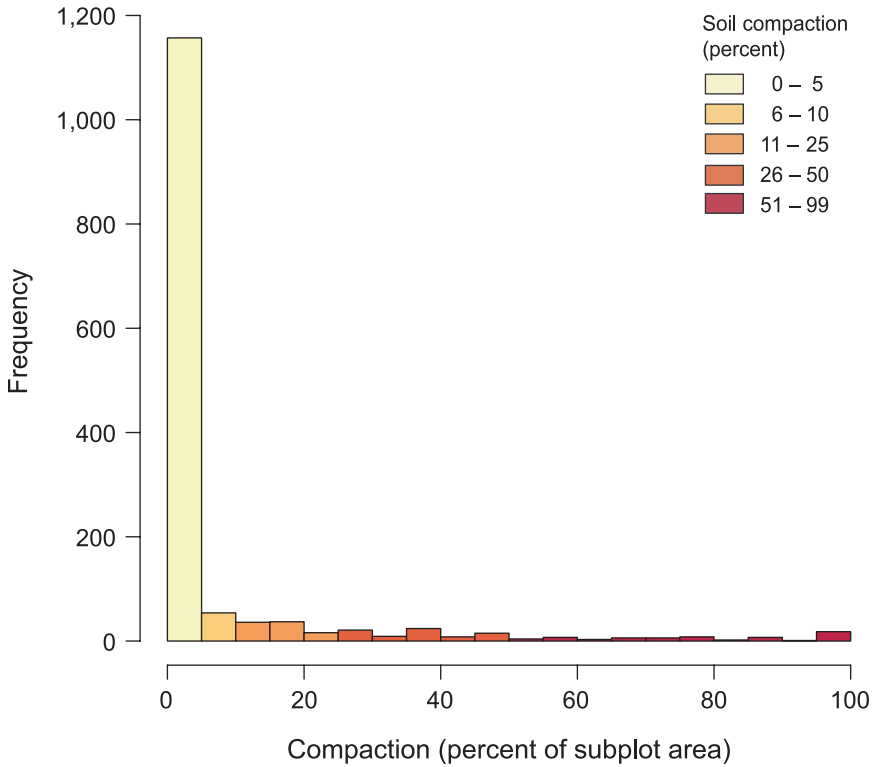
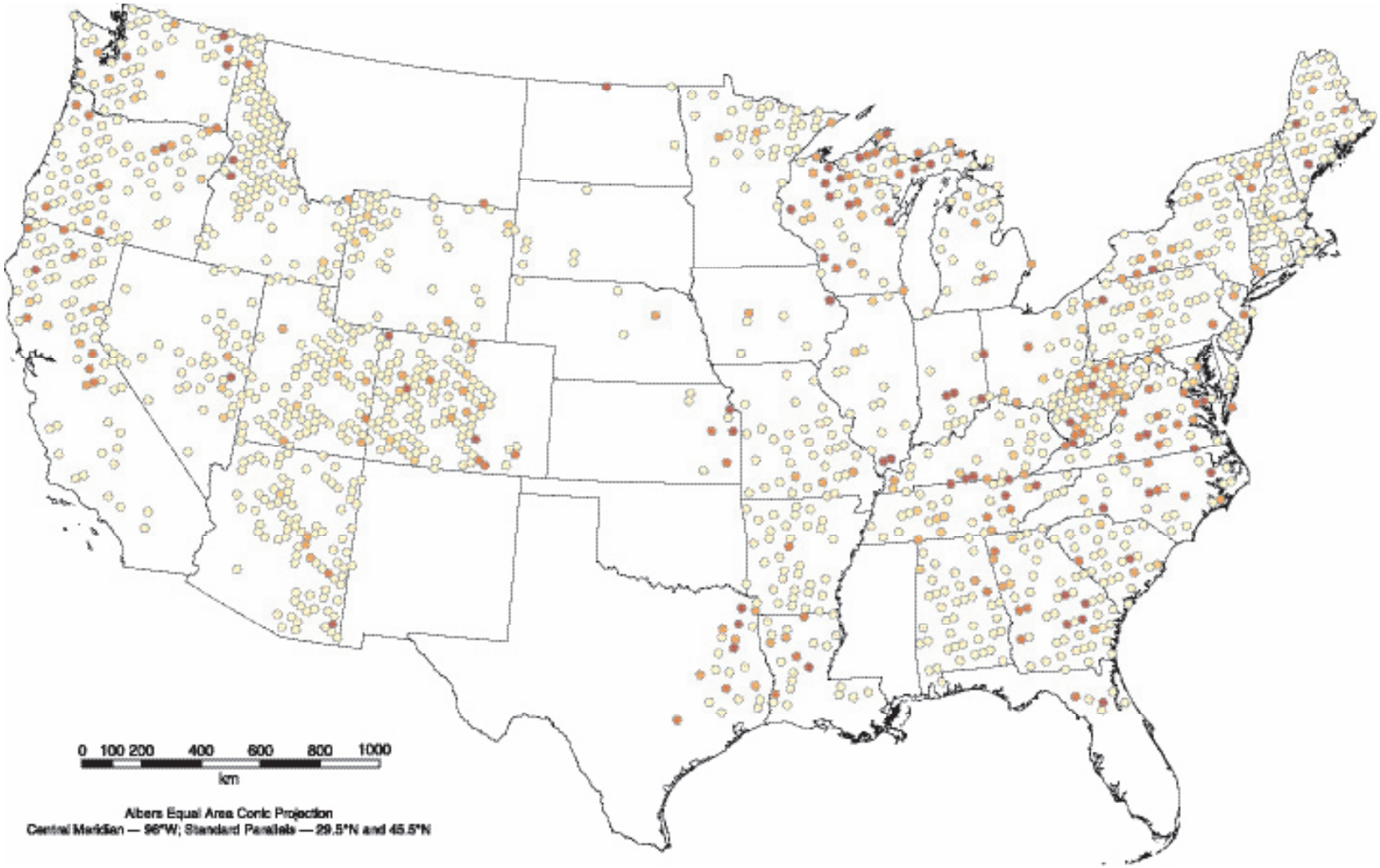


Figure 8.4—Distribution of soil compaction observations (2001–02). Each observation represents the maximum percentage of subplot area compacted recorded on any of four subplots on each plot. (75th percentile = 5 percent, mean = 7.4 percent, median = 0 percent, 25th percentile = 0 percent of area compacted.) The colors represent the same compaction percentages they represent in figure 8.5. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)



Soil compaction
(percent)

- 0 – 5
- 6 – 10
- 11 – 25
- 26 – 50
- 51 – 99

Figure 8.5—Soil compaction observations (2001–02) by Environmental Monitoring and Assessment Program (EMAP) hexagon (White and others 1992). Values shown represent the average of the maximum percent compaction observed on each plot in the EMAP hexagon. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

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CRITERION 4—

Chapter 9. Chemical Properties of Forest Soils

Charles H. Perry and
Michael C. Amacher

Why Is Soil Chemistry Important?

The soil quality indicator was initially developed as a tool for assessing the current status of forest soil resources and predicting potential changes in soil properties. Soil chemistry data can be used to diagnose tree vigor and document the deposition of atmospheric pollutants (e.g., acid rain). This chapter focuses on two chemical properties of the soil: soil pH and effective cation exchange capacity (ECEC).

Soil pH is considered by some to be the single most diagnostic chemical measurement of the soil (McBride 1994). Soil pH is responsive to air pollution and precipitation chemistry (Bailey and others 2005). In addition to its rare direct effects on roots and soil microorganisms, soil pH also influences metal toxicity, micronutrient availability, ion exchange, microbial activity, reduction/oxidation reactions, and soil aggregate stability (McBride 1994). For all of these reasons, soil pH is an important indicator for the maintenance of forest ecosystem health and vitality.

ECEC is a measure of the storage capacity of soils for key nutrients such as potassium, magnesium, and calcium and also for the key acid-generating element in soils, aluminum. Clay minerals and organic matter are the soil components chiefly responsible for soil ECEC. Soils with high ECEC can store large amounts of cationic nutrients [sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), and calcium (Ca^{2+})] or acid-generating cations [aluminum (Al^{3+}) and hydrogen (H^+)], depending on soil pH. The total amount of exchangeable cations that a soil can hold is referred to as the ECEC, while the percent base saturation is the total amount of basic cations (Na^+, K^+, Mg^{2+}, and Ca^{2+}) expressed as a percentage of the total cation exchange capacity of the soil (base cations plus exchangeable Al^{3+}) (Potash and Phosphate Institute 1995). It is generally held that increases in percent base saturation are correlated with improved forest soil fertility (Pritchett and Fisher 1987). In the Forest Inventory and Analysis (FIA) protocol, ECEC is calculated as the sum of the amounts of exchangeable bases (Na^+, K^+, Mg^{2+}, and Ca^{2+}) and Al^{3+} in soils and is measured at the natural soil pH. The measurement unit is centimoles of cation charge per unit mass of soil (cmol(+)/kg).

Methods

Soil samples for chemical analysis are collected as part of the FIA soil quality indicator. Between 2001 and 2003, samples were collected in most of the continental United States (fig. 9.1). The sample size will increase as work in these States is completed and additional States are inventoried. The changing sample size and refinement of the database management and estimation algorithms together suggest that the results presented here should be considered preliminary.

One mineral soil sample was collected on each phase 3 plot according to well-documented protocols[1] and sent to regional laboratories for chemical analysis (U.S. Department of Agriculture Forest Service 2006). Additional details on field measurements, laboratory processing, and estimation procedures are available[2] (O'Neill and others 2005).

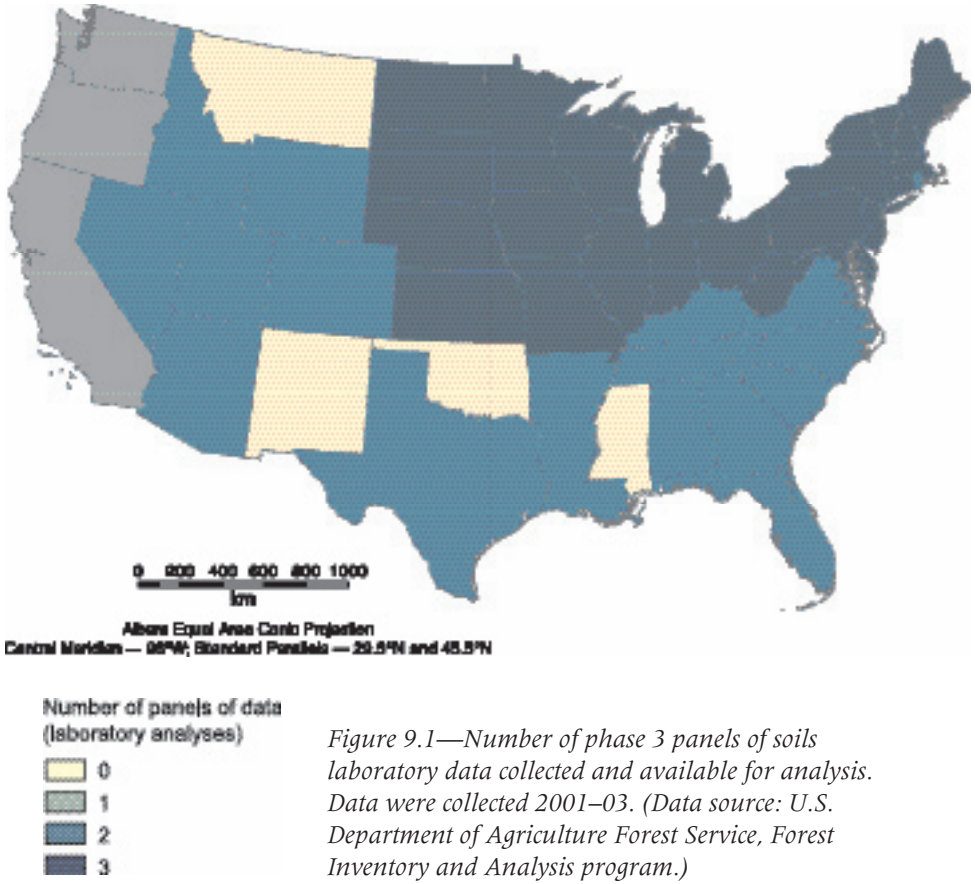


Figure 9.1—Number of phase 3 panels of soils laboratory data collected and available for analysis. Data were collected 2001–03. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

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

[2] The current version of the *Forest Inventory and Analysis National Core Field Guide* is available online at: http://fia.fs.fed.us/library/field-guides-methods-proc/.

Soil pH and ECEC were determined for each plot by queries to the soils database. Only the top 10 cm of mineral soil were evaluated. Spatially explicit comma-delimited files were exported from the database and imported into ArcMap (Harlow and others 2004). For mapping purposes, soil chemical properties were assigned to hexagons developed by the Environmental Monitoring and Assessment Program (EMAP) of the U.S. Environmental Protection Agency (White and others 1992). Approximately 90 percent of the hexagons had only one measurement in them; the remaining 105 hexagons had two observations, which were averaged. Each hexagon has an area of approximately 648 km^2, and their center points are roughly 27 km apart. Numeric data were imported into R (Venables and others 2005) for statistical analysis and plotting. Results for soil pH were aggregated into classes developed by Amacher and others (in press).

What Do the Data Show?

Forest soil pH in the United States tends toward the acidic (fig. 9.2). This can affect the

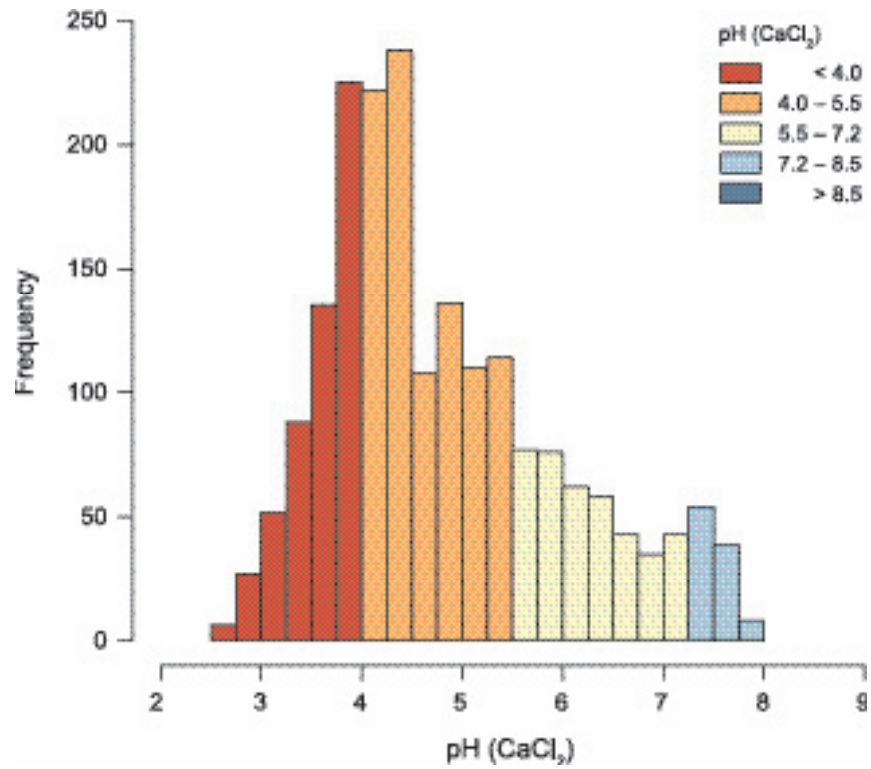


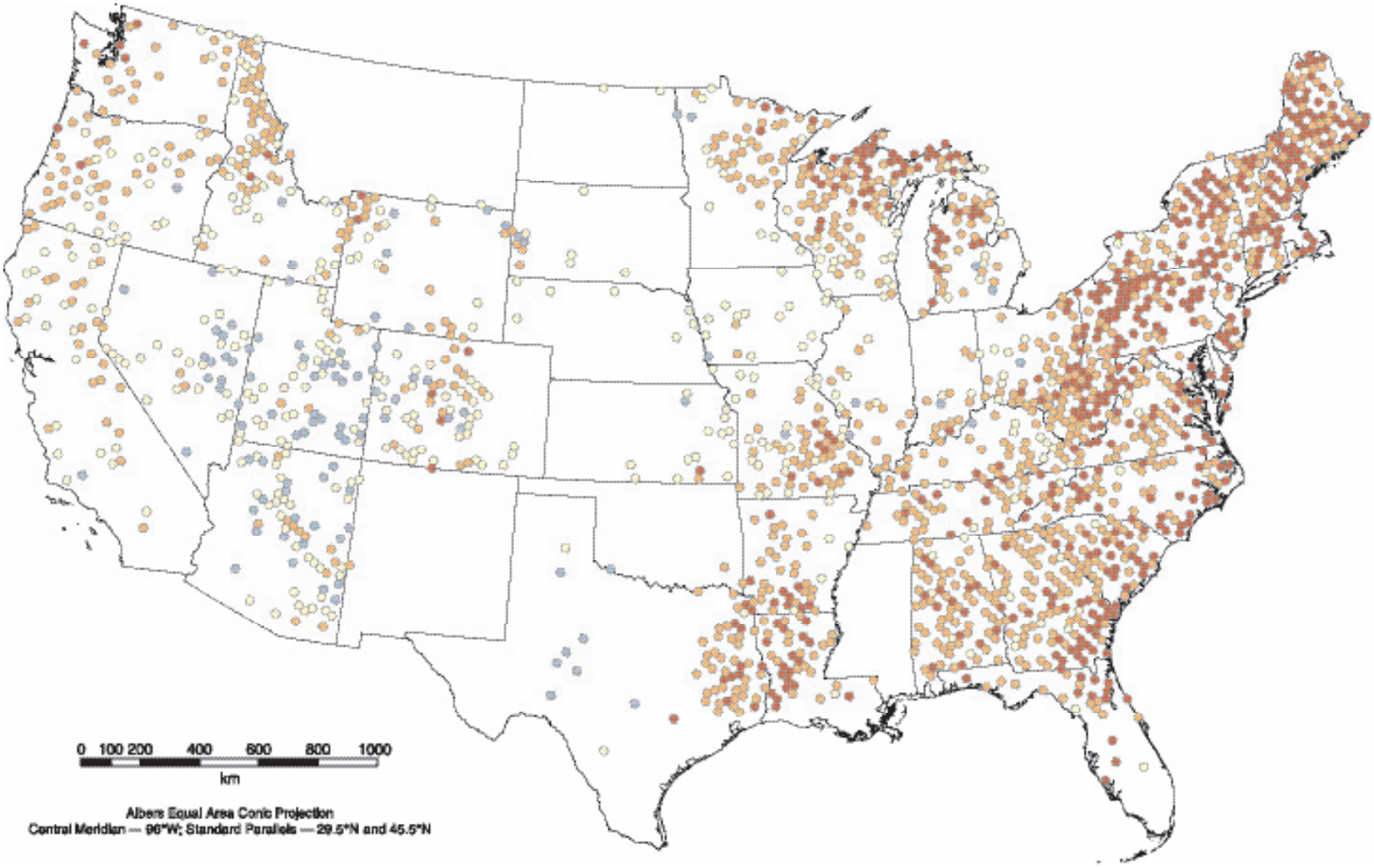
Figure 9.2—Distribution of observations of soil pH in the top 10 cm of soil (2001–03). (75th percentile = 5.5, mean = 4.8, median = 4.5, 25th percentile = 4.0.) The colors represent the same pH levels they represent in figure 9.3. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

growth of acid-intolerant plant species (table 9.1). Eastern soils tend to be more acidic than their western counterparts (fig. 9.3). The spatial distribution of low pH values coincides with previous observations of acid deposition (see National Atmospheric Deposition Program 2005). Future research will investigate whether there is any causal relationship between atmospheric deposition and low soil pH. Soils of the arid Southwest are generally alkaline (fig. 9.3) because low precipitation allows for the accumulation of acid-neutralizing carbonate minerals in the soil profile.

Table 9.1—Soil pH with associated interpretations[a]

Soil pH	Interpretation
< 4.0	Strongly acid – only the most acid tolerant plants can grow in this pH range and then only if organic matter levels are high enough to mitigate high levels of extractable Al and other metals
4.0 – 5.5	Moderately acid – growth of acid intolerant plants is affected depending on levels of extractable Al, Mn, and other metals
5.5 – 7.2	Slightly acid to near neutral – optimum for many plant species
7.2 – 8.5	Slightly to moderately alkaline – optimum for many plant species except those that prefer acid soils, possible deficiencies of available P and some metals (e.g., Zn)
> 8.5	Strongly alkaline – preferred by plants adapted to this pH range, possible B and other oxyanion toxicities

[a] Amacher and others (in press).



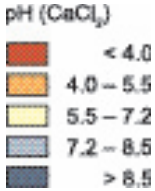


Figure 9.3—National map of observations of soil pH in the top 10 cm of soil (2001–03) by Environmental Monitoring and Assessment Program (EMAP) hexagon (White and others 1992). Soil pH was measured in a calcium chloride ($CaCl_2$) solution. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

The mean ECEC value for forest soils in the United States is 10.4 cmol(+)/kg, with the vast majority of forested areas having ECEC levels < 20 cmol(+)/kg (fig. 9.4). Forest soils with higher ECEC levels have high clay mineral or organic matter content, or both. Many forest soils in the Western United States, upper Midwest, and portions of the Northeast had high ECEC levels (fig. 9.5). The Southeastern United States with its predominance of more highly weathered ultisols tended to have the greater proportion of forest soils with low ECEC levels. These soils tend to be low in soil organic matter as indicated by soil carbon levels (see chapter 10) and tend to have the low ECEC clay mineral, kaolinite, as the dominant clay mineral in the soil profile.

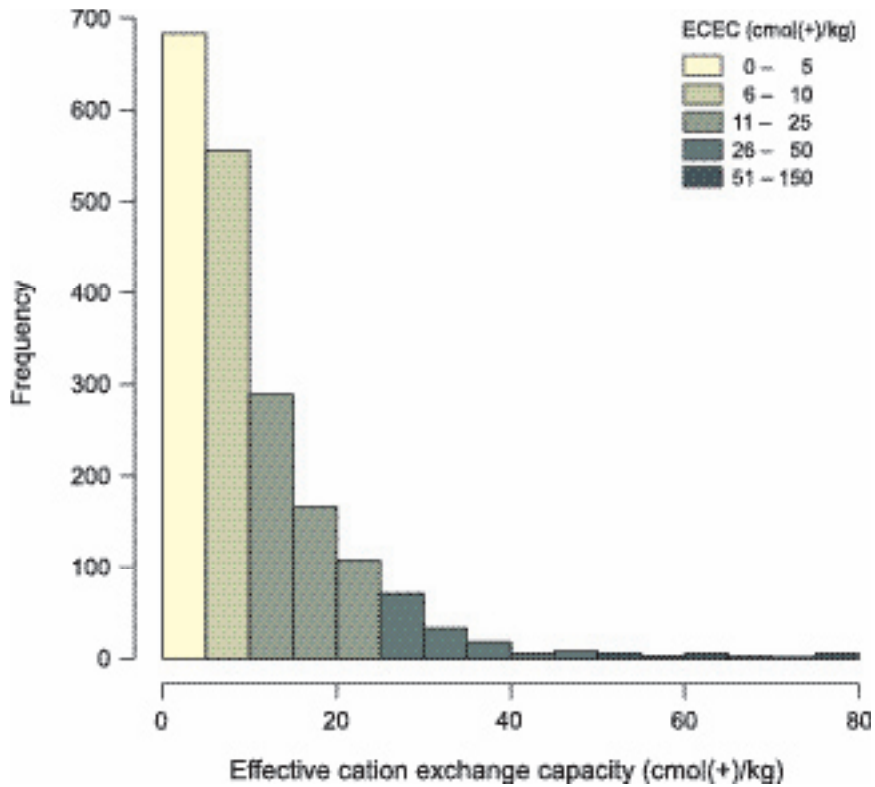


Figure 9.4—Distribution of observations of effective cation exchange capacity (ECEC) in the top 10 cm of soil (2001–03). Effective cation exchange capacity was calculated by summation of sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and aluminum (Al^{3+}). (75th percentile = 13.8, mean = 10.4, median = 7.2, 25th percentile = 3.7 cmol(+)/kg .) The colors represent the same ECEC levels they represent in figure 9.5. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

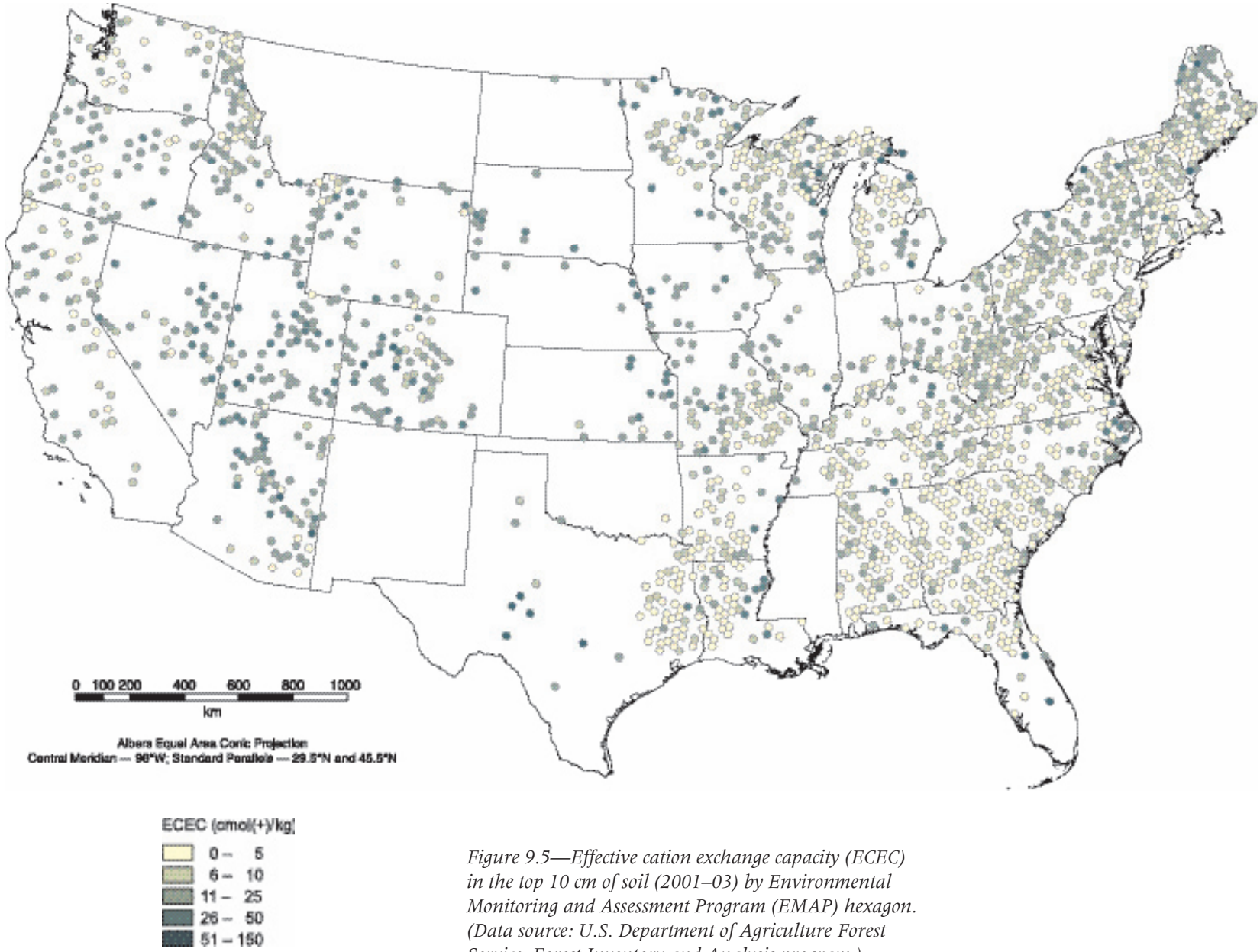


Figure 9.5—Effective cation exchange capacity (ECEC) in the top 10 cm of soil (2001–03) by Environmental Monitoring and Assessment Program (EMAP) hexagon. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

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CRITERION 5—

Chapter 10. Soil Carbon

Charles H. Perry and
Michael C. Amacher

Why Is Soil Carbon Important?

The sequestration of carbon by forest and agricultural soils has the potential to significantly reduce greenhouse gas concentrations (Pacala and Socolow 2004). Many countries are implementing field inventories of soil carbon, often combined with data from other sources, to estimate soil carbon sequestration rates and amounts (Kurz and Apps 2003; McKenzie and others 2000; Scott and others 2002). Models are currently used to predict the contribution of soil carbon to the total forest carbon sequestration in the United States (Heath and others 2002, Smith and Heath 2002). Current estimates suggest that > 50 percent of the total stored forest carbon is held in the soil with an additional fraction in the forest floor (Birdsey and Heath 1997, Heath and Birdsey 1997, Smith and others 2004). Our relatively new effort to inventory soil carbon should enrich these efforts to model soil carbon and document forest sequestration of atmospheric carbon dioxide.

The soil quality indicator was initially developed in part to assess the contribution of forest soils to the global carbon cycle, and the data can be used to construct soil carbon budgets. Once this information is linked to Forest Inventory and Analysis (FIA) phase 2 data, whole-forest carbon budgets can be constructed from the forest inventory.

Soil carbon is also important because it is the principal element of soil organic matter, and organic matter is a key component of soils. Stevenson (1986) outlines several different roles and functions of soil organic matter. It increases water holding capacity and aeration and improves soil permeability. It provides nutrients to plants and energy to microbes and other soil fauna. It contributes significantly to ECEC (see chapter 9). It can also detoxify soil pollutants by binding metals and organic compounds. Its influence on soil properties and processes is so large that without it, soils would largely be incapable of sustaining microbial populations and plant communities.

Methods

Soil samples are collected for analysis as part of the FIA soil quality indicator inventory. Between 2001 and 2003, samples were collected in most of the continental United States (see chapter 9, fig. 9.1). The sample size will increase as work in these States is completed and additional States are inventoried. The changing sample size and refinement of the database management and estimation algorithms together suggest that the results presented here should be considered preliminary.

Soil carbon content (in percent) is measured in three sampling units: (1) the forest floor, (2) 0 to 10 cm depth, and (3) 10 to 20 cm depth. Three forest floor samples and one mineral soil sample are usually collected on each plot; the forest floor samples were averaged at the plot level. The mass of the forest floor samples, the known sampling area, and the sample carbon content are used to calculate carbon on a mass per unit area basis in megagrams per hectare (Mg/ha). For the mineral soil, soil carbon content is combined with measured bulk density and corrected for the coarse fragment content to calculate soil carbon in Mg/ha. Additional details on field measurements, laboratory processing, and estimation procedures are available[1] (O'Neill and others 2005).

Spatially explicit, comma-delimited files were exported from the database and imported into ArcMap (Harlow and others 2004). For mapping purposes, soil carbon values were assigned to hexagons developed by the Environmental Monitoring and Assessment Program (EMAP) of the U.S. Environmental Protection Agency (White and others 1992). Approximately 90 percent of the hexagons had only one measurement in them; the remaining 10 percent had two observations, which were averaged. Each hexagon has an area of approximately 648 km^2, and their center points are roughly 27 km apart. Numeric data were imported into R (Venables and others 2005) for statistical analysis and plotting.

[1] The current version of the Forest Inventory and Analysis National Core Field Guide is available online at: http://fia.fs.fed.us/library/field-guides-methods-proc/.

What Do the Data Show?

Forest floor carbon accumulation is a function of annual litterfall minus decomposition. Annual litterfall is remarkably consistent among tree species growing in similar soils and climates (Pritchett and Fisher 1987). While annual litter production is inversely related to latitude, carbon accumulation is generally greater in higher latitudes because of the slower decay rates (Pritchett and Fisher 1987). Most of the carbon is stored in the top 10 cm of soil (table 10.1, fig. 10.1). The bottom mineral soil unit also stores more carbon than the forest floor (table 10.1, fig. 10.1). As a region, the Southeastern United States, with its highly weathered ultisols, has some of the lowest soil carbon values; the Interior West also has little soil carbon (fig. 10.2). Total soil carbon content is generally highest in the Northern United States where decay rates are very low (fig. 10.2).

Table 10.1—Representative carbon values for different soil layers (2001–03)

Descriptive statistics	Forest floor	0 – 10 cm	10 – 20 cm	All layers
	- - - - - - carbon content (Mg/ha) - - - - - -			
Minimum	0.01	1.37	0.14	5.03
25th percentile	2.87	16.54	7.85	32.40
Median	5.23	23.38	12.78	44.52
Mean	7.11	27.41	17.02	51.55
75th percentile	9.39	33.58	20.25	62.37
Maximum	56.84	302.32	217.58	444.26

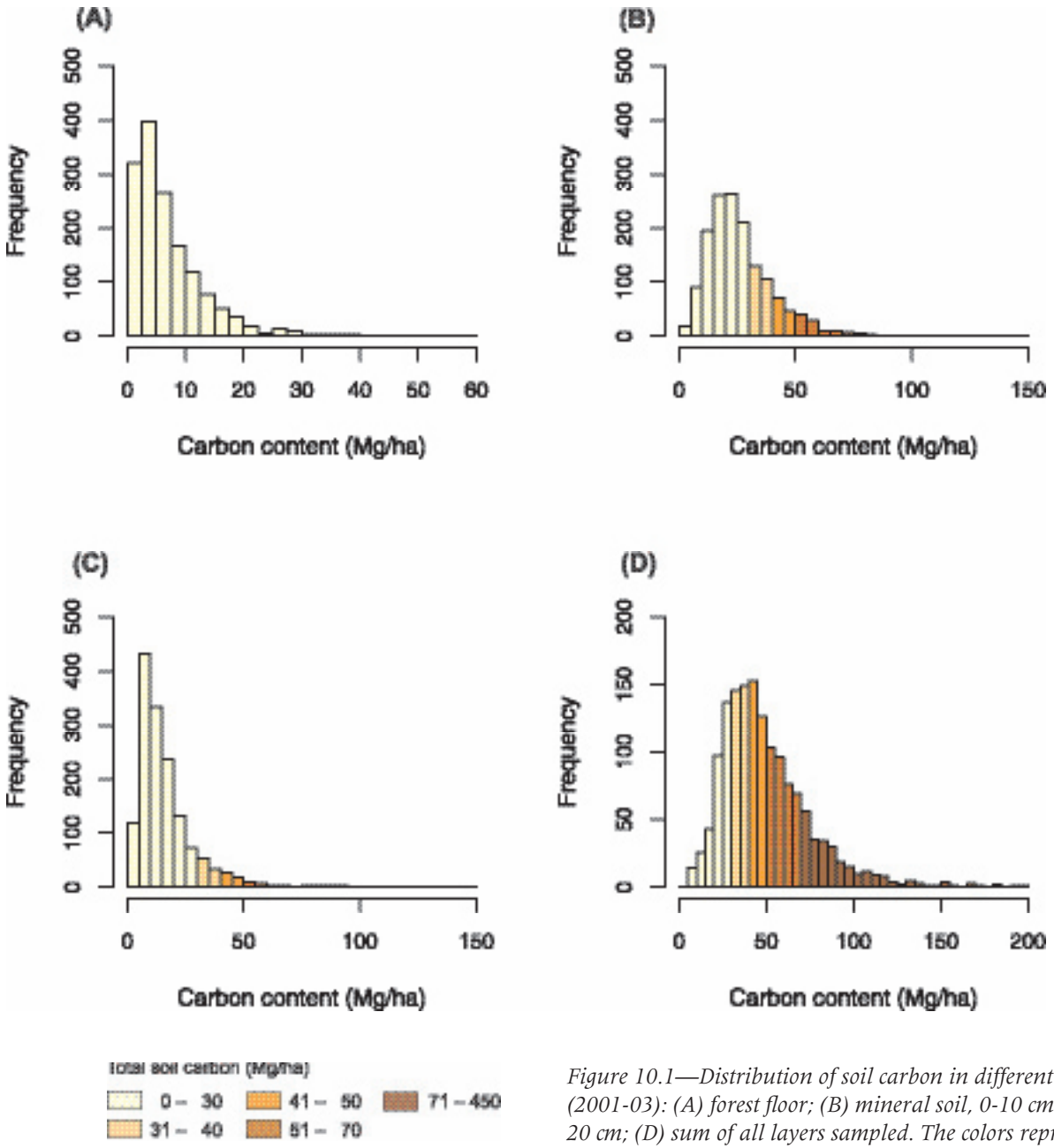

Figure 10.1—Distribution of soil carbon in different sampling units (2001-03): (A) forest floor; (B) mineral soil, 0-10 cm; (C) mineral soil, 10-20 cm; (D) sum of all layers sampled. The colors represent the same soil carbon levels they represent in figure 10.2. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

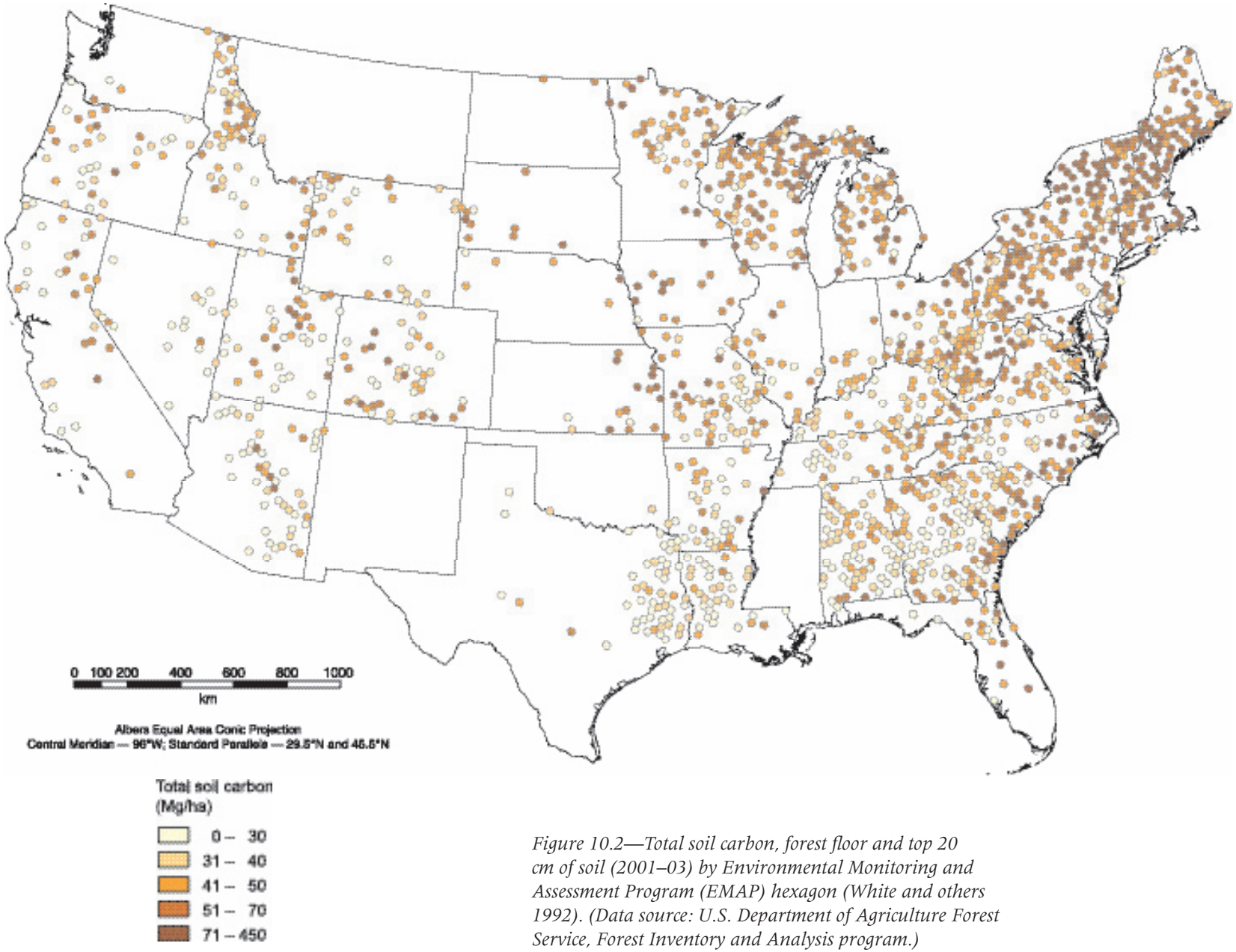

Figure 10.2—Total soil carbon, forest floor and top 20 cm of soil (2001–03) by Environmental Monitoring and Assessment Program (EMAP) hexagon (White and others 1992). (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program.)

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Chapter 11. Summary

Mark J. Ambrose

Forest Health Monitoring (FHM), together with cooperating researchers both in and outside of the U.S. Department of Agriculture Forest Service, continues to investigate the variety of issues relating to forest health. This report provides a review of the latest analyses and results. The broad range of indicators presented alone demonstrates how difficult it is to draw general conclusions about the condition of U.S. forests.

Perhaps the most widespread issue affecting U.S. forests presented in the report is that of forest fragmentation. Compared with conditions prior to European settlement, the forests of the conterminous United States are heavily fragmented by human activities, but they are relatively intact compared to those of highly developed Europe. More attention must be given to interpreting assessments of fragmentation to determine the impacts of fragmentation on ecological endpoints such as biodiversity and water quality over extremely large regions. FHM will continue to assess and report the status and trends of forest fragmentation, and will continue to assist ecologists and forest managers in understanding and making use of the data.

A number of stressors are affecting U.S. forests to varying degrees. Drought periodically affects nearly all U.S. forests to some extent. Over the past decade (1995-2004), much of the Western United States was considerably more droughty than the historic average. However, with some exceptions, ecoregion sections in the Eastern United States experienced the expected amount of drought, or less, over the same period. Fire also periodically affects many U.S. forests. The lower 48 States had a relatively mild fire season in 2004, but the 2004 fire season was quite severe in Alaska.

Anthropogenic stressors, such as air pollution, are a concern because of possible impacts on forest health and productivity. One pollutant of concern, tropospheric ozone, does not appear to pose a large-scale threat to five commercially important tree species considered. However, there are specific areas where bioindicator plant injury from ozone was severe and where there is a higher risk of negative impact.

A variety of insects and pathogens affects U.S. forests. Many different species of mortality-causing and defoliation-causing

agents were recorded during aerial surveys of the conterminous United States in 2003. Of mortality-causing species, mountain pine beetle, Douglas-fir beetle, fir engraver, and southern pine beetle were the most frequently observed. Forest tent caterpillar, Swiss needle cast, western spruce budworm, and gypsy moth were the most frequently observed defoliation-causing agents. The analyses presented in this report have identified hotspots of insect and pathogen activity in each FHM region. Continued monitoring of forested areas is important to determine when the activity of insects and pathogens warrants follow-up investigation or management action.

The monitoring and analysis of some aspects of forest condition is still very new, and we have only very preliminary results. Since 2001, Forest Inventory and Analysis (FIA)'s down woody material inventory has been accumulating data on this indicator of fuel loadings, wildlife habitat, and carbon pools. The inventory is still a work in progress. Preliminary results show that fuel loadings of larger down woody pieces [i.e., coarse woody debris (CWD)] are highest in the Pacific Northwest and are also high in the Lake States and northern New England. Fuel loadings of smaller down woody pieces [i.e., fine woody debris (FWD)] are more randomly distributed across the United States. Together, CWD and FWD contain a substantial fraction of the total carbon sequestered in forest ecosystems.

Similarly, FIA's soil quality indicator has been fully implemented only since 2001. Preliminary results suggest that bare soil, which facilitates erosion, and soil compaction are problems only in relatively small areas of U.S. forests. Analyses of soil samples are producing data on soil pH and effective cation exchange capacity. Further analyses are necessary to determine how these values relate to forest management, possible effects of air pollution, and forest health and productivity. Analysis of soil carbon is generating data that can be used to build total forest carbon budgets. More soils data need to be collected to more fully investigate the several issues relating to forest soils.

The results presented in this report reflect the output of FHM's national scale detection monitoring efforts. It is important to be aware that forest health issues of local or regional

importance may exist that, because of their small scale, are not detected in these analyses. Also, it is possible to fail to detect national scale forest health problems if the indicators being measured do not show a strong signal relative to the natural variability in forest conditions. Whenever a potential forest health problem is discovered through such large-scale analyses, it is important to follow up with more detailed study to verify the findings and determine the extent and seriousness of the issue.

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The Forest Health Monitoring program's annual national technical report presents results of forest health analyses from a national perspective using data from a variety of sources. The report is organized according to the Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests of the Santiago Declaration. The results of several analyses of forest fragmentation are synthesized to evaluate fragmentation in U.S. forests. Drought in 2004 is presented, and drought over the decade 1995-2004 is compared with the historical average. Areas of intense forest fire activity during the 2004 fire season are identified. Ozone bioindicator data are used to create an interpolated ozone map of the United States, and the possible impact on sensitive tree species is examined. Aerial survey data are used to identify hotspots of insect and disease activity based on the relative exposure to defoliation- and mortality-causing agents. Data from the Forest Inventory and Analysis down woody materials indicator are analyzed to produce preliminary per-acre estimates of amounts of woody debris and carbon pools stored in down woody materials. Data from the Forest Inventory and Analysis soil quality indicator are analyzed to provide preliminary information about erosion and soil compaction, soil pH, and effective cation exchange capacity, and to produce preliminary per-hectare estimates of soil carbon.

Keywords—Criteria and indicators, down woody materials, drought, fire, forest soils, fragmentation, ozone bioindicator.

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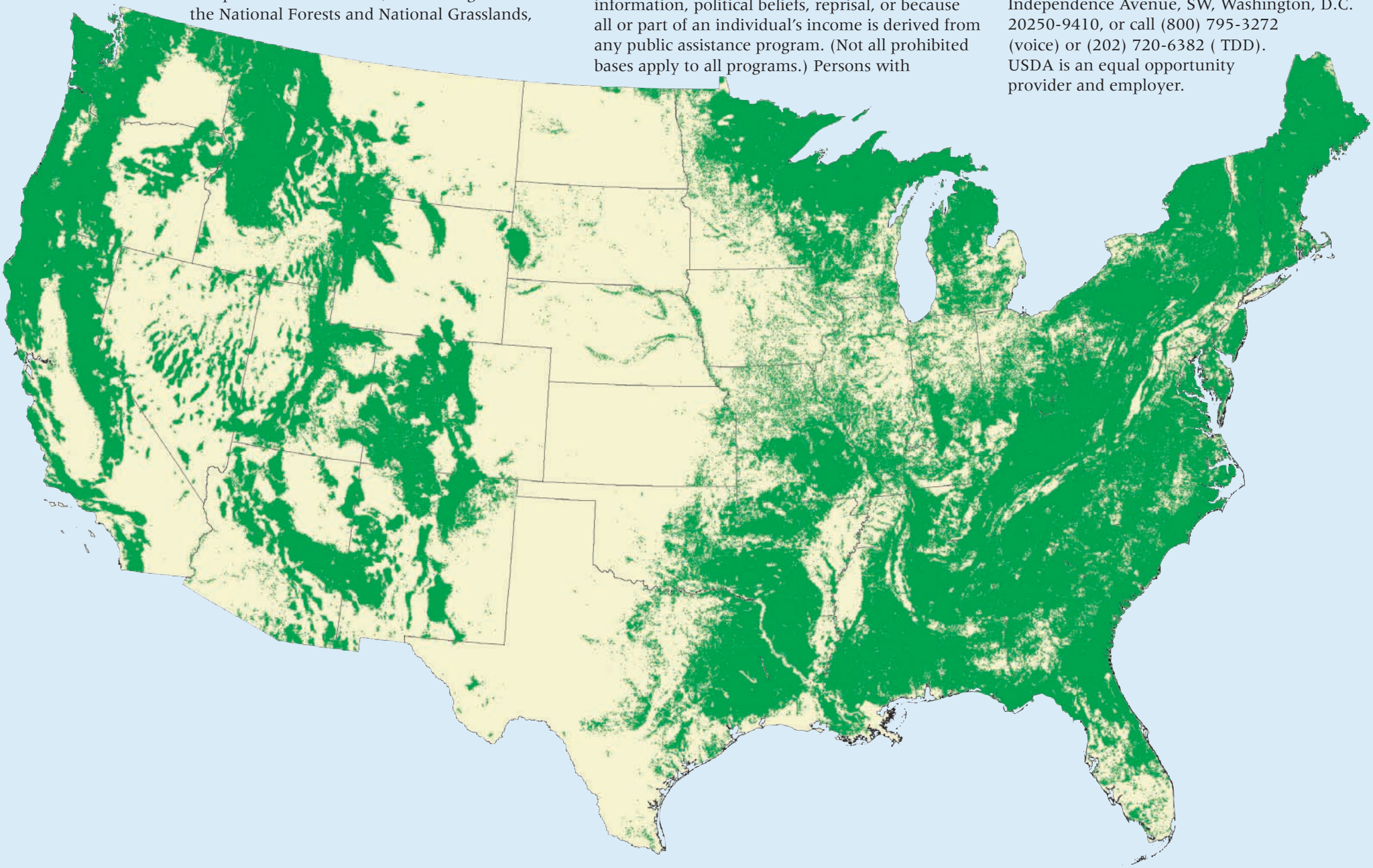
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