Chapter 1. Introduction

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Forests cover a vast area of the United States: 303.1 million ha or approximately one-third of the Nation's land (Smith and others 2004). These forests are of substantial ecological, economic, and social importance. Both their ecological integrity and their continued capacity to provide goods and services are of considerable concern in the face of a long list of threats, including insect and disease infestation, fragmentation, catastrophic fire, invasive species, and the effects of global climate change.

Assessing and monitoring the health of these forests is a critical and challenging task. While there is no universally accepted definition of forest health, the current understanding of ecosystem dynamics suggests that evaluations of forest health should emphasize factors that affect the inherent processes and resilience of forests (Raffa and others 2009). Consistent with this understanding, Kolb and others (1994) listed four characteristics that a healthy forest ecosystem is likely to possess:

- The physical environment, biotic resources, and energy consumption networks to support productive forests during at least some successional stages.
- Resistance to catastrophic change or the ability to recover from catastrophic change at the landscape level.
- A functional equilibrium between supply and demand of essential resources (water, nutrients, light, growing space) for major portions of the vegetation.
- A diversity of seral stages and stand structures that provide habitat for many native species and all essential ecosystem processes.

This annual national technical report on the health of the forests of the United States is produced by the Forest Health Monitoring Program (FHM) of the Forest Service, U.S. Department of Agriculture, with three specific objectives. The first is to present information about forest health from a national perspective, or from a multi-State regional perspective when appropriate, using data collected by the Forest Health Protection (FHP) and Forest Inventory and Analysis (FIA) programs of the Forest Service, as well as data from other sources. The first section of the report achieves this objective, with results stemming from the ongoing national-scale Detection Monitoring efforts from FHM and its cooperators using a wide variety of regional-scale data and analytical techniques. While in-depth interpretation and analysis of specific geographic or ecological regions are beyond the scope of this section of the report, the chapters in the first section of the report present information for the identification of areas that may require investigation at a finer scale.

The second objective of the report is to present new techniques for analyzing forest health data as well as new applications of established techniques. Examples in this report are chapter 5, which presents metrics quantifying the invasiveness of nonnative forest tree species and the large-scale potential for ecological impacts on forest communities by nonnative tree species; chapter 10, which describes a newly developed drought index methodology that allows for the comparison of moisture conditions between geographical areas and across periods of time; and chapters 4 and 9, which use a geographical information system (GIS) hot spot analysis to detect significant clusters of forest mortality and defoliation as well as significant clusters of forest fire occurrences.

The third objective of the report, addressed in the second section, is to present results of recently completed evaluation monitoring (EM) projects funded through the FHM national program. These projects determine the extent, severity, and causes of forest health problems (FHM 2009), generally at a finer scale than that addressed by the analyses in the first section of the report. Each chapter in the second section of the report contains an overview of the EM project, key results, and contacts for more information.

Organization of the Report

The Forest Service has adopted the Santiago Declaration and accompanying Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Montréal Process Working Group 2007) as a forest sustainability assessment framework (Smith and others 2001, USDA Forest Service 2004). The seven criteria are:

Criterion 1—Conservation of biological diversity

Criterion 2—Maintenance of productive capacity of forest ecosystems

Criterion 3—Maintenance of forest ecosystem health and vitality

Criterion 4—Conservation and maintenance of soil and water resources

Criterion 5—Maintenance of forest contribution to global carbon cycles

Criterion 6—Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of societies

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

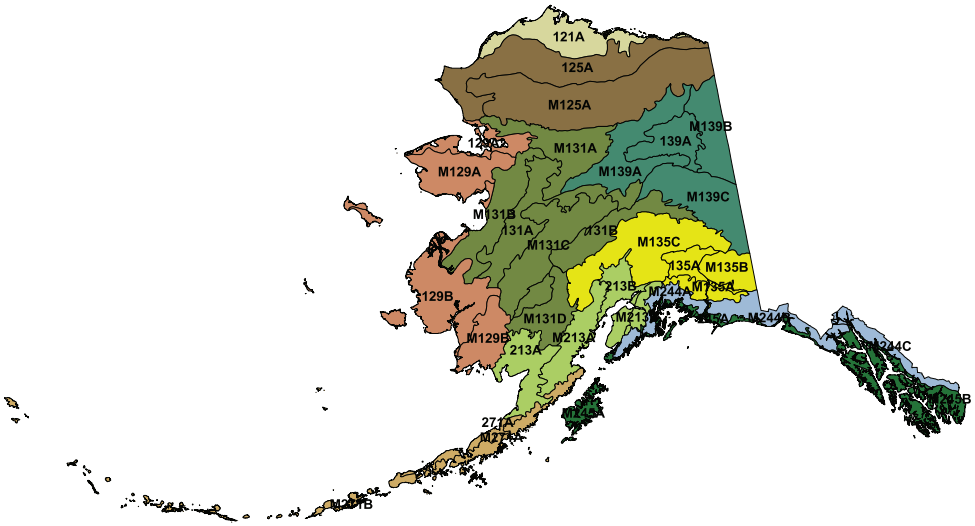
Chapter 2 addresses Criterion 1, conservation of biological diversity. The rest of the first section of this report is limited to assessments relating to Criterion 3, maintenance of forest ecosystem health and vitality, specifically Indicator 15, which quantifies the area and percent of forest affected by biotic agents beyond reference conditions (chapters 3, 4, 5, 6, and 7), and Indicator 16, which quantifies the area and percent of forest affected by abiotic agents beyond reference conditions (chapters 8, 9, and 10).

When appropriate throughout this report, authors use Bailey's revised ecoregion provinces and sections (Cleland and others 2007) as a common ecologically based spatial framework for their forest health assessments (fig. 1.1). Specifically, when the spatial scale of the data and the expectation of an identifiable pattern in the data are appropriate, authors use ecoregion sections as assessment units for their analyses. In Bailey's hierarchical system, the two broadest ecoregion scales, domains and divisions, are based on large ecological climate zones, while each division is broken into provinces based on vegetation macrofeatures (Bailey 1995). Provinces are further divided into sections, which may be thousands of km^2 in extent and are expected to encompass regions similar in their geology, climate, soils, potential natural vegetation, and potential natural communities (Cleland and others 1997).

Data Sources

Forest Service data sources included in this report are FIA annualized phase 2 survey data, FHP insect and disease survey forest mortality and defoliation data (1997–2008), Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States database (2001–08), and forest cover data developed from MODIS satellite imagery by the U.S. Forest Service Remote Sensing Applications Center.

Other sources of data are a list from the Animal and Plant Health Inspection Service (APHIS), U.S. Department of Agriculture, of proven and associated hosts for *Phytophthora ramorum* (USDA Animal and Plant Health Inspection Service 2008); daily weather station data from the National Climatic Data Center (NCDC); Biota of North America county-level plant species distribution data (Kartesz 2009); digital representations of the distributions of North American forest tree species (United States Geological Survey 1999); wildland-urban interface data (Radeloff and others 2005); Parameter-elevation Regression on Independent Slopes (PRISM) climate mapping system data (PRISM Group 2009); and the 2001 National Land Cover Database (NLCD) map (Homer and others 2007).



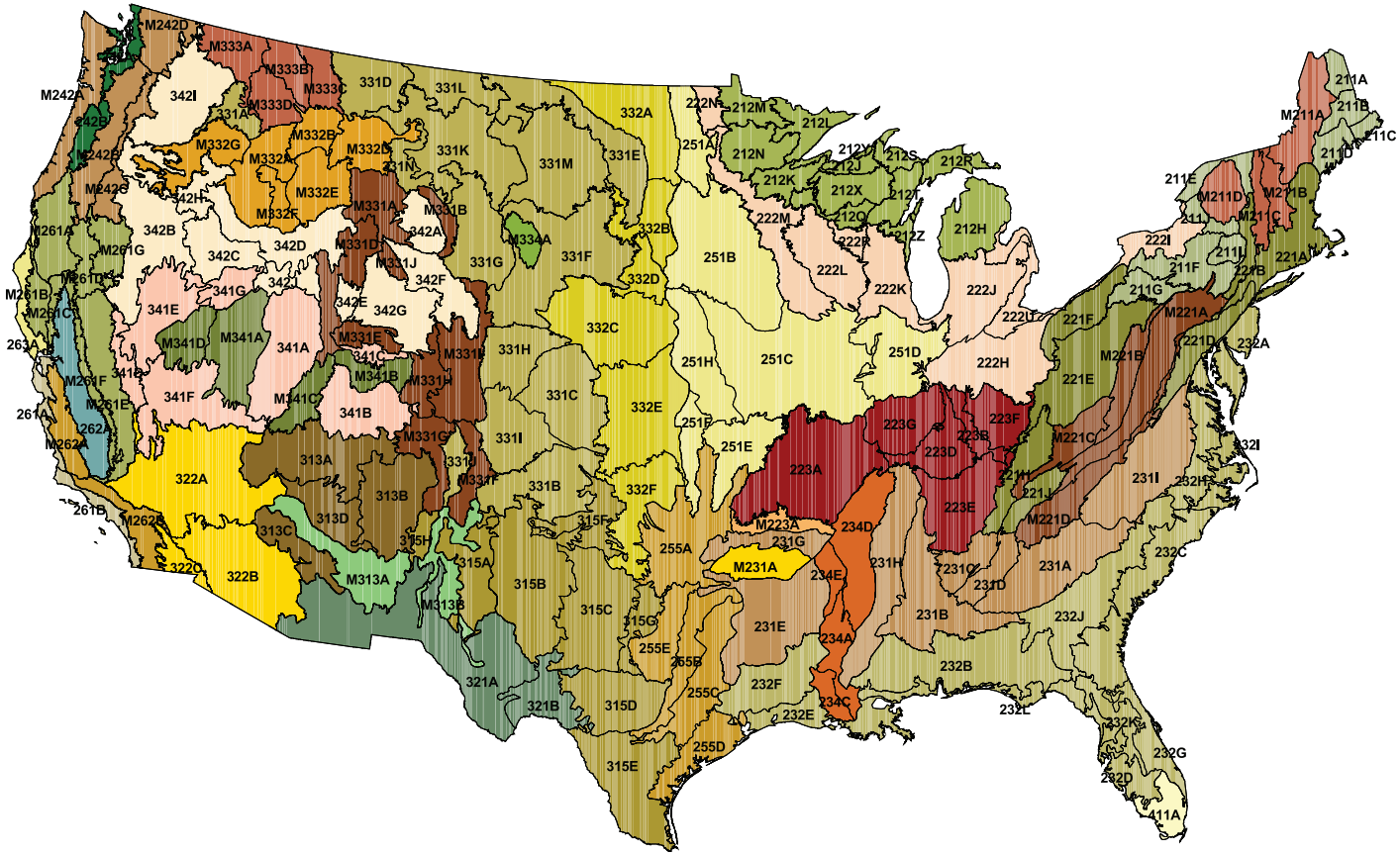


Figure 1.1—Ecoregion provinces and ecoregion sections for the conterminous United States (Cleland and others 2007) and Alaska (Nowacki and Brock 1995). Ecoregion sections within each ecoregion province are shown in the same color.

Alaska ecoregion provinces

- Alaska Mixed Forest (213)
- Alaska Range Taiga (135)
- Aleutian Meadow (271)
- Arctic Tundra (121)
- Bering Sea Tundra (129)
- Brooks Range Tundra (125)
- Pacific Coastal Icefields (244)
- Pacific Gulf Coast Forest (245)
- Upper Yukon Taiga (139)
- Yukon Intermontaine Taiga (131)

Eastern ecoregion provinces

- Adirondack—New England Mixed Forest—Coniferous Forest—Alpine Meadow (M211)
- Central Appalachian Broadleaf Forest—Coniferous Forest—Meadow (M221)
- Central Interior Broadleaf Forest (223)
- Eastern Broadleaf Forest (221)
- Everglades (411)
- Laurentian Mixed Forest (212)
- Lower Mississippi Riverine Forest (234)
- Midwest Broadleaf Forest (222)
- Northeastern Mixed Forest (211)
- Ouachita Mixed Forest—Meadow (M231)
- Outer Coastal Plain Mixed Forest (232)
- Ozark Broadleaf Forest (M223)
- 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—Redwood Forest (263)
- California Dry Steppe (262)
- Cascade Mixed Forest—Coniferous Forest—Alpine Meadow (M242)
- Chihuahuan Semi-Desert (321)
- Colorado Plateau Semi-Desert (313)
- Great Plains—Palouse Dry Steppe (331)
- Great Plains Steppe (332)
- Intermountain Semi-Desert (342)
- Intermountain Semi-Desert and Desert (341)
- Middle Rocky Mountain Steppe—Coniferous Forest—Alpine Meadow (M332)
- Nevada—Utah Mountains Semi-Desert—Coniferous Forest—Alpine Meadow (M341)
- Northern Rocky Mountains Forest-Steppe—Coniferous Forest—Alpine Meadow (M333)
- Pacific Lowland Mixed Forest (242)
- Sierran Steppe—Mixed Forest—Coniferous Forest—Alpine Meadow (M261)
- Southern Rocky Mountain Steppe—Open Woodland—Coniferous Forest—Alpine Meadow (M331)
- Southwest Plateau and Plains Dry Steppe and Shrub (315)

A major source of data for FHM analyses is the FIA program, which collects forest inventory information across all forest land ownerships in the United States. The FIA program maintains a network of more than 125,000 permanent ground plots across the conterminous United States, with a sampling intensity of approximately one plot per 2,428 ha. The FIA program's phase 2 encompasses the annualized inventory measured on plots at regular intervals, with each plot surveyed every 5 to 7 years in most eastern States, but with plots in the Rocky Mountain and Pacific Northwest regions surveyed once every 10 years (Reams and others 2005). The standard 0.067-ha plot (fig. 1.2) consists of four 7.315-meter radius subplots (approximately 168.6 m^2), on which field crews measure trees at least 5 inches in diameter. Within each of these subplots is nested a 2.073-meter radius microplot (approximately 13.48 m^2), on which crews measure trees smaller than 5 inches in diameter. A core-optional variant of the standard design includes four "macroplots," each with radius of 17.953 meters or approximately 0.1012 hectare that originates at the center of each subplot (FIA 2009).

FIA phase 3 plots represent a subset of these phase 2 plots, with one phase 3 plot for every 16 standard phase 2 plots. In addition to traditional forest inventory measurements, data for a variety of important ecological indicators are collected from phase 3 plots, including tree crown condition, lichen communities, down woody material, soil condition, and vegetation

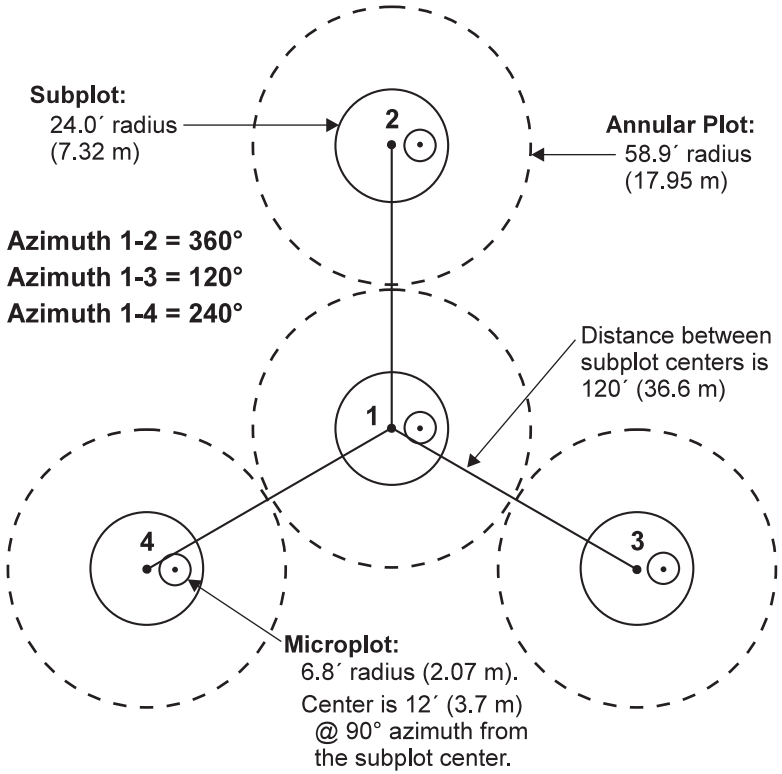


Figure 1.2—The mapped plot design used by the Forest Inventory and Analysis Program of the Forest Service, U.S. Department of Agriculture. Subplot 1 is the center of the cluster with subplots 2, 3, and 4 located 120 feet away at azimuths of 360°, 120°, and 240°, respectively (Forest Inventory and Analysis 2009).

structure and diversity. Additionally, data on ozone bioindicator plants are collected on a separate grid of plots. Most of these additional forest health indicators were measured as part of the FHM Detection Monitoring ground plot system prior to 2000[1] (Palmer and others 1991).

The Forest Health Monitoring Program

The national FHM Program is designed to determine the status, changes, and trends in indicators of forest condition on an annual basis, and covers all forested lands through a partnership encompassing the Forest Service, State foresters, and other State and Federal agencies and academic groups (FHM 2008). The FHM program utilizes data from a wide variety of data sources, both inside and outside the Forest Service, and develops analytical approaches for addressing forest health issues that affect the sustainability of forest ecosystems. It has five major activities (fig. 1.3):

- Detection Monitoring—nationally standardized aerial and ground surveys to evaluate status and change in condition of forest ecosystems

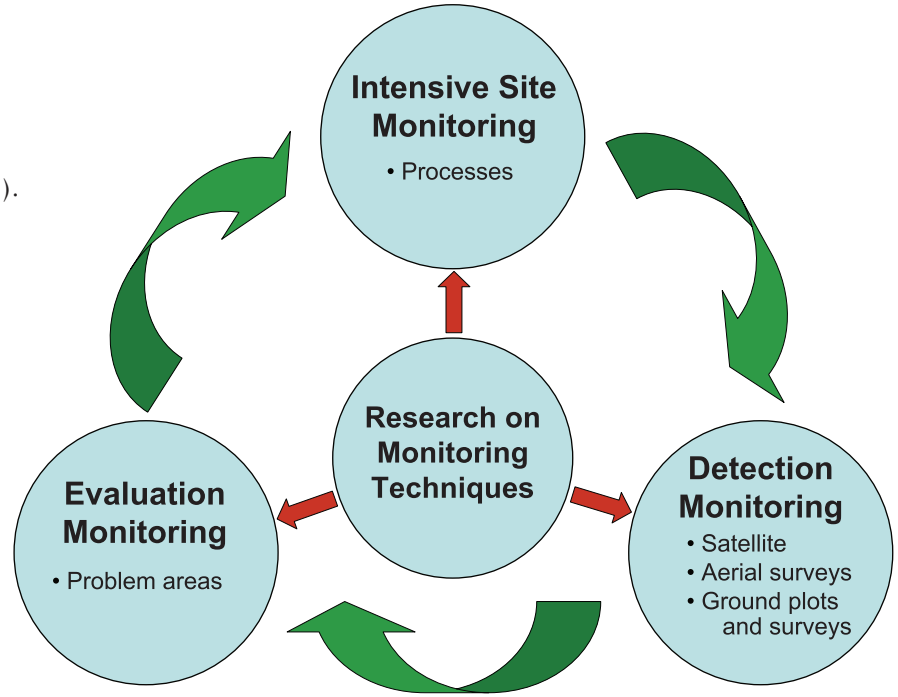


Figure 1.3—The design of the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture (FHM 2003). A fifth component, analysis and reporting of results, draws from the four FHM components shown here and provides timely information to help support land management policies and decisions.

[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, 3041 Cornwallis Rd., Research Triangle Park, NC 27709.

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

In addition to its national reporting efforts, the FHM program generates regional and State reports. These reports may be produced with FHM partners, both within the Forest Service and in State forestry and agricultural departments. Recent examples are Cumming and others (2006, 2007), Keyes and others (2003), Lake and others (2006), Laustsen and others (2003), Morin and others (2006), Neitlich and others (2003), and Steinman (2004). The Forest Health Highlights series, available on the FHM Web site at www.fs.fed.us/foresthealth/fhm, is produced by the FHM regions in cooperation with their respective State partners. The FHM program and its partners also produce reports on monitoring techniques and analytical methods, including analyzing forest health data (Smith and Conkling 2004), soils as an indicator of forest health (O'Neill and others 2005), crown-condition classification (Schomaker and others 2007), and sampling and estimation procedures for vegetation diversity and structure (Schulz and others 2009).

For more information, visit the FHM Web site at www.fs.fed.us/foresthealth/fhm. This report is produced by the national FHM research team, part of the Eastern Forest Environmental Threat Assessment Center, which was established under the Healthy Forest Restoration Act to generate knowledge and tools needed to anticipate and respond to environmental threats. For more information about the research team, and about threats to forests, please visit www.forestthreats.org/about.

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