CHAPTER 1.
Introduction

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Forests cover a vast area of the United States, 304 million ha or approximately one-third of the Nation's land area (Smith and others 2009). These forests possess the capacity to provide a broad range of goods and services to current and future generations, to safeguard biological diversity, and to contribute to the resilience of ecosystems, societies, and economies (USDA Forest Service 2011). Their ecological roles include supplying large and consistent quantities of clean water, preventing soil erosion, and providing habitat for a broad diversity of plant and animal species. Their socioeconomic benefits include wood products, nontimber goods, recreational opportunities, and pleasing natural beauty. Both the ecological integrity and the continued capacity of these forests to provide ecological and economic goods and services are of concern, however, in the face of a long list of threats, including insect and disease infestation, fragmentation and conversion to other land uses, catastrophic fire, invasive species, and the effects of climate change.

Natural and anthropogenic stresses vary among biophysical regions and local environments; they also change over time and interact with each other. These and other factors make it challenging to establish baselines of forest health and to detect important departures from normal forest ecosystem functioning (Riitters and Tkacz 2004). Monitoring the health of forests is a critically important task, however, reflected within the Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Montréal Process Working Group 1995), which the Forest Service, U.S. Department of Agriculture (USDA), uses as a forest sustainability assessment framework (USDA Forest Service 2004, 2011). The primary objective of such monitoring is to identify ecological resources whose condition is deteriorating in subtle ways over large regions in response to cumulative stresses, a goal that requires consistent, large-scale, and long-term monitoring of key indicators of forest health status, change, and trends (Riitters and Tkacz 2004). This is best accomplished through the participation of multiple Federal, State, academic, and private partners.

Although the concept of a healthy forest has universal appeal, forest ecologists and managers have struggled with how exactly to define forest health (Teale and Castello 2011), and there is no universally accepted definition. Most definitions of forest health can be categorized as representing an ecological or a utilitarian perspective (Kolb and others 1994). From an ecological perspective, the current understanding of ecosystem dynamics suggests that healthy ecosystems are those that are able to maintain their organization and autonomy over time while remaining resilient to stress (Costanza 1992), and that evaluations of forest health should emphasize factors that affect the inherent processes and resilience of forests (Edmonds and others 2011, Kolb and others 1994, Raffa and others 2009). On the other hand, the utilitarian perspective holds that a forest is healthy if management objectives are met, and that a forest is unhealthy if these objectives are not met (Kolb and others 1994). Although this definition may be appropriate when a single, unambiguous management objective exists, such as the production of wood fiber or the maintenance of wilderness attributes, it is too narrow when multiple management objectives are required (Edmonds and others 2011, Teale and Castello 2011). Teale and Castello (2011) incorporate both ecological and utilitarian perspectives into their two-component definition of forest health: First, a healthy forest must be sustainable with respect to its size structure, including a correspondence between baseline and observed mortality; second, a healthy forest must meet the landowner's objectives, provided that these objectives do not conflict with sustainability.

This national report, the 17th in an annual series sponsored by the Forest Health Monitoring (FHM) Program of the Forest Service, attempts to quantify the status of, changes to, and trends in a wide variety of broadly defined indicators of forest health. The indicators described in this report encompass forest insect and disease activity, wildland fire occurrence, drought, tree mortality, understory vegetation, and regeneration, among others. The previous reports in this series are Ambrose and Conkling (2007, 2009), Conkling (2011), Conkling and others (2005), Coulston and others (2005a, 2005b, 2005c), and Potter and Conkling (2012a, 2012b, 2013a, 2013b, 2014, 2015a, 2015b, 2016, 2017).

This report has 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 from other sources available at a wide extent. The chapters that present analyses at a national scale, or multi-State regional scale, are divided between section 1 and section 2 of the report. Section 1 presents results from the analyses of forest health data that are available on an annual basis. Such repeated analyses of regularly collected indicator measurements allow for the detection of trends over time and help establish a baseline for future comparisons (Riitters and Tkacz 2004). Section 2 presents longer-term forest health trends, in addition to describing new techniques for analyzing forest health data at national or regional scales (the second objective of the report). While in-depth interpretation and analysis of specific geographic or ecological regions are beyond the scope of these parts of the report, the chapters in sections 1 and 2 present information that can be used to identify 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, often applied to longer timescales, presented in selected chapters of section 2. Examples in this report are chapters 6 and 7, which, respectively, assess the use of FIA plot-level lichen data as bioindicators for large-scale monitoring of air quality across eastern U.S. forests, and present a national summary of crown condition across the United States for 2011–15 and apply change over time in crown dieback to identify species in decline.

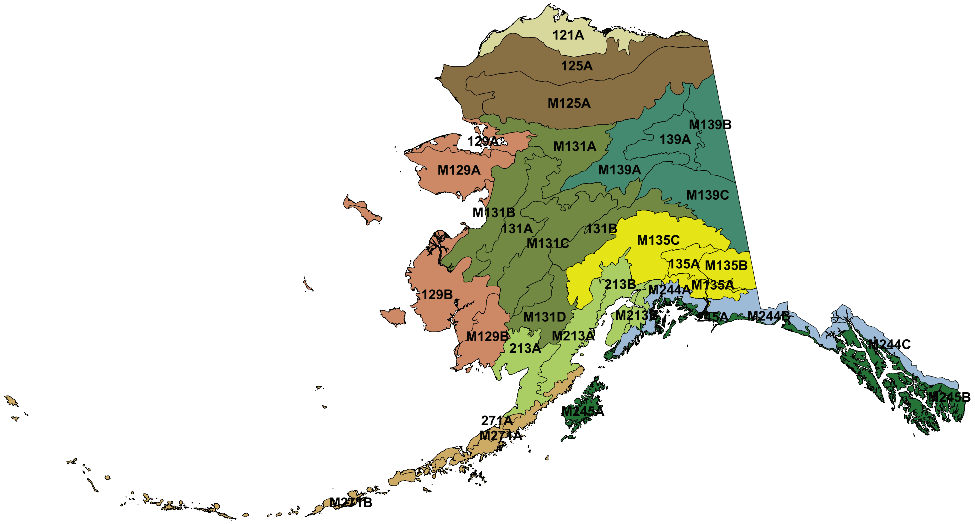
The third objective of the report is to present results of recently completed Evaluation Monitoring (EM) projects funded through the FHM national program. These project summaries, presented in section 3, determine the extent, severity, and/or cause of forest health problems (FHM 2016), generally at a finer scale than that addressed by the analyses in sections 1 and 2. Each of the eight chapters in section 3 contains an overview of an EM project, key results, and contacts for more information.

When appropriate throughout this report, authors use the Forest Service revised ecoregions (Cleland and others 2007, Nowacki and Brock 1995) 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 or provinces as assessment units for their analyses. Bailey's hierarchical system bases the two broadest ecoregion scales, domains and divisions, on large ecological climate zones, while each division is broken into provinces based on vegetation macro features (Bailey 1995). Provinces are further divided into sections, which may be thousands of square kilometers in area and are expected to encompass regions similar in their geology, climate, soils, potential natural vegetation, and potential natural communities (Cleland and others 1997).

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 2016). 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. The FHM Program has five major components (fig. 1.2):

- Detection Monitoring—nationally standardized aerial and ground surveys to evaluate status and change in condition of forest ecosystems (sections 1 and 2 of this report).
- Evaluation Monitoring—projects to determine the extent, severity, and causes of undesirable changes in forest health identified through Detection Monitoring (section 3 of this report).



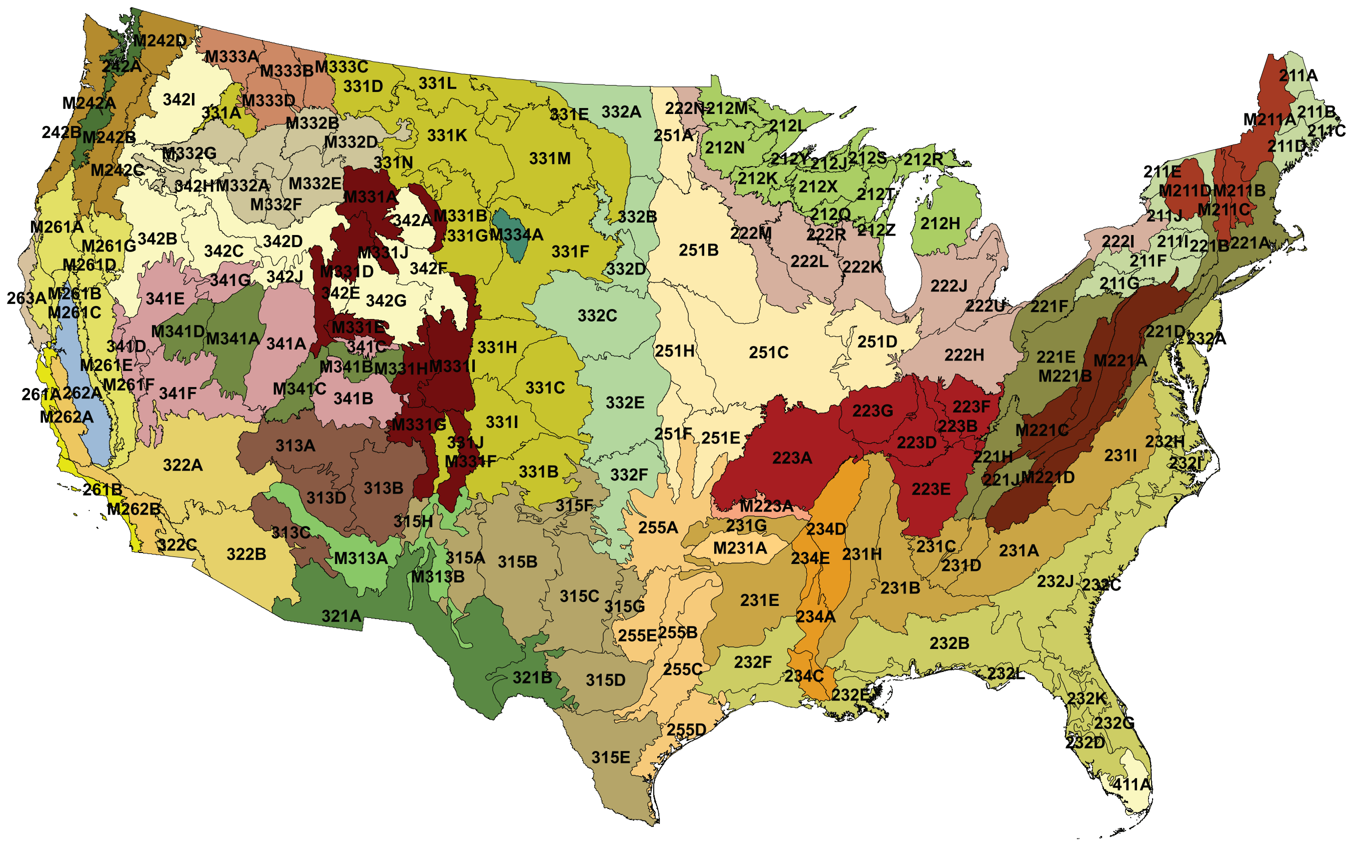


Figure 1.1—Ecoregion provinces and sections for the conterminous United States (Cleland and others 2007) and Alaska (Nowacki and Brock 1995). Ecoregion sections within each ecoregion province are shown in the same color. Note: no equivalent ecoregion treatment exists for Hawaii.

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)

Conterminous States ecoregion provinces

- Adirondack-New England Mixed Forest - Coniferous Forest - Alpine Meadow (M211)
- American Semi-Desert and Desert (322)
- Arizona-New Mexico Mountains Semi-Desert - Open Woodland - Coniferous Forest - Alpine Meadow (M313)
- Black Hills Coniferous Forest (M334)
- California Coastal Chaparral Forest and Shrub (261)
- California Coastal Range Open Woodland - Shrub - Coniferous Forest - Meadow (M262)
- California Coastal Steppe - Mixed Forest - Redwood Forest (263)
- California Dry Steppe (262)
- Cascade Mixed Forest - Coniferous Forest - Alpine Meadow (M242)
- Central Appalachian Broadleaf Forest - Coniferous Forest - Meadow (M221)
- Central Interior Broadleaf Forest (223)
- Chihuahuan Semi-Desert (321)
- Colorado Plateau Semi-Desert (313)
- Eastern Broadleaf Forest (221)
- Everglades (411)
- Great Plains - Palouse Dry Steppe (331)
- Great Plains Steppe (332)
- Intermountain Semi-Desert and Desert (341)
- Intermountain Semi-Desert (342)
- Laurentian Mixed Forest (212)
- Lower Mississippi Riverine Forest (234)
- Middle Rocky Mountain Steppe - Coniferous Forest - Alpine Meadow (M332)
- Midwest Broadleaf Forest (222)
- Nevada-Utah Mountains Semi-Desert - Coniferous Forest - Alpine Meadow (M341)
- Northeastern Mixed Forest (211)
- Northern Rocky Mountain Forest-Steppe - Coniferous Forest - Alpine Meadow (M333)
- Ouachita Mixed Forest - Meadow (M231)
- Outer Coastal Plain Mixed Forest (232)
- Ozark Broadleaf Forest (M223)
- Pacific Lowland Mixed Forest (242)
- Prairie Parkland (Subtropical) (255)
- Prairie Parkland (Temperate) (251)
- Sierran Steppe - Mixed Forest - Coniferous Forest - Alpine Meadow (M261)
- Southeastern Mixed Forest (231)
- Southern Rocky Mountain Steppe - Open Woodland - Coniferous Forest - Alpine Meadow (M331)
- Southwest Plateau and Plains Dry Steppe and Shrub (315)

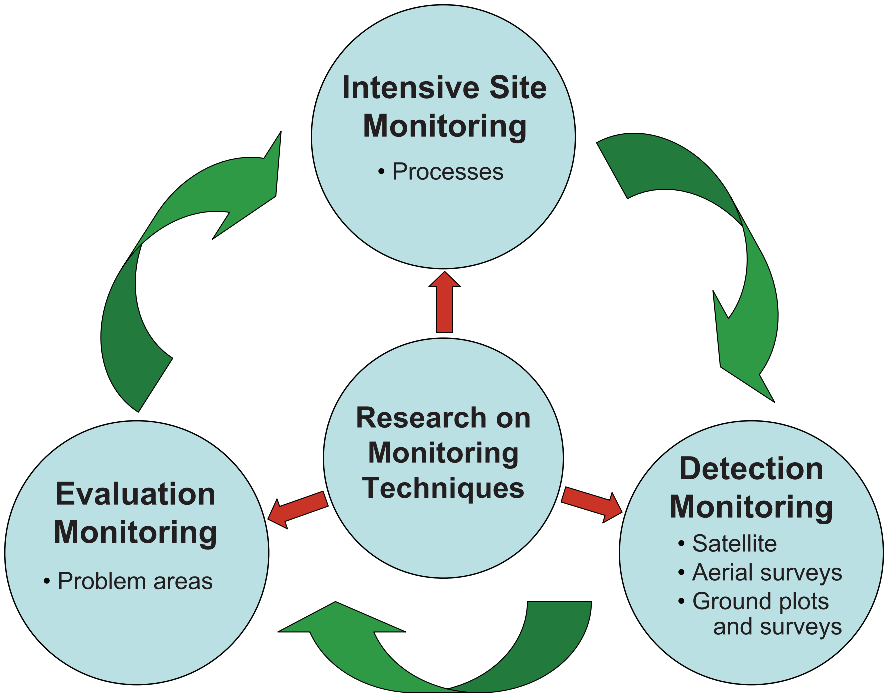


Figure 1.2—The design of the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture (FHM 2003). A fifth component, Analysis and Reporting of Results, draws from the four FHM components shown here and provides information to help support land management policies and decisions.

- Intensive Site Monitoring—projects to enhance an understanding of cause-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 (section 3 of this report).
- 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 (section 2 of this report).
- Analysis and Reporting of Results—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 (sections 1, 2, and 3 of this report).

The FHM Program, in addition to national reporting, generates regional and State reports, often in cooperation with FHM partners, both within the Forest Service and in State forestry and agricultural departments. For example, the FHM regions cooperate with their respective State partners to produce the annual Forest Health Highlights report series, available on the FHM Web site at www.fs.fed.us/foresthealth/fhm. Other examples include Steinman (2004) and Harris and others (2011).

The FHM Program and its partners also produce reports and journal articles on monitoring techniques and analytical methods, including forest health data (Potter and others 2016, Smith and Conkling 2004); soils as an indicator of forest health (O'Neill and others 2005); urban forest health monitoring (Bigsby and others 2014; Cumming and others 2006, 2007; Lake and others 2006); remote sensing of forest disturbances (Chastain and others 2015, Rebbeck and others 2015); health conditions in national forests (Morin and others 2006); crown conditions (Morin and others 2015; Randolph 2010a, 2010b, 2013; Randolph and Moser 2009; Schomaker and others 2007); indicators of regeneration (McWilliams and others 2015); vegetation diversity and structure (Schulz and Gray 2013, Schulz and others 2009, Simkin and others 2016); forest lichen communities (Jovan and others 2012, Root and others 2014); downed woody materials in forests (Woodall and others 2012, 2013); drought (Vose and others 2016); ozone monitoring (Rose and Coulston 2009); patterns of nonnative invasive plant occurrence (Guo and others 2015, 2017; Iannone and others 2015, 2016a, 2016b; Oswalt and others 2015); assessments of alien-invasive forest insect and disease risk (Koch and others 2011, 2014; Krist and others 2014; Vogt and Koch 2016; Yemshanov and others 2014); spatial patterns of landcover (Riitters 2011; Riitters and others 2012, 2016, 2017; Riitters and Wickham 2012); impacts of deer browse on forest structure (Russell and others 2017); broad-scale assessments of forest biodiversity (Potter and Koch 2014; Potter and Woodall 2012, 2014); predictions and indicators of climate change effects on forests and forest tree species (Fei and others 2017, Heath and others 2015, Potter and Hargrove 2013); and the overall forest health indicator program (Woodall and others 2010).

For more information about the FHM Program, visit the FHM Web site at www.fs.fed.us/foresthealth/fhm. Among other things, this Web site includes links to all past national forest health reports (www.fs.fed.us/foresthealth/fhm/pubs), information about funded Evaluation Monitoring projects (www.fs.fed.us/foresthealth/fhm/em), and annual State forest health highlight reports (www.fs.fed.us/foresthealth/fhm/fhh/fhmusamap.shtml).

DATA SOURCES

Forest Service data sources in this edition of the FHM national report include FIA annualized Phase 2 and Phase 3 survey data (Bechtold and Patterson 2005, Woodall and others 2010, Woudenberg and others 2010); FHP national insect and disease survey forest mortality and defoliation data for 2016 (FHP 2014); Moderate

Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States data for 2016 (USDA Forest Service 2017); and forest cover data developed from MODIS satellite imagery by the Forest Service Remote Sensing Applications Center. Other sources of data include Parameter-elevation Regression on Independent Slopes Model (PRISM) climate mapping system data (PRISM Climate Group 2017) and FIA's publicly available Environmental Monitoring and Assessment Program (EMAP) hexagons (Brand and others 2000).

As a major source of data for several FHM analyses, the FIA Program merits detailed description. The FIA Program collects forest inventory information across all forest land ownerships in the United States and maintains a network of more than 130,000 permanent forested ground plots across the conterminous United States and southeastern Alaska, with a sampling intensity of approximately one plot/2428 ha. Forest Inventory and Analysis 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. 1.3) consists of four 7.315-m (24.0-foot) radius subplots (approximately 168.6 m^2 or 1/24th acre), on which field crews measure trees at least 12.7 cm (5.0 inches) in diameter. Within each of these subplots is nested a 2.073-m (6.8-foot) radius microplot (approximately 13.48 m^2 or 1/300th acre), on which crews measure trees smaller than 12.7 cm

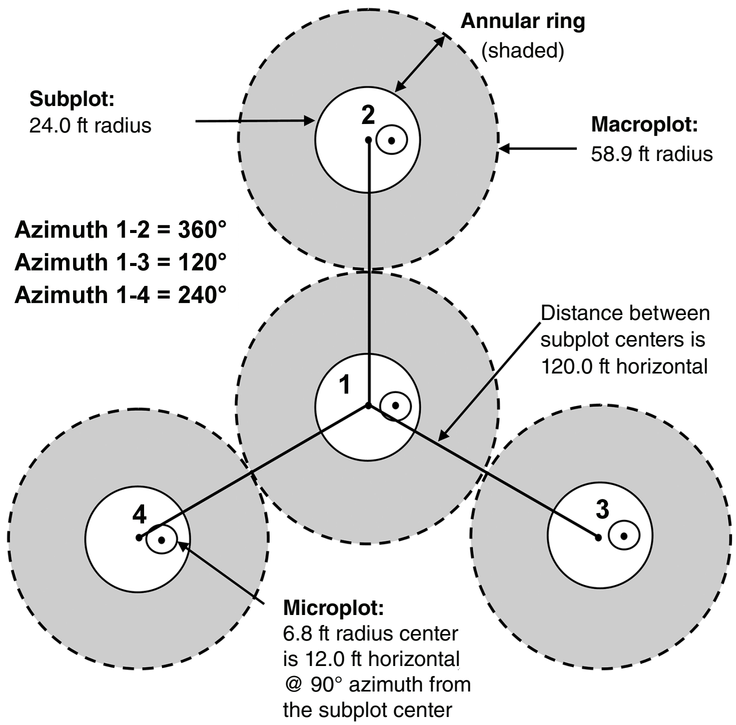


Figure 1.3—The Forest Inventory and Analysis mapped plot design. Subplot 1 is the center of the cluster with subplots 2, 3, and 4 located 120 feet away at azimuths of 360°, 120°, and 240°, respectively (Woudenberg and others 2010).

(5.0 inches) in diameter. A core-optional variant of the standard design includes four "macroplots," each with a radius of 17.953 m (or approximately 0.1012 ha) that originates at the center of each subplot (Woudenberg and others 2010).

FIA Phase 3 plots have represented a subset of these Phase 2 plots, with one Phase 3 plot for every 16 standard FIA Phase 2 plots.

In addition to traditional forest inventory measurements, data for a variety of important ecological indicators have been collected from Phase 3 plots, including tree crown condition, lichen communities, downed woody material, soil condition, and vegetation structure and diversity, whereas data on ozone bioindicator plants have been collected on a separate grid of plots (Woodall and others 2010, 2011). 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).

FHM REPORT PRODUCTION

This FHM national report, the 17th in a series of such annual documents, is produced by forest health monitoring researchers at the Eastern Forest Environmental Threat Assessment Center (EFETAC) in collaboration with North Carolina State University cooperators. A unit of the Southern Research Station of the Forest Service, EFETAC was established under the Healthy Forests Restoration Act of 2003 to generate the knowledge and tools needed to anticipate and respond to environmental threats. For more information about the research team and about threats to U.S. forests, please visit www.forestthreats.org/about.

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