CHAPTER 1

Introduction

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Forests and woodlands cover an extensive area of the United States, 333 million ha or approximately 36 percent of the Nation's land area (Oswalt and others 2019). These forests provide a broad range of goods and services for current and future generations, safeguard biological diversity, and contribute to the resilience of ecosystems, societies, and economies (McGinley and others 2023). Their socioeconomic benefits include wood products, nontimber goods, reduction of air pollutants, moderation of city temperatures, recreational opportunities, and natural beauty. 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. At the same time, both the ecological integrity and the continued capacity of these forests to provide ecological and economic goods and services face a long list of threats, including insect and disease infestation, drought, fragmentation and forest 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. Such variations along with 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, reflected within the Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Montréal Process Working Group 1995), which the U.S. Department of Agriculture, Forest Service uses as a forest sustainability assessment framework (McGinley and others 2023; 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). Given the magnitude of this task, it is best accomplished through the participation of multiple Federal, State, academic, and private partners.

The concept of a healthy forest has universal appeal, but forest ecologists and managers have struggled with how exactly to define forest health (Teale and Castello 2011). No universally accepted definition exists. Most definitions of forest health can be categorized as representing either 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 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

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be appropriate when a single, unambiguous management objective exists, such as the production of wood fiber or the maintenance of wilderness attributes, it can be 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 "Forest Health Monitoring: National Status, Trends, and Analysis" report, the 23rd 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, tree mortality, forest fragmentation, and drought, 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, 2018, 2019, 2020, 2021, 2022, 2023). Visit https://www.fs.usda.gov/science-technology/forest-health-protection/publications-reports/forest-health-monitoring-publications/annual-national-forest-health-monitoring-reports for links to each of these reports in their entirety and for searchable lists of links to chapters included in the reports.

The first objective of this report is to present information about forest health from a national perspective, or from a multistate 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 that are available at a wide extent, such as subregions within the United States. Even though all the chapters in this report have a national or multistate regional perspective, they differ in their spatial extent, largely depending on the data availability for the respective kind of analysis. For example, the fire occurrence analysis (ch. 3) covers the conterminous United States (CONUS), Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands, but the tree mortality analysis (ch. 4) is limited to the Eastern and Central United States.

The second objective of this report is to provide analyses from various temporal scales. Chapters in this report vary by their extent of temporal data. For example, the insect and disease damage (ch. 2) and tree mortality (ch. 4) chapters present analyses of forest health on an annual basis or from a short-term perspective. 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). Other chapters, such as those about forest fragmentation (ch. 5) or drought (ch. 6 and 7), present analyses of long-term trends. Some others, like the fire occurrence analysis (ch. 3), provide forest health scenarios from both short- and long-term perspectives.

The third 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 timelines. Examples from this report include updates to sustainability indicators for forest fragmentation (ch. 5); analysis of multiyear drought trends across and within the subregions of the United States, as well as summaries of forest ecosystem exposure to droughts (ch. 6); and an evaluation of a new multiyear dryness exposure index and its association with forest disturbances (ch. 7).

Summaries of the results from recently completed Evaluation Monitoring projects funded through the national FHM Program, which generally focus on forest health problems at finer scales (FHM 2022), have been published in a section of this report since 2008. These project summaries will now be presented in a separate document.

When appropriate throughout this report, authors use the Forest Service revised ecoregions for the CONUS and Alaska (Cleland and others 2007, Spencer and others 2002) 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, larger scale provinces, or smaller scale subsections 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 macrofeatures (Bailey 1995). Provinces are further divided into sections, which may be thousands of km^2 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). Subsections are nested within sections as the smallest level in the hierarchy. This hierarchical system does not address either Hawaii or Puerto Rico beyond including each in a unique, single ecoregion province (Bailey 1995). A set of Hawaii ecoregions based on moisture and elevational characteristics was developed for use in FHM national reports (Potter 2023) because a finer scale and ecologically oriented spatial assessment framework was needed to estimate the impacts of a destructive forest disease (ch. 2) and of forest fire occurrences (ch. 3) (fig. 1.2).

(A)

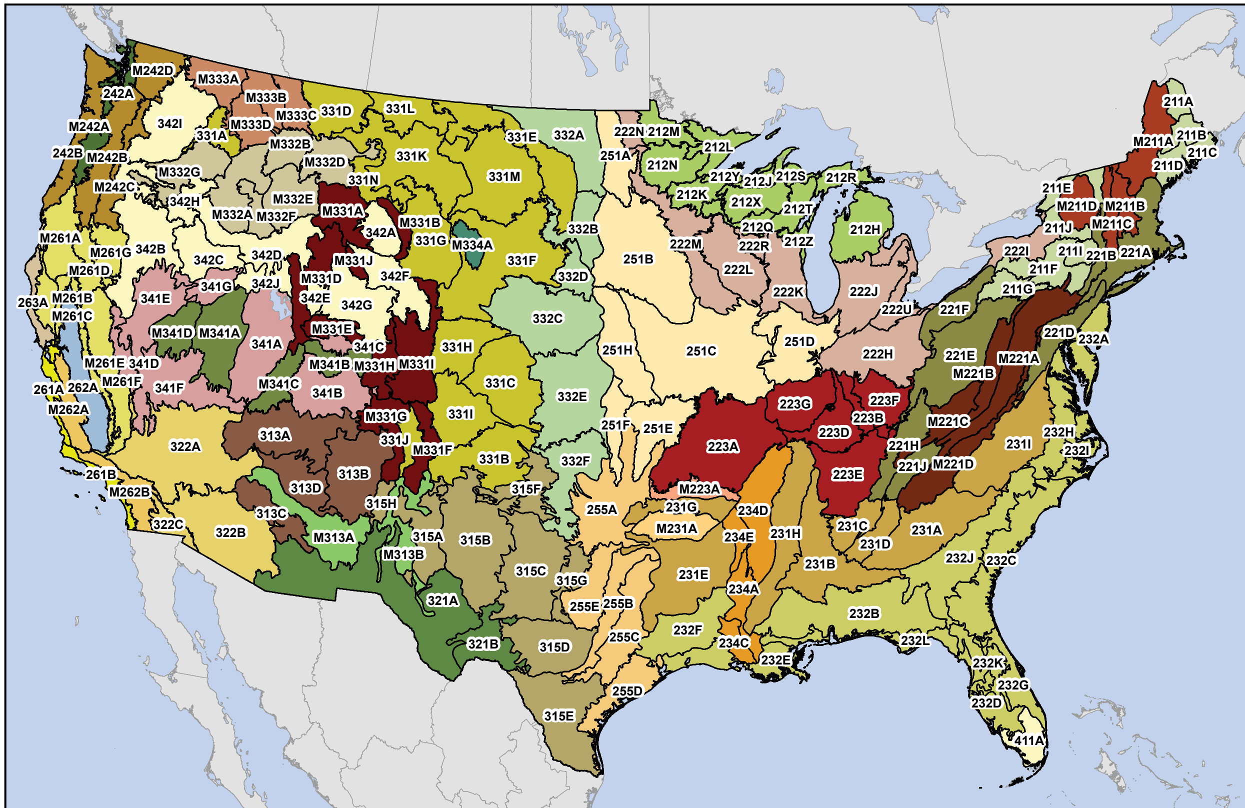
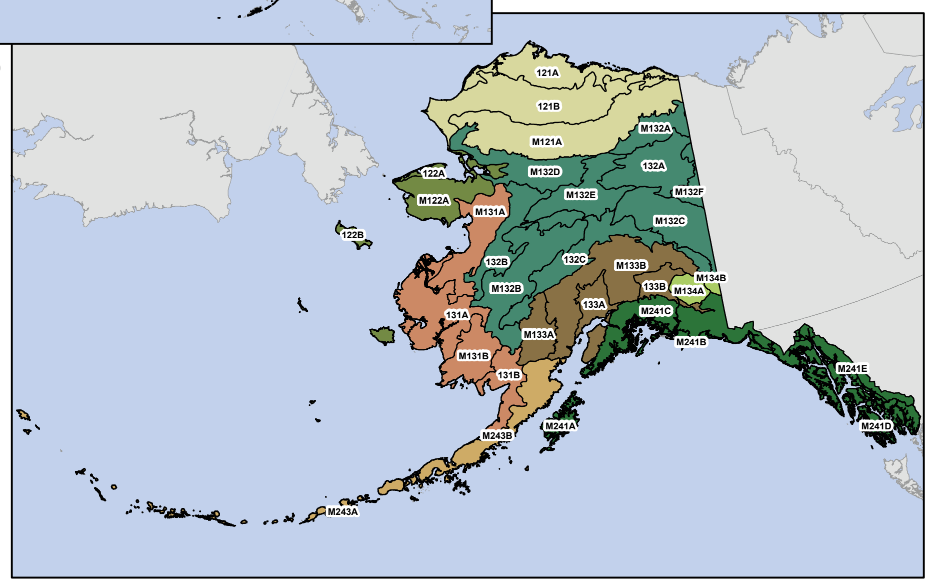


Figure 1.1—Ecoregion provinces and sections for (A) the conterminous United States (Cleland and others 2007) and (B) Alaska (Spencer and others 2002). Ecoregion sections within each ecoregion province are shown in the same color.

(B)



Conterminous States ecoregion provinces

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

Alaska ecoregion provinces

- 121: Arctic Tundra
- M122: Bering Tundra
- M131: Bering Taiga
- M132: Intermontane Boreal
- 133: Alaska Range Transition
- M134: Coastal Mountains Transition
- M241: Coastal Rainforest
- M243: Aleutian Meadows

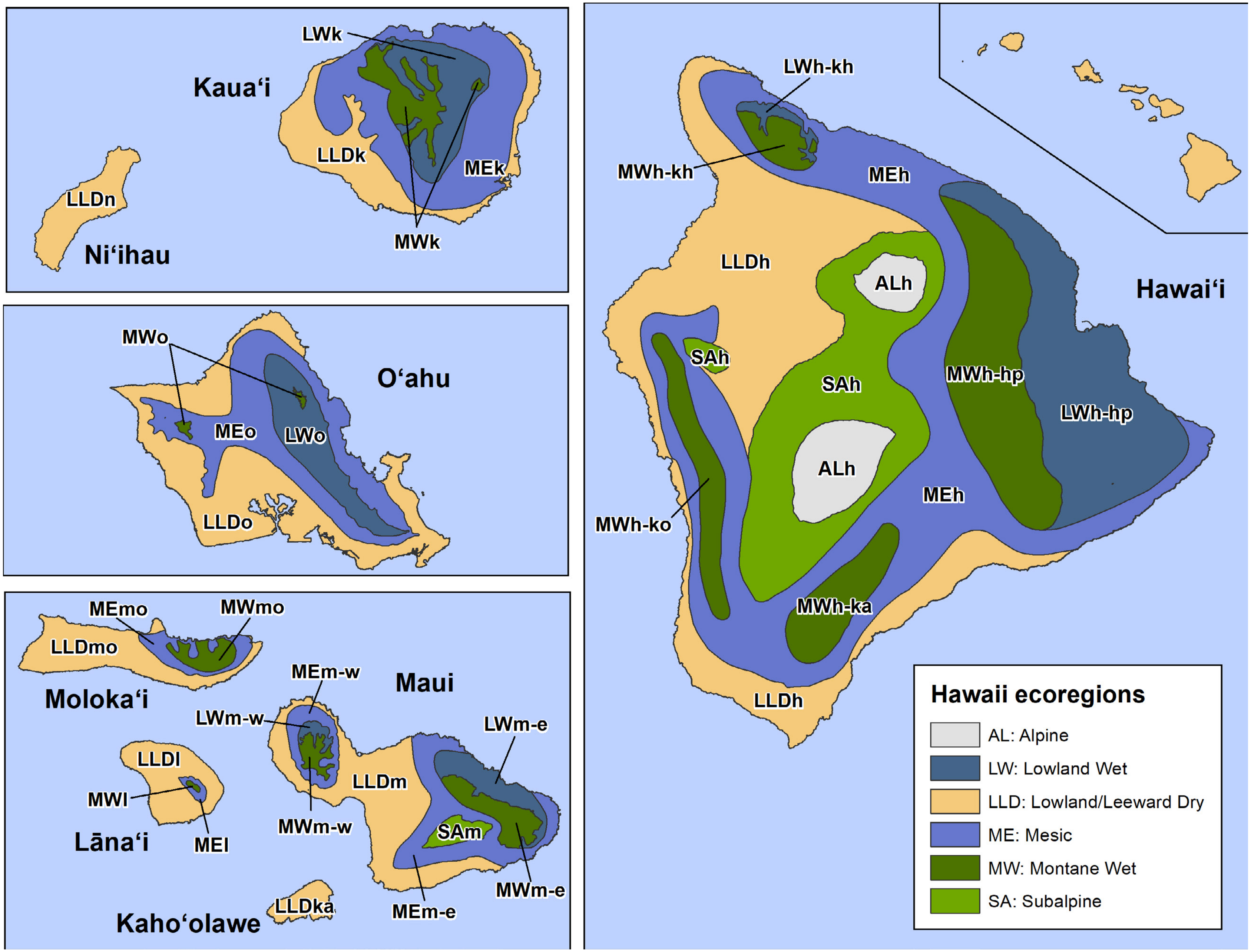


Figure 1.2—Ecoregions, and ecoregion subunits, for Hawaii (Potter 2023), developed based on moisture zones and elevation (see box 1.1). Ecoregion subunits are shown in the same color by ecoregion.

THE FOREST HEALTH MONITORING PROGRAM

The national FHM Program is designed to deliver actionable data and information on the status, trends, and future of forest conditions to land managers and decision makers. FHM implements this goal 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 2022). 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 three major approaches (fig. 1.3), which are interlinked and provide feedback to each other:

- **Survey and Detection**—identifying forest health challenges at local and landscape scales through nationally standardized aerial and ground surveys
- **Monitoring and Analysis**—tracking the status and trends of forest health challenges and assessing impacts on forest resources and their benefits through synthesis and evaluation of information from various data sources within and external to the Forest Service
- **Communications**—supporting decision making and communicating regional, long-term forest health trends and their implications to forest resources and their benefits

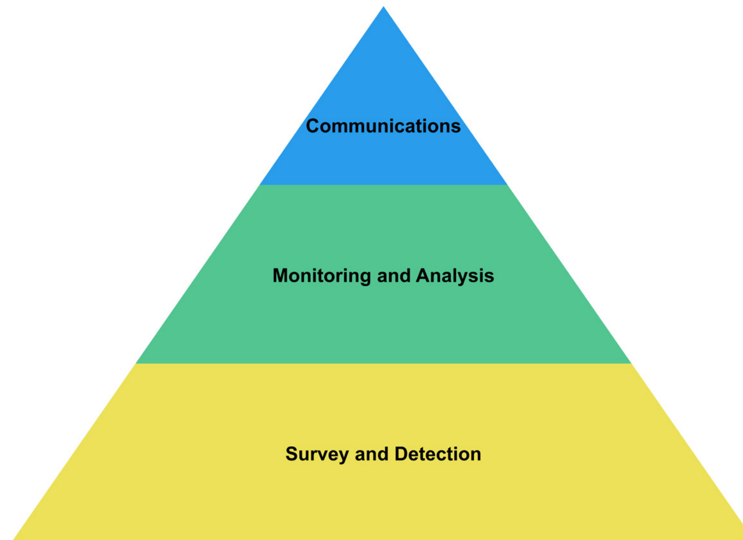


Figure 1.3—The design of the Forest Health Monitoring Program.

The FHM Program is divided into four "megaregions." These correspond with the two Forest Service regions in the Eastern United States (Eastern and Southern) while joining four Forest Service regions into the Interior West megaregion (Northern, Rocky Mountain, Southwestern, and Intermountain) and three Forest Service regions into the West Coast megaregion (Pacific Southwest, Pacific Northwest, and Alaska) (fig. 1.4). Some analyses in this FHM national report provide results by FHM megaregion, though they separate Alaska and Hawaii from the rest of the West Coast megaregion, and Puerto Rico and the U.S. Virgin Islands from the rest of the Southern megaregion. In addition to national reporting, the FHM

Program 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 megaregions cooperate with their respective State partners to produce the annual "Forest Health Highlights" report series, available on the FHM website at https://www.fs.usda.gov/science-technology/forest-health-protection/publications-reports/forest-health-monitoring-publications/forest-health-highlights. Other examples include Steinman (2004) and Harris and others (2011).

The FHM Program and its partners also produce peer-reviewed reports and journal articles on monitoring techniques and analytical methods (see https://www.fs.usda.gov/science-technology/forest-health-protection/publications-reports/forest-health-monitoring-publications). The emphases of these publications include forest health data (Potter and others 2016, Siry and others 2018, 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; Hudgins and others 2022; 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 (Crockett and others 2023, Schulz and Gray 2013, Schulz and others 2009, Simkin and others 2016); forest lichen communities (Jovan and others 2012, Root and others 2014); down woody materials in forests (Woodall and others 2012, 2013); drought (Costanza and others 2023, 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, 2018; Jo and others 2018; Oswalt and others 2015; Potter and others 2023; Riitters and others 2018a, 2018b); assessments of forest risk or tree species vulnerability to exotic invasive forest insects and diseases (Asaro and others 2023; Koch and others 2011, 2014; Krist and others 2014; Potter and others 2019a, 2019b; Vogt and Koch 2016; Yemshanov and others 2014); spatial patterns of land cover and forest fragmentation (Guo and others 2018; Riitters 2011; Riitters and Costanza 2019; Riitters and Wickham 2012; Riitters and others 2012, 2016, 2017); impacts of deer browse on forest structure (Russell and others 2017); broad-scale assessments of forest biodiversity (Guo and others 2019; Potter 2018; Potter and Koch 2014; Potter and Woodall 2012, 2014); predictions and indicators of climate change effects on forests and forest tree species (Anderson and others 2021, Fei and others 2017, Heath and others 2015, Potter and Hargrove 2013); legal, institutional, and economic indicators of forest conservation and sustainable management (McGinley and Cubbage 2020); and the overall forest health indicator program (Woodall and others 2010).

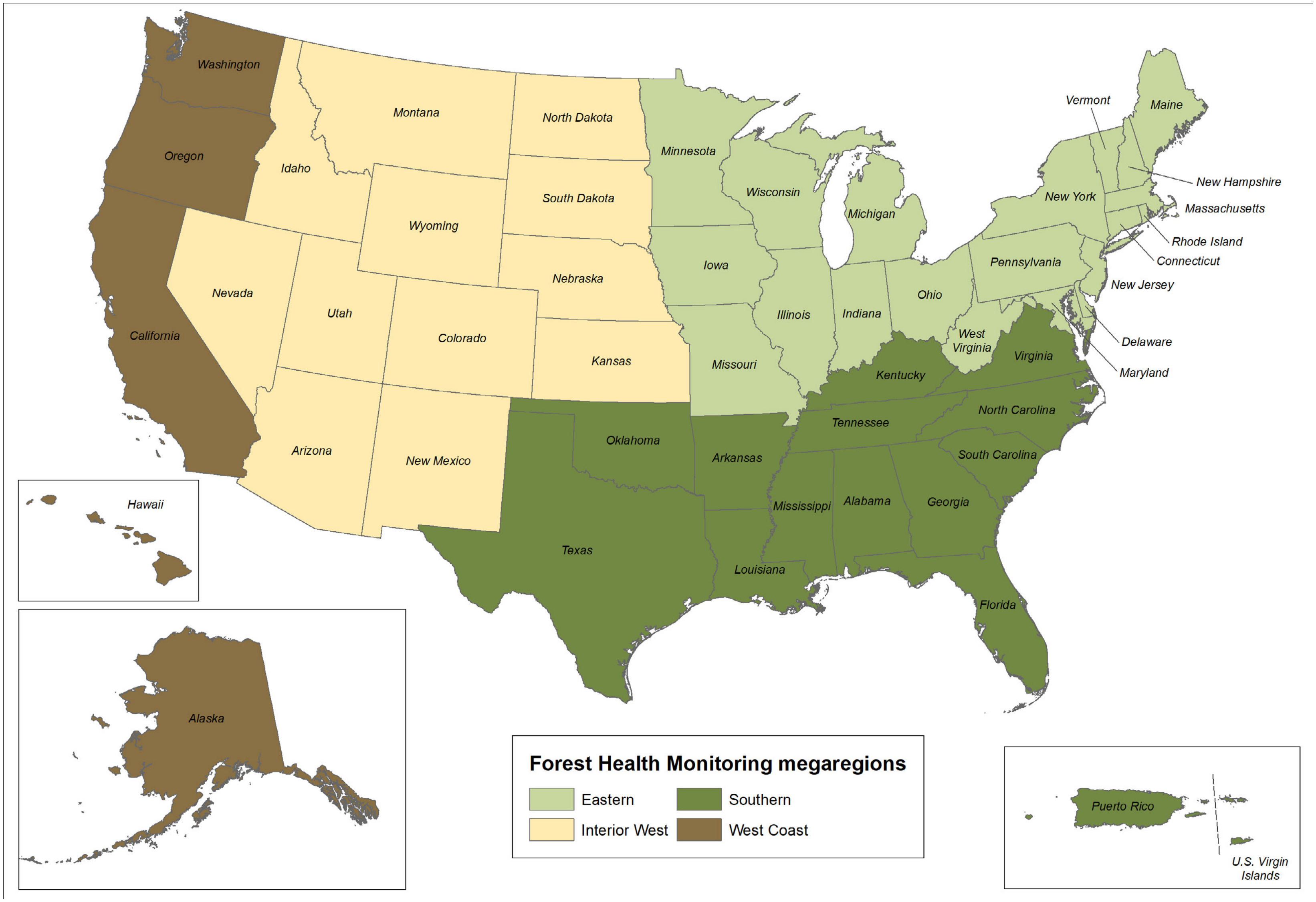


Figure 1.4—TThe four megaregions of the Forest Health Monitoring Program.

DATA SOURCES

Forest Service data sources in this edition of the FHM national report include FIA annualized Phase 2 survey data from a nationwide network of permanent plots located in nonurban forested areas that are remeasured on a 5- to 10-year cycle (Burrill and others 2021, Westfall and others 2022, Woodall and others 2010); FHP national Insect and Disease Survey forest mortality and defoliation data for 2022 (FHP 2023); tree canopy cover data generated from the 2011 National Land Cover Database (NLCD) (Homer and others 2015) through a cooperative project between the Multi-Resolution Land Characteristics Consortium and Forest Service Geospatial Technology and Applications Center (GTAC) (Coulston and others 2012); national Burned Area Boundaries dataset for 1984–2021 compiled within the Wildland Fire Management Research, Development, and Application (WFMRDA) and wildfire incident records for 2022 from Wildland Fire Interagency Geospatial Services (WFIGS) (WFIGS 2022, WFMRDA 2021); and FIA's publicly available Environmental Monitoring and Assessment Program (EMAP) hexagons (Brand and others 2000). Other sources of data include climate data from Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM Climate Group 2023); Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States data for 2022 (NASA Fire Information for Resource Management System 2023); 2019 NLCD products (Dewitz and USGS 2021); and Alaskan forest and shrub cover derived from the 2011 NLCD. For more information about the FIA Program, which is a major source of data for several FHM analyses, see box 1.1.

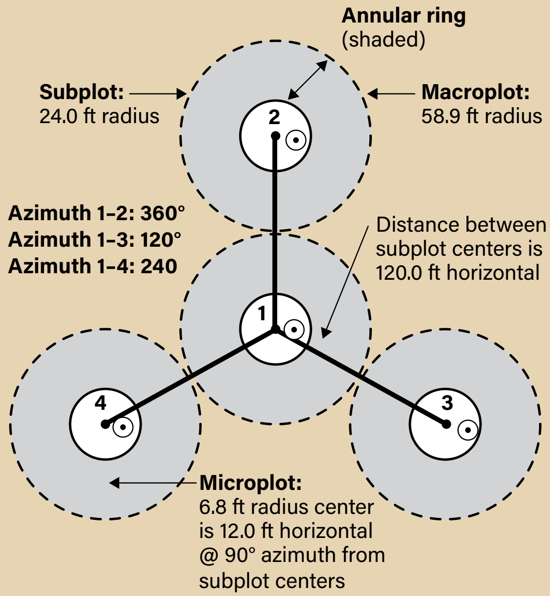
FOREST HEALTH MONITORING REPORT PRODUCTION

The FHM national report is produced annually by forest health monitoring researchers at the Eastern Forest Environmental Threat Assessment Center (EFETAC) in collaboration with North Carolina State University cooperators in the Forest Health Monitoring Research Group (https://go.ncsu.edu/foresthealth), with the support of the FHM Program. 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 https://www.forestthreats.org/about.

BOX 1.1

The Forest Inventory and Analysis (FIA) Program collects information on the topographic and other site characteristics, land use, trees, and vegetation occurring at plots on forest land and lands that are capable of being forested in all nonurban areas in the United States. The program maintains a network of more than 130,000 permanent forested ground plots across the conterminous United States, southeastern Alaska, Hawaii, Caribbean territories, and U.S.-Affiliated Pacific Islands with a sampling intensity of approximately one plot/2428 ha (one plot per 6,000 acres). FIA Phase 2 encompasses the annualized inventory measured annually on a subset of plots, with each plot surveyed every 5 to 7 years in the Eastern States and every 10 years in the Western United States (Reams and others 2005). The standard 0.067-ha plot (see figure) consists of four 7.315-m (24-foot) radius subplots (approximately 168.6 m^2 or 1/24 acre), on which field crews measure trees at least 12.7 cm (5 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 1/300 acre), on which crews measure trees smaller than 12.7 cm (5 inches) in diameter. An optional variant of the standard design includes four "macroplots," each with a radius of 17.953 m or 58.9 feet (approximately 0.1012 ha or 1/4 acre) that originates at the center of each subplot (Burrill and others 2021). Macroplots are used in highly productive sites (such as the West Cascades) in California, Oregon, and Washington.

FIA Phase 3 plots previously represented a subset of these Phase 2 plots, with 1 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 were from Phase 3 plots, including tree crown condition, lichen communities, down woody material, soil condition, and vegetation structure and diversity, whereas data on ozone bioindicator plants were 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 Forest Health Monitoring Detection Monitoring ground plot system prior to 2000[1] (Palmer and others 1991). The FIA Program recently updated its sampling techniques with flexible spatial and temporal intensities for some of these ecosystem health indicators (including down woody material, vegetation diversity and structure, and crown conditions) to improve field operation efficiency, address emerging user demands, and adjust to evolving forest health science (Castillo and Alvarez 2020). This "Phase 2 Plus Program/Ecosystem Indicator Program" (P2+) sampling scheme facilitates the collection of a national core set of indicator information on more plots for less cost than the original indicator protocols, with sampling based on a systematic subsample that can change in response to budgetary fluctuations without compromising long-term analytical capabilities. The enhanced indicator protocols collect less-detailed information on each sampled plot than on the previous Phase 3 plots, but substantially more plots are sampled, increasing the statistical power of forest health analyses and improving the reliability of estimates in important national assessments (Castillo and Alvarez 2020).



Box 1.1 figure—The Forest Inventory and Analysis plot layout. 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 (Burrill and others 2018).

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