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 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. 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 an 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 19th 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, and vegetation phenology change, 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). Visit https://www.fs.fed.us/foresthealth/publications/fhm/fhm-annual-national-reports.shtml for links to each of these reports in their entirety and for searchable lists of links to chapters included in the reports.

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.

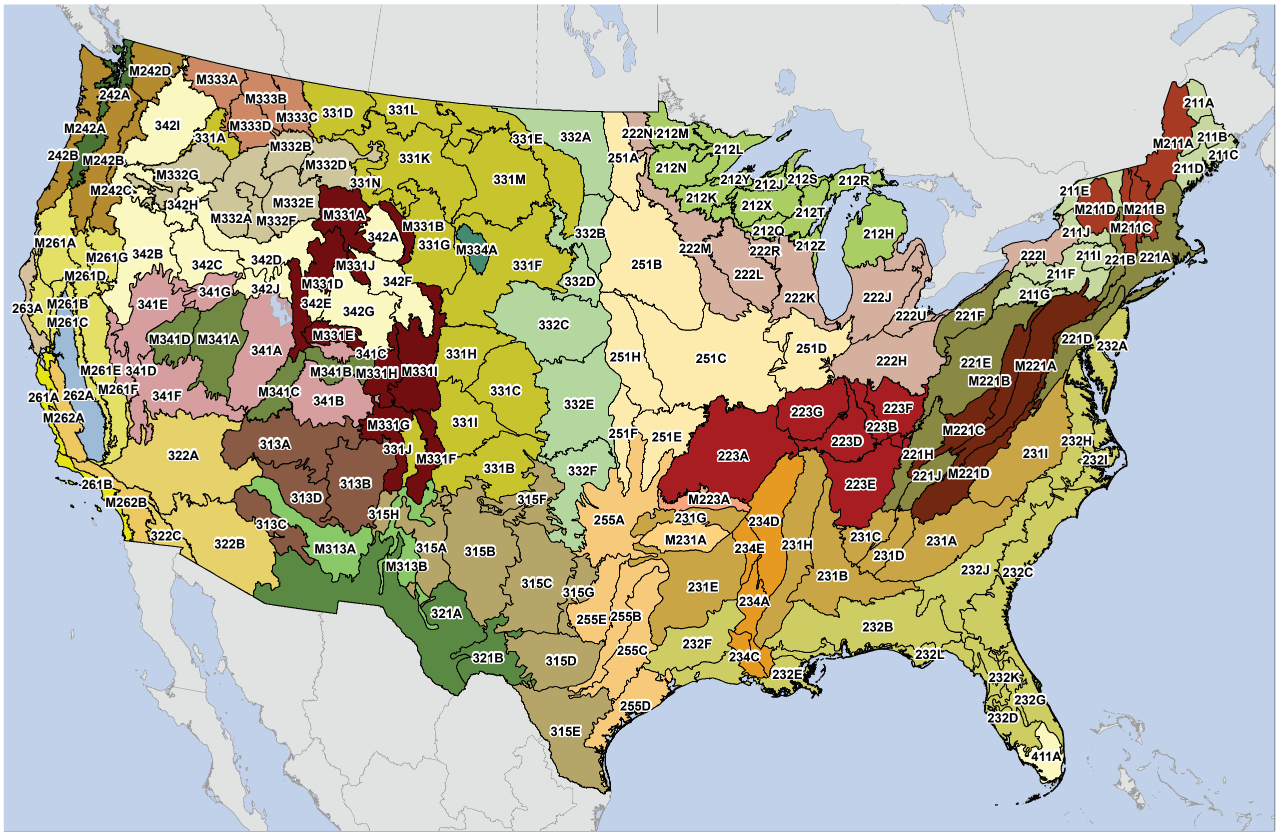
The second objective of the report is to present new techniques for analyzing forest health data as well as new applications of established techniques, often applied to longer timescales, presented in selected chapters of section 2. Examples in this report are chapters 6 and 7. Chapter 6 presents the results of analyses

of 20 years of national Insect and Disease Survey data providing a retrospective long-term analysis of insect and disease damage to forests across the United States. Chapter 7, meanwhile, describes a new measure of forest disturbance that combines the magnitude and duration of satellite-detected vegetation phenology change to isolate locations with substantive and sustained disturbance impacts across the conterminous United States.

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 2019), generally at a finer scale than that addressed by the analyses in sections 1 and 2. Each of the two 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 for the conterminous United States 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 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 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). This hierarchical system does not address either Hawaii or Puerto Rico beyond including each in a unique, single ecoregion province (Bailey 1995). Previous FHM reports have summarized forest health indicators at the island level in these jurisdictions, and/or by county council district for the Big Island of Hawai'i. A set of Hawaii ecoregions based on moisture and elevational characteristics was developed for use in this and future FHM national reports 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 fires associated with volcanic eruptions (ch. 3) (fig. 1.2, box 1.1).

(A)



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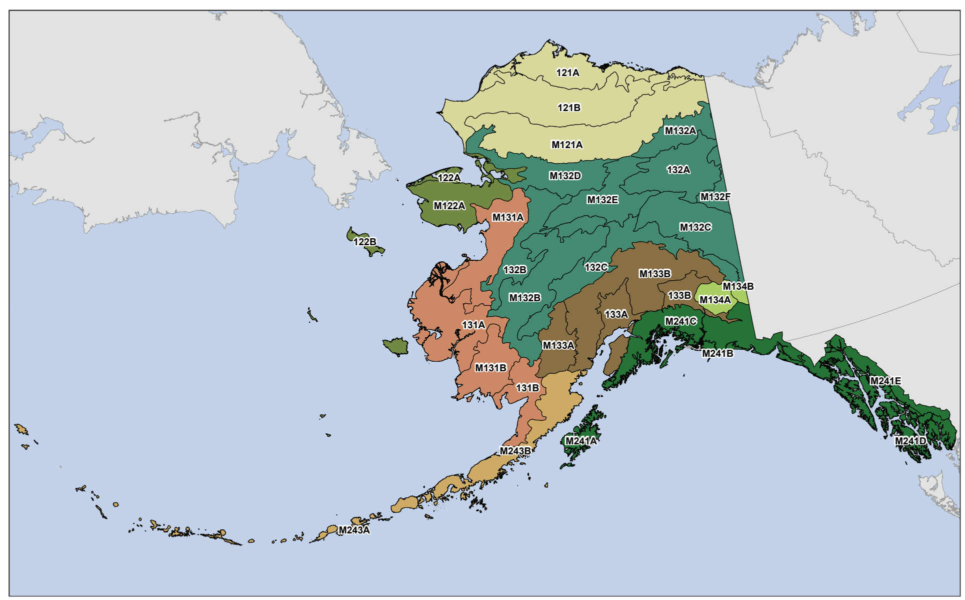

Figure 1.1—Ecoregion provinces and sections for (A) the conterminous United States (Cleland and others 2007) and (B) Alaska (Spencer and others 2002). Ecoregion sections within each ecoregion province are shown in the same color.

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

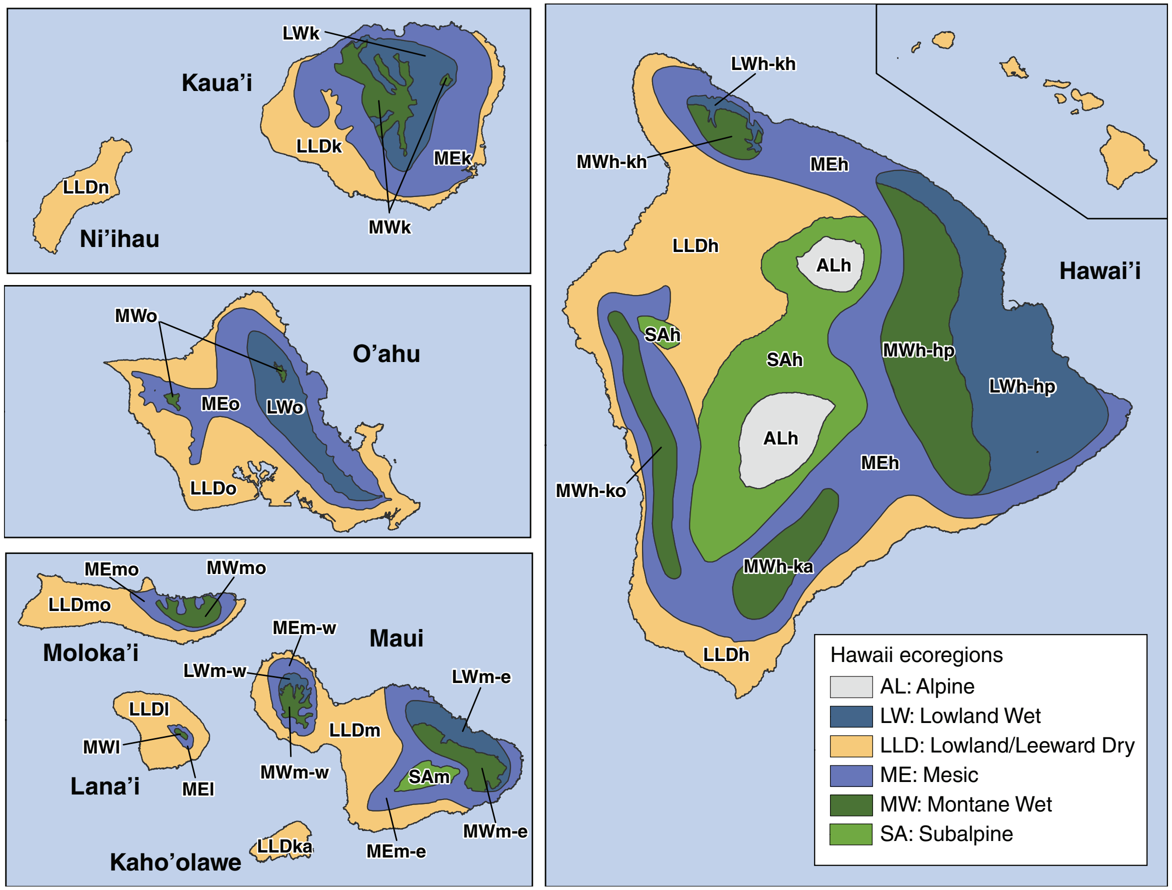

Figure 1.2—Ecoregions, and within-island ecoregion units, for Hawaii, developed based on moisture zones and elevation (see box 1.1). Within-island ecoregion units are shown in the same color by ecoregion. See the table in box 1.1 for the names of the within-island ecoregion units listed on the map.

Box 1.1

The Hawaiian archipelago encompasses a great deal of variation in several ecological factors, including climate, elevation, and natural communities, and possesses a unique flora with some of the highest levels of endemism in the world (Ziegler 2002). Monitoring assessments that aggregate and summarize data to islands within the archipelago, as done in previous Forest Health Monitoring (FHM) national reports, are not accounting for ecological variation within the islands that could affect the spatial occurrence of forest health indicators. A delineation of ecoregions within the State of Hawaii was therefore an important improvement for the FHM national reports. This delineation, described here, is based on the two environmental factors most important for grouping major natural native vegetation zones in Hawaii: moisture regime and elevation (Cuddihy 1989).

The moisture regime data are from Price and others (2007), which encompass seven moisture zones determined based on a moisture availability index (MAI), calculated as the difference between median annual precipitation (MAP) and potential evapotranspiration (PET). The moisture zones range from arid to very wet. For the delineation of Hawaii ecoregions, the seven moisture zones were combined into three: dry (Arid, Very Dry, and Moderately Dry), mesic (Seasonal Mesic and Moist Mesic), and wet (Moderately Wet and Very Wet). Dry areas are those where PET exceeds MAP (MAI <0), and the breakpoint between mesic and wet is MAI = 1661 mm (Price and others 2007).

The elevational data are polygons of 500-foot range contours for the islands of Hawai‘i, Kaua‘i, Maui, Moloka‘i, and O‘ahu, and 100-foot contours for Lāna‘i and Kaho‘olawe, derived from U.S. Geological Survey digital elevation models (State of Hawaii, Office of Planning 2019). For the delineation of Hawaiian ecoregions, four elevation zones were created: lowland (0–2,500 feet), montane (2,501–6,000 feet), subalpine (6,001–10,500 feet), and alpine (>10,500 feet). These elevational ranges correspond with broad vegetational zones (Cuddihy 1989). The original dataset did not include Ni‘ihau, but this arid island is relatively low-lying, so it was classified as lowland.

The moisture zones and elevational zones were intersected using ArcMap® (ESRI 2015). The resulting mesic lowland and mesic montane combinations were grouped into a single Mesic ecoregion, while the lowland dry and montane dry combinations were grouped into a single Lowland/Leeward Dry ecoregion. There were six final ecoregions: Lowland Wet (LW), Lowland/Leeward Dry (LLD), Mesic (ME), Montane Wet (MW), Subalpine (SA), and Alpine (AL) (fig. 1.2). The Alpine ecoregion encompasses the volcanic summits of Mauna Loa and Mauna Kea on the Big Island of Hawai‘i, while the Subalpine ecoregion occurs only on the Big Island and on Maui. The Lowland/Leeward Dry ecoregion is present on all eight major islands, while the Mesic and Montane Wet ecoregions are present on all but the two lowest-elevation islands (Kaho‘olawe and Ni‘ihau). The Lowland Wet ecoregion occurs on the four largest islands (Hawai‘i, Maui, O‘ahu, and Kaua‘i). The largest ecoregion is Lowland/Leeward Dry, which is about 551 000 ha in extent and has about 26.7 percent tree canopy cover (see table). The Montane Wet and Lowland Wet ecoregions have 94.8 percent and 93.9 percent tree canopy cover, respectively. The Mesic ecoregion has 60.9 percent canopy cover, while the percent of tree canopy cover in the Subalpine and Alpine ecoregions is extremely small to almost nonexistent.

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Forest health monitoring efforts require assessing the status of forest resources within ecoregion units on individual islands, so the six broad ecoregions were intersected with the Hawaiian Islands in ArcMap® (ESRI 2015). Different shapefiles of the same ecoregion on each island were merged into single polygons, with a few exceptions. On the Big Island, there were four separate large Montane Wet ecoregion parts (Hilo-Puna [MWh-hp], Ka‘ū [MWh-ka], Kohala-Hāmākua [MWh-kh], and Kona [MWh-ko]) and two large Lowland Wet parts (Hilo-Puna [LWh-hp] and Kohala-Hāmākua [LWh-kh]), each separated within their larger ecoregions by at least 10 km. These were kept as separate subunits because of the size of the island and the need to assess forest health indicators in different areas of the island. Maui similarly has two sets each of Mesic, Lowland Wet, and Montane wet ecoregion subunits, each at the western and eastern ends of the island. These too were kept and labeled accordingly. The result was a set of 34 ecoregion subunits (see table, fig. 1.2).

The six ecoregions and 34 ecoregion subunits for the State of Hawaii, including total area, area of forest canopy cover, and percent of total area with tree canopy cover

Ecoregion	Subunit	Area	Canopy area	Percent canopy
		ha	*ha*	
AL: Alpine	Alh: Alpine-Hawai'i	48 911.2	11.5	0.0
LW: Lowland Wet	LWh-hp: Lowland Wet-Hawai'i-Hilo-Puna	133 282.8	121 000.8	90.8
	LWh-kh: Lowland Wet-Hawai'i-Kohala-Hāmākua	5105.4	5063.8	99.2
	LWk: Lowland Wet-Kaua'i	27 192.0	27 166.6	99.9
	LWm-e: Lowland Wet-Maui-East	19 239.9	18 977.0	98.6
	LWm-w: Lowland Wet-Maui-West	3355.2	3343.7	99.7
	LWo: Lowland Wet-O'ahu	25 085.2	24 759.7	98.7
	All subunits	213 260.7	200 311.6	93.9
LLD: Lowland/Leeward Dry	LLDh: Lowland/Leeward Dry-Hawai'i	254 722.5	28 740.4	11.3
	LLDka: Lowland/Leeward Dry-Kaho'olawe	11 352.2	342.1	3.0
	LLDk: Lowland/Leeward Dry-Kaua'i	36 877.7	22 237.6	60.3
	LLDl: Lowland/Leeward Dry-Lāna'i	33 593.8	4963.7	14.8
	LLDm: Lowland/Leeward Dry-Maui	76 990.3	21 795.3	28.3

continued

(continued) The six ecoregions and 34 ecoregion subunits for the State of Hawaii, including total area, area of forest canopy cover, and percent of total area with tree canopy cover

Ecoregion	Subunit	Area	Canopy area	Percent canopy
		ha	*ha*	
	LLDmo: Lowland/Leeward Dry-Moloka'i	45 596.8	11 610.4	25.5
	LLDn: Lowland/Leeward Dry-Ni'ihau	18 719.3	14 058.5	75.1
	LLDo: Lowland/Leeward Dry-O'ahu	73 476.6	43 520.2	59.2
	All subunits	551 329.2	147 268.2	26.7
ME: Mesic	MEh: Mesic-Hawai'i	286 566.1	135 893.5	47.4
	MEk: Mesic-Kaua'i	64 682.6	56 249.4	87.0
	MEl: Mesic-Lāna'i	2117.0	1646.3	77.8
	MEm-e: Mesic-Maui-East	44 143.3	24 745.6	56.1
	MEm-w: Mesic-Maui-West	13 373.4	12 142.7	90.8
	MEmo: Mesic-Moloka'i	12 407.5	11 407.3	91.9
	MEo: Mesic-O'ahu	55 141.8	49 492.9	89.8
	All subunits	478 431.7	291 577.7	60.9
MW: Montane Wet	MWh-hp: Montane Wet-Hawai'i-Hilo-Puna	96 224.2	90 116.8	93.7
	MWh-ka: Montane Wet-Hawai'i-Ka'	30 543.8	28 738.9	94.1
	MWh-kh: Montane Wet-Hawai'i-Kohala-Hāmākua	11 971.9	11 527.8	96.3
	MWh-ko: Montane Wet-Hawai'i-Kona	29 949.6	27 133.7	90.6
	MWk: Montane Wet-Kaua'i	14 759.4	14 759.4	100.0
	MWl: Montane Wet-Lāna'i	490.6	462.4	94.3
	MWm-e: Montane Wet-Maui-East	16 953.8	16 940.7	99.9
	MWm-w: Montane Wet-Maui-West	5724.8	5718.1	99.9
	MWmo: Montane Wet-Moloka'i	9212.8	9124.5	99.0
	MWo: Montane Wet-O'ahu	996.8	996.8	100.0
	All subunits	216 827.6	205 519.0	94.8
SA: Subalpine	SAh: Subalpine-Hawai'i	145 342.8	6202.2	4.3
	SAm: Subalpine-Maui	8405.7	65.4	0.8
	All subunits	153 748.5	6267.5	4.1

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 2019). 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 four major components (fig. 1.3):

- 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)

- 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)

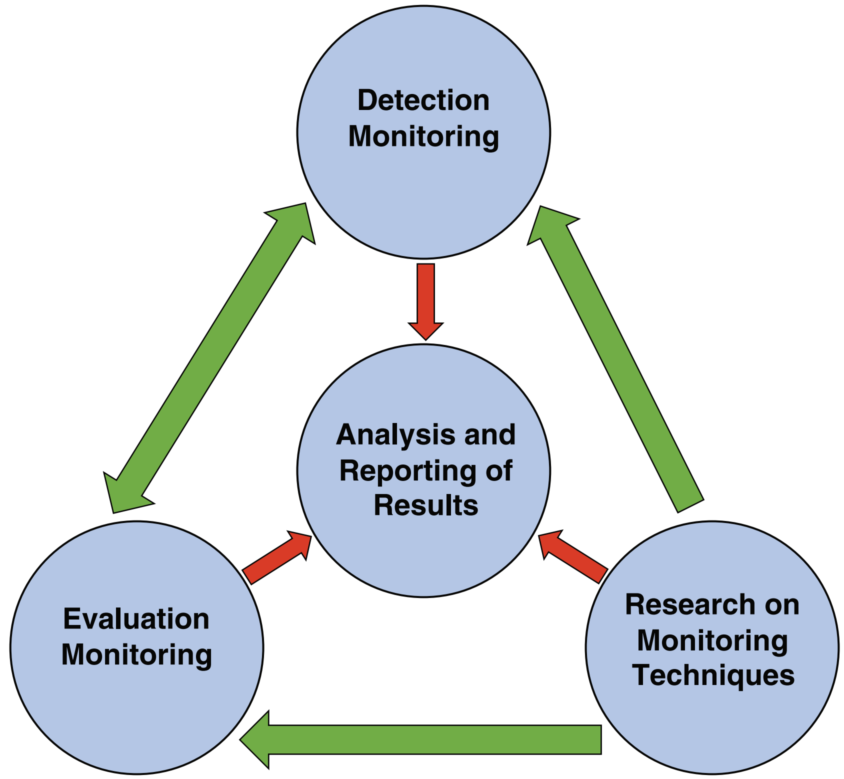


Figure 1.3—The design of the Forest Health Monitoring Program (FHM 2003).

- 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 (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 website at https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. 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 (see https://www.fs.fed.us/foresthealth/publications/fhm/fhm-publications.shtml). 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; 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, 2018; Jo and others 2018; Oswalt and others 2015; Riitters and others 2018a, 2018b); assessments of forest risk or tree species vulnerability to exotic invasive forest insects and diseases (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 landcover and forest fragmentation (Guo and others 2018; Riitters 2011; Riitters and Costanza 2018; 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 (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 website at https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/. Among other resources,

this website includes links to all past national forest health reports (https://www.fs.fed.us/foresthealth/publications/fhm/fhm-annual-national-reports.shtml), information about funded EM projects (https://www.fs.fed.us/foresthealth/fhm/em), and annual State Forest Health Highlights reports (https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml).

DATA SOURCES

Forest Service data sources in this edition of the FHM national report include FIA annualized Phase 2 survey data (Bechtold and Patterson 2005, Burrill and others 2018, Woodall and others 2010); FHP national Insect and Disease Survey forest mortality and defoliation data for 2018 (FHP 2019); Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States data for 2018 (USDA Forest Service 2019); 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); and FIA's publicly available Environmental Monitoring and Assessment Program (EMAP) hexagons (Brand and others 2000). Other sources of data include Parameter-elevation Regression on Independent Slopes Model (PRISM) climate mapping system data (PRISM Climate Group 2019), twice-daily MODIS Normalized Difference Vegetation Index (NDVI) data from the Terra and Aqua satellites provided by NASA's Global Inventory Monitoring and Modeling Studies (GIMMS) Global Agricultural Monitoring (GLAM) system, 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 1.2.

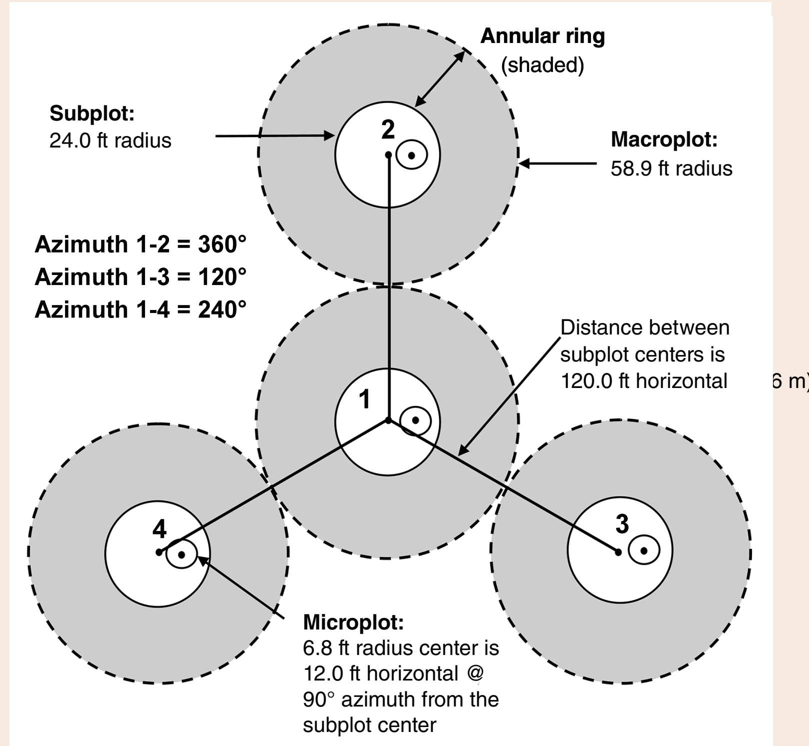
FHM REPORT PRODUCTION

This FHM national report, the 19th 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 https://www.forestthreats.org/about.

Box 1.2

The Forest Inventory and Analysis (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, Hawaii, and southeastern Alaska, with a sampling intensity of approximately one plot/2428 ha (one plot per 6,000 acres). 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 (see figure) consists of four 7.315-m (24-foot) radius subplots (approximately 168.6 m^2 or 1/24th 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 1/300th acre), on which crews measure trees smaller than 12.7 cm (5 inches) in diameter. A core-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 2018).

Forest Inventory and Analysis 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 are 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 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 (Burrill and others 2018).

[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, Forest Health Monitoring program. 473 p. On file with: Forest Health Monitoring program, 3041 Cornwallis Rd., Research Triangle Park, NC 27709.

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