

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, 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 not (Kolb and others 1994). Although this definition may be appropriate when a single, unambiguous

CHAPTER 1.

Introduction

KEVIN M. POTTER

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 15th in an annual series sponsored by the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, 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 fragmentation, 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).

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, as noted above, is to present new techniques for analyzing forest health data as well as new applications of established techniques, presented in selected chapters of section 2. The example in this report is chapter 6, which assesses long-term trends in fragmentation using national land cover data.

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 2014), generally at a finer scale than that addressed by the analyses in sections 1 and 2. Each of the 11 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 USDA 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 extent 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 2014). 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).
- 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).

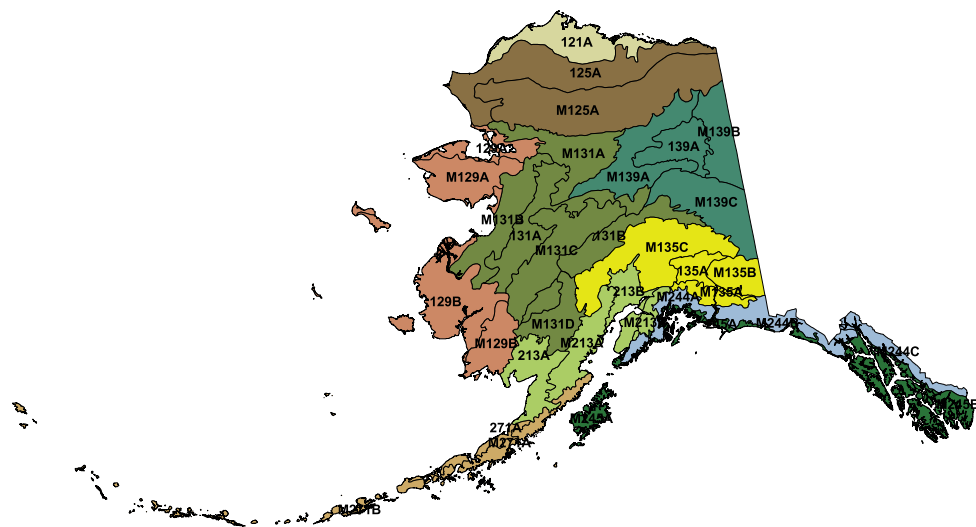
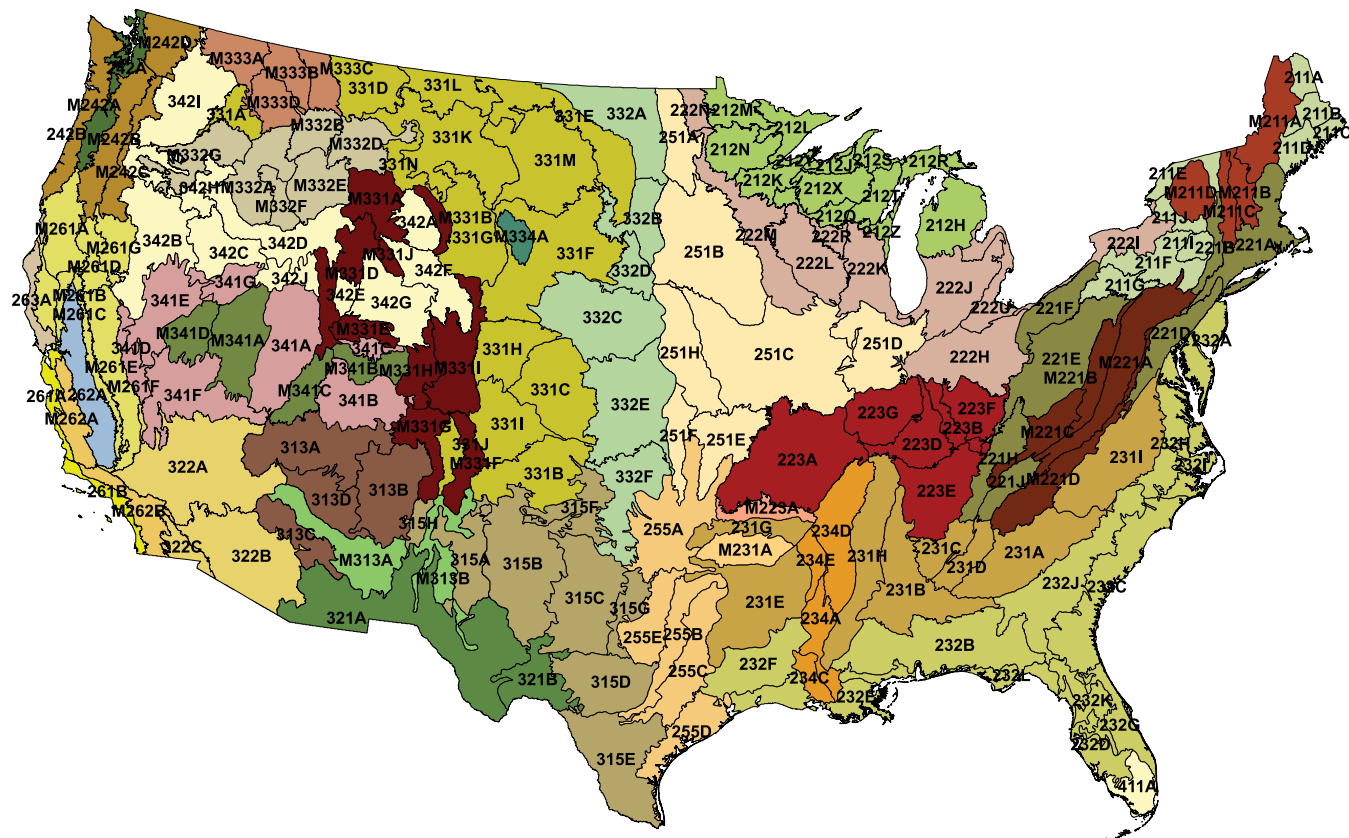
















































Figure 1.1—Ecoregion provinces and sections for the conterminous United States (Cleland and others 2007) and Alaska (Nowacki and Brock 1995). Ecoregion sections within each ecoregion province are shown in the same color. Note: no equivalent ecoregion treatment exists for Hawai'i.



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)

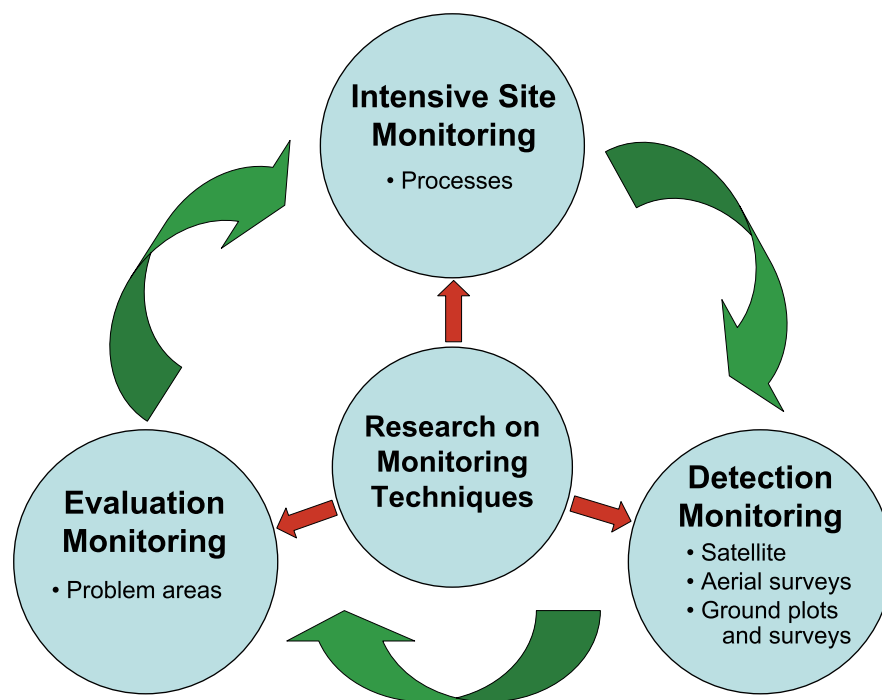


Figure 1.2—The design of the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture (FHM 2003). A fifth component, Analysis and Reporting of Results, draws from the four FHM components shown here and provides information to help support land management policies and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

- 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 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 (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); 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); vegetation diversity and structure (Schulz and Gray 2013, Schulz and others 2009); forest lichen indicators (Jovan and others 2012, Root and others 2014); downed woody materials in forests (Woodall and others 2012, 2013); ozone monitoring (Rose and Coulston 2009); patterns of nonnative invasive plant occurrence (Oswalt and others 2015); assessments of alien-invasive forest insect and disease risk (Koch and others 2011, 2014; Krist and others 2014, Yemshanov and others 2014); spatial patterns of land cover (Riitters 2011, Riitters and others 2012, Riitters and Wickham 2012); broad-scale assessments of forest biodiversity (Potter and Koch 2014; Potter and Woodall 2012, 2014); predictions of climate change effects on forest tree species (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.

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 2014 (FHP 2014); Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States database for 2014 (USDA Forest Service 2015); and forest cover data developed from MODIS satellite imagery by the U.S. Forest Service Remote Sensing Applications Center. Other sources of data include Parameter-elevation Regression on Independent Slopes (PRISM) climate mapping system data (PRISM Climate Group 2015) and 2001, 2006, and 2011 National Land Cover Database land cover maps (U.S. Geological Survey 2014a, 2014b, 2014c).

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 125,000 permanent forested ground plots across the conterminous United States and southeastern Alaska, with a sampling intensity of approximately one plot per 2 428 ha. FIA 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 radius subplots (approximately 168.6 m² or 1/24th acre), on which field crews measure trees at least 12.7 cm in diameter. Within each of these subplots is nested a 2.073-m radius microplot (approximately 13.48 m² or 1/300th acre), on which crews measure trees smaller than 12.7 cm 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 represent 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 are collected from phase 3 plots, including tree crown condition, lichen communities, down

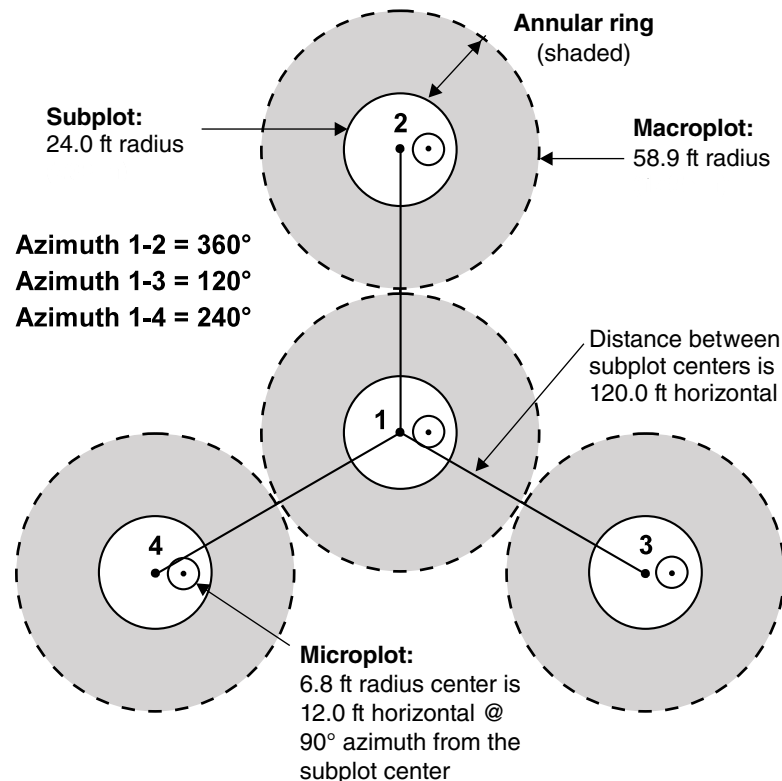


Figure 1.3—The Forest Inventory and Analysis mapped plot design. Subplot 1 is the center of the cluster with subplots 2, 3, and 4 located 120 feet away at azimuths of 360°, 120°, and 240°, respectively (Woudenberg and others 2010).

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 FHM Detection Monitoring ground plot system prior to 2000¹ (Palmer and others 1991).

FHM REPORT PRODUCTION

This FHM national report, the 15th 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.

LITERATURE CITED

Ambrose, M.J.; Conkling, B.L., eds. 2007. Forest Health Monitoring 2005 national technical report. Gen. Tech. Rep. SRS-104. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 76 p.

Ambrose, M.J.; Conkling, B.L., eds. 2009. Forest Health Monitoring 2006 national technical report. Gen. Tech. Rep. SRS-117. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 118 p.

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.

Bailey, R.G. 1995. Descriptions of the ecoregions of the United States. 2d ed. Misc. Publ. No. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 108 p. [Map scale 1:7,500,000].

Bechtold, W.A.; Patterson, P.L., eds. 2005. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p.

Bigsby, K.M.; Ambrose, M.J.; Tobin, P.C.; Sills, E.O. 2014. The cost of gypsy moth sex in the city. *Urban Forestry & Urban Greening*. 13(3): 459–468.

Chastain, R.A.; Fisk, H.; Ellenwood, J.R. [and others]. 2015. Near-real time delivery of MODIS-based information on forest disturbances. In: Lippitt, C.D.; Stow, D.A.; Coulter, L.L., eds. *Time sensitive remote sensing*. New York, NY: Springer: 147–164.

Cleland, D.T.; Avers, P.E.; McNab, W.H. [and others]. 1997. National hierarchical framework of ecological units. In: Boyce, M. S.; Haney, A., eds. *Ecosystem management applications for sustainable forest and wildlife resources*. New Haven, CT: Yale University Press: 181–200.

Cleland, D.T.; Freeouf, J. A.; Keys, J.E.; [and others]. 2007. Ecological subregions: sections and subsections for the conterminous United States. In: Sloan, A.M., tech. ed. Washington, DC: U.S. Department of Agriculture, Forest Service. Gen. Tech. Rep. WO-76D. Map, presentation scale 1:3,500,000; colored. Also on CD-ROM as a GIS coverage in ArcINFO format.

Conkling, B.L., ed. 2011. Forest Health Monitoring 2007 national technical report. Gen. Tech. Rep. SRS-147. Asheville, North Carolina: U.S. Department of Agriculture, Forest Service, Southern Research Station. 159 p.

Conkling, B.L.; J.W. Coulston; M.J. Ambrose, eds. 2005. Forest Health Monitoring 2001 national technical report. Gen. Tech. Rep. SRS-81. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 204 p.

Costanza, R. 1992. Toward an operational definition of ecosystem health. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. *Ecosystem health: new goals for environmental management*. Washington, DC: Island Press: 239–256.

- Coulston, J.W.; Riitters, K.H.; Conkling, B.L., eds. 2005a. Forest Health Monitoring 2002 national technical report. Gen. Tech. Rep. SRS-84. Asheville, North Carolina: U.S. Department of Agriculture, Forest Service, Southern Research Station. 97 p.
- Coulston, J.W.; Ambrose, M.J.; Riitters, K.H. [and others], eds. 2005b. Forest Health Monitoring 2003 national technical report. Gen. Tech. Rep. SRS-85. Asheville, North Carolina: U.S. Department of Agriculture Forest Service, Southern Research Station. 97 p.
- Coulston, J.W.; Ambrose, M.J.; Riitters, K.H.; Conkling, B.L., eds. 2005c. Forest Health Monitoring 2004 national technical report. Gen. Tech. Rep. SRS-90. Asheville, North Carolina: U.S. Department of Agriculture, Forest Service, Southern Research Station. 81 p.
- Cumming, A.B.; Nowak, D.J.; Twardus, D.B. [and others]. 2007. Urban forests of Wisconsin: pilot monitoring project 2002. NA-FR-05-07. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 33 p. Available online: Low resolution: http://www.na.fs.fed.us/pubs/fhm/pilot/pilot_study_wisconsin_02_lr.pdf. High resolution: http://www.na.fs.fed.us/pubs/fhm/pilot/pilot_study_wisconsin2_02_hr.pdf. [Date accessed: October 19, 2007].
- Cumming, A.B.; Twardus, D.B.; Smith, W.D. 2006. National Forest Health Monitoring Program, Maryland and Massachusetts street tree monitoring pilot projects. NA-FR-01-06. Newtown Square, PA: U.S. Department of Agriculture, Forest Service Northeastern Area, State and Private Forestry. 23 p.
- Edmonds, R.L.; Agee, J.K.; Gara, R.I. 2011. Forest health and protection. Long Grove, IL: Waveland Press, Inc. 667 p.
- Forest Health Monitoring (FHM). 2003. Forest Health Monitoring: a national strategic plan. http://fhm.fs.fed.us/annc/strategic_plan03.pdf. 7 p. [Date accessed: June 28, 2013].
- Forest Health Monitoring (FHM). 2014. Program description. Forest Health Monitoring Fact Sheet Series. <http://www.fhm.fs.fed.us/fact/>. [Date accessed: July 29, 2014].
- Forest Health Protection (FHP). 2014. Insect and Disease Detection Survey Database (IDS) [database on the Internet]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. Available: <http://foresthealth.fs.usda.gov/ids>. [Date accessed: July 20, 2015].
- Harris, J.L., comp.; Region 2 Forest Health Protection staff. 2011. Forest health conditions, 2009–2010: Rocky Mountain Region (R2). R2-11-RO-31. Golden, CO: U.S. Department of Agriculture, Forest Service, Renewable Resources, Forest Health Protection, Rocky Mountain Region. 108 p.
- Jovan, S.; Riddell, J.; Padgett, P.E.; Nash, T.H., III. 2012. Eutrophic lichens respond to multiple forms of N: implications for critical levels and critical loads research. *Ecological Applications*. 22(7): 1910–1922.
- Koch, F.H.; Yemshanov, D.; Colunga-Garcia, M. [and others]. 2011. Potential establishment of alien-invasive forest insect species in the United States: where and how many? *Biological Invasions*. 13: 969–985.
- Koch, F.H.; Yemshanov, D.; Haack, R.A.; Magarey, R.D. 2014. Using a network model to assess risk of forest pest spread via recreational travel. *PLoS ONE* 9(7): e102105.
- Kolb, T.E.; Wagner, M.R.; Covington, W.W. 1994. Concepts of forest health: utilitarian and ecosystem perspectives. *Journal of Forestry*. 92: 10–15.
- Krist, F.J., Jr.; Ellenwood, J.R.; Woods, M.E. [and others]. 2014. 2012–2027 national insect and disease forest risk assessment. FHTET-14-01. U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 199 p. http://www.fs.fed.us/foresthealth/technology/pdfs/2012_RiskMap_Report_web.pdf. [Date accessed: July 24, 2014].
- Lake, M.; Marshall, P.; Mielke, M. [and others]. 2006. National Forest Health Monitoring Program monitoring urban forests in Indiana: pilot study 2002, part 1. Analysis of field methods and data collection. Gen. Tech Rep. NA-FR-06-06. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area. Available at: <http://www.fhm.fs.fed.us/pubs/ufhm/indianaforests02/indianaforests02.html>. [Date accessed: November 6, 2007].

- Montréal Process Working Group. 1995. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests. <http://www.montrealprocess.org/>. [Date accessed: March 4, 2015].
- Morin, R.S.; Liebhold, A.M.; Gottschalk, K.W. [and others]. 2006. Analysis of Forest Health Monitoring surveys on the Allegheny National Forest (1998–2001). Gen. Tech. Rep. NE-339. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 102 p. http://www.fs.fed.us/ne/newtown_square/publications. [Date accessed: November 6, 2007].
- Morin, R.S.; Randolph, K.C.; Steinman, J. 2015. Mortality rates associated with crown health for eastern forest tree species. *Environmental Monitoring and Assessment*. 187(3): 87.
- Nowacki, G.; Brock, T. 1995. Ecoregions and subregions of Alaska [EcoMap]. Version 2.0. Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Region. [Map, presentation scale 1:5,000,000; colored].
- O'Neill, K.P.; Amacher, M.C.; Perry, C.H. 2005. Soils as an indicator of forest health: a guide to the collection, analysis, and interpretation of soil indicator data in the Forest Inventory and Analysis Program. Gen. Tech. Rep. NC-258. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 53 p.
- Oswalt, C.M.; Fei, S.; Guo, G. [and others]. 2015. A subcontinental view of forest plant invasions. *NeoBiota*. 24: 49–54.
- Palmer, C.J.; Riitters, K.H.; Strickland, T. [and others]. 1991. Monitoring and research strategy for forests—Environmental Monitoring and Assessment Program (EMAP). EPA/600/4-91/012. Washington, DC: U.S. Environmental Protection Agency. 189 p.
- Potter, K.M.; Conkling, B.L., eds. 2012a. Forest Health Monitoring 2008 national technical report. Gen. Tech. Rep. SRS-158. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 179 p.
- Potter, K.M.; Conkling, B.L., eds. 2012b. Forest Health Monitoring 2009 national technical report. Gen. Tech. Rep. SRS-167. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 252 p.
- Potter, K.M.; Conkling, B.L., eds. 2013a. Forest Health Monitoring: national status, trends, and analysis 2010. Gen. Tech. Rep. SRS-176. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 162 p.
- Potter, K.M.; Conkling, B.L., eds. 2013b. Forest Health Monitoring: national status, trends, and analysis 2011. Gen. Tech. Rep. SRS-185. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 149 p.
- Potter, K.M.; Conkling, B.L., eds. 2014. Forest Health Monitoring: national status, trends, and analysis 2012. Gen. Tech. Rep. SRS-198. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 192 p.
- Potter, K.M.; Conkling, B.L., eds. 2015a. Forest Health Monitoring: national status, trends, and analysis 2013. Gen. Tech. Rep. SRS-207. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 199 p.
- Potter, K.M.; Conkling, B.L., eds. 2015b. Forest Health Monitoring: national status, trends, and analysis 2014. Gen. Tech. Rep. SRS-209. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 190 p.
- Potter, K.M.; Hargrove, W.W. 2013. Quantitative metrics for assessing predicted climate change pressure on North American tree species. *Mathematical and Computational Forestry and Natural Resources Sciences*. 5(2): 151–169.
- Potter, K.M.; Koch, F.H. 2014. Phylogenetic community structure of forests across the conterminous United States: regional ecological patterns and forest health implications. *Forest Science*. 60(5): 851–861.
- Potter, K.M.; Woodall, C.W. 2012. Trends over time in tree and seedling phylogenetic diversity indicate regional differences in forest biodiversity change. *Ecological Applications*. 22(2): 517–531.
- Potter, K.M.; Woodall, C.W. 2014. Does biodiversity make a difference? Relationships between species richness, evolutionary diversity, and aboveground live tree biomass across U.S. forests. *Forest Ecology and Management*. 321: 117–129.

- PRISM Climate Group. 2015. 2.5-arcmin (4 km) gridded monthly climate data. <http://www.prism.oregonstate.edu>. [Date accessed: June 23, 2015].
- Raffa, K.F.; Aukema, B.; Bentz, B.J. [and others]. 2009. A literal use of “forest health” safeguards against misuse and misapplication. *Journal of Forestry*. 107: 276–277.
- Randolph, K.C. 2010a. Equations relating compacted and uncompacted live crown ratio for common tree species in the South. *Southern Journal of Applied Forestry*. 34(3): 118–123.
- Randolph, K.C. 2010b. Comparison of the arithmetic and geometric means in estimating crown diameter and crown cross-sectional area. *Southern Journal of Applied Forestry*. 34(4): 186–189.
- Randolph, K.C. 2013. Development history and bibliography of the U.S. Forest Service crown-condition indicator for forest health monitoring. *Environmental Monitoring and Assessment*. 185(6): 4977–4993.
- Randolph, K.C.; Moser, W.K. 2009. Tree crown condition in Missouri, 2000–2003. Gen. Tech. Rep. SRS-113. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 11 p.
- Reams, G.A.; Smith, W. D.; Hansen, M.H. [and others]. 2005. The Forest Inventory and Analysis sampling frame. In: Bechtold, W.A.; Patterson, P.L., ed. *The enhanced Forest Inventory and Analysis Program—national sampling design and estimation procedures*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 11–26.
- Riitters, K.H. 2011. Spatial patterns of land cover in the United States: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-136. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 64 p.
- Riitters, K.H.; Coulston, J.W.; Wickham, J.D. 2012. Fragmentation of forest communities in the Eastern United States. *Forest Ecology and Management*. 263: 85–93.
- Riitters, K.H.; Tkacz, B. 2004. The U.S. Forest Health Monitoring Program. In: Wiersma, G.B., ed. *Environmental monitoring*. Boca Raton, FL: CRC Press: 669–683.
- Riitters, K.H.; Wickham, J.D. 2012. Decline of forest interior conditions in the conterminous United States. *Scientific Reports*. 2: 653. 4 p. DOI: 10.1038.srep00653. [Published online: September 13, 2012].
- Root, H.T.; McCune, B.; Jovan, S. 2014. Lichen communities and species indicate climate thresholds in southeast and south-central Alaska, USA. *The Bryologist*. 117(3): 241–252.
- Rose, A.K.; Coulston, J.W. 2009. Ozone injury across the Southern United States, 2002–06. Gen. Tech. Rep. SRS-118. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 25 p.
- Schomaker, M.E.; Zarnoch, S.J.; Bechtold, W.A. [and others]. 2007. Crown-condition classification: a guide to data collection and analysis. Gen. Tech. Rep. SRS-102. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 78 p.
- Schulz, B.K.; Bechtold, W.A.; Zarnoch, S.J. 2009. Sampling and estimation procedures for the vegetation diversity and structure indicator. Gen. Tech. Rep. PNW-GTR-781. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 53 p.
- Schulz, B.K.; Gray, A.N. 2013. The new flora of Northeastern USA: quantifying introduced plant species occupancy in forest ecosystems. *Environmental Monitoring and Assessment*. 185: 3931–3957.
- Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-78. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Washington Office. 336 p.
- Smith, W.D.; Conkling, B.L. 2004. Analyzing forest health data. Gen. Tech. Rep. SRS-077. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 33 p. http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs077.pdf. [Date accessed: November 6, 2007].
- Steinman, J. 2004. Forest Health Monitoring in the Northeastern United States: disturbances and conditions during 1993–2002. NA-Technical Paper 01-04. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 46 p. http://fhm.fs.fed.us/pubs/tp/dist_cond/dc.shtml. [Date accessed: December 8, 2009].

- Teale, S.A.; Castello, J.D. 2011. The past as key to the future: A new perspective on forest health. In: Castello, J.D.; Teale, S.A., eds. *Forest health: an integrated perspective*. New York: Cambridge University Press: 3–16.
- U.S. Department of Agriculture (USDA) Forest Service. 2004. National report on sustainable forests—2003. FS-766. Washington, DC: U.S. Department of Agriculture, Forest Service. 139 p.
- U.S. Department of Agriculture (USDA) Forest Service. 2011. National report on sustainable forests—2010. Report FS-979. Washington, DC: U.S. Department of Agriculture, Forest Service. 134 p.
- U.S. Department of Agriculture (USDA) Forest Service. 2015. MODIS active fire mapping program: fire detection GIS data. <http://activefiremaps.fs.fed.us/gisdata.php>. [Date accessed: February 13, 2015].
- U.S. Geological Survey. 2014a. NLCD 2001 Land Cover (2011 edition). Sioux Falls, SD: U.S. Geological Survey.
- U.S. Geological Survey. 2014b. NLCD 2006 Land Cover (2011 edition). Sioux Falls, SD: U.S. Geological Survey.
- U.S. Geological Survey. 2014c. NLCD 2011 Land Cover (2011 edition). Sioux Falls, SD: U.S. Geological Survey.
- Woodall, C.W.; Conkling, B.L.; Amacher, M.C. [and others]. 2010. The Forest Inventory and Analysis database version 4.0: database description and users manual for phase 3. Gen. Tech. Rep. NRS-61. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 180 p.
- Woodall, C.W.; Amacher, M.C.; Bechtold, W.A. [and others]. 2011. Status and future of the forest health indicators program of the USA. *Environmental Monitoring and Assessment*. 177:419–436.
- Woodall, C.W.; Walters, B.F.; Westfall, J.A. 2012. Tracking downed dead wood in forests over time: development of a piece matching algorithm for line intercept sampling. *Forest Ecology and Management*. 277: 196–204.
- Woodall, C.W.; Walters, B.F.; Oswalt, S.N. [and others]. 2013. Biomass and carbon attributes of downed woody materials in forests of the United States. *Forest Ecology and Management*. 305: 48–59.
- Woudenberg, S.W.; Conkling, B.L.; O’Connell, B.M. [and others]. 2010. The Forest Inventory and Analysis database: database description and users manual version 4.0 for phase 2. Gen. Tech. Rep. RMRS-GTR-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 336 p.
- Yemshanov, D.; Koch, F.H.; Lu, B. [and others]. 2014. There is no silver bullet: the value of diversification in planning invasive species surveillance. *Ecological Economics*. 104: 61–72.