

**F**orests 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 substantial ecological and socioeconomic importance. Both their ecological integrity and their continued capacity to provide goods and services are of concern 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.

Assessing and monitoring the health of these forests are critical and challenging tasks. This is 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, uses as a forest sustainability assessment framework (USDA Forest Service 2004, 2011a). While there is no universally accepted definition of forest health, 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 (Kolb and others 1994, Raffa and others 2009). This report, the 11<sup>th</sup> in an annual series produced 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 such indicators of forest health. These indicators encompass forest insect and disease activity, wildland fire occurrence, drought, tree mortality,

forest fragmentation, introduced plant species, lichen diversity, and ozone injury.

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, allowing for the detection of trends over time and changes from one year to the next. 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, presented in selected chapters of section 2. Examples in this report are chapter 6, which demonstrates an approach to improve national assessments of forest fragmentation by incorporating information about the specific forest types that are

# CHAPTER 1.

## Introduction

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fragmented; and chapter 7, which uses FIA phase 3 data to examine factors important in determining the regional distribution of invasive plants in the upper Midwest and in the Northeastern 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 2011), generally at a finer scale than that addressed by the analyses in sections 1 and 2. Each chapter in section 3 contains an overview of an EM project, key results, and contacts for more information.

When appropriate throughout this report, authors use Bailey's revised ecoregions (Cleland and others 2007) as a common ecologically based spatial framework for their forest health assessments (fig. 1.1). Specifically, when the spatial scale of the data and the expectation of an identifiable pattern in the data are appropriate, authors use ecoregion sections or provinces as assessment units for their analyses. In Bailey's hierarchical system, the two broadest ecoregion scales, domains and divisions, are based on large ecological climate zones, while each division is broken into provinces based on vegetation 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).

#### 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)



## DATA SOURCES

Forest Service data sources included in this report are FIA annualized phase 2 and phase 3 survey data and ozone bioindicator plant data (Bechtold and Patterson 2005), FHP insect and disease detection survey forest mortality and defoliation data for 2010, Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States database for 2010 (USDA Forest Service 2011b), and forest cover data developed from MODIS satellite imagery by the U.S. Forest Service Remote Sensing Applications Center. Other sources of data are Parameter-Elevation Regression on Independent Slopes (PRISM) climate mapping system data (PRISM Group 2010) and the 2001 National Land Cover Database (NLCD) map (Homer and others 2007).

A major source of data for FHM analyses has been the FIA program, which collects forest inventory information across all forest land ownerships in the United States. FIA 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 regions surveyed once every 10 years (Reams and others 2005). The standard 0.067-ha plot (fig. 1.2) consists of four 7.315-m radius subplots (approximately 168.6 m<sup>2</sup> or 1/24 acre), on which field crews measure trees at

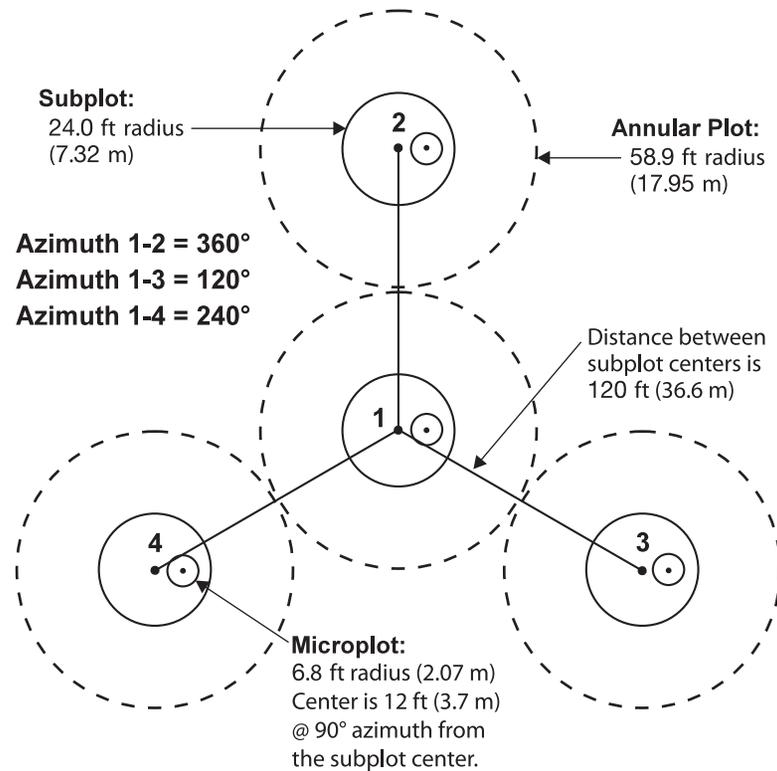


Figure 1.2—The Forest Inventory and Analysis mapped plot design. Subplot 1 is the center of the cluster with subplots 2, 3, and 4 located 120 feet away at azimuths of 360°, 120°, and 240°, respectively (Woudenberg and others 2010).

least 12.7 cm in diameter. Within each of these subplots is nested a 2.073-m radius microplot (approximately 13.48 m<sup>2</sup> 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 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 woody material, soil condition, and vegetation structure and diversity, while 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 2000<sup>1</sup> (Palmer and others 1991).

## THE FOREST HEALTH MONITORING PROGRAM

The national FHM program is designed to determine the status, changes, and trends in indicators of forest condition on an annual basis, and covers all forested lands through a partnership encompassing the Forest Service, State foresters, and other State and Federal agencies and academic groups (FHM 2011). The FHM program utilizes data from a wide variety of data sources, both inside and outside the Forest Service, and develops analytical

<sup>1</sup> USDA Forest Service. 1998. Forest health monitoring 1998 field methods guide. Research Triangle Park, NC: USDA Forest Service, National Forest Health Monitoring Program. 473 p. On file with: Forest Health Monitoring Program, 3041 Cornwallis Rd., Research Triangle Park, NC 27709.

approaches for addressing forest health issues that affect the sustainability of forest ecosystems. The FHM program has five major components (fig. 1.3):

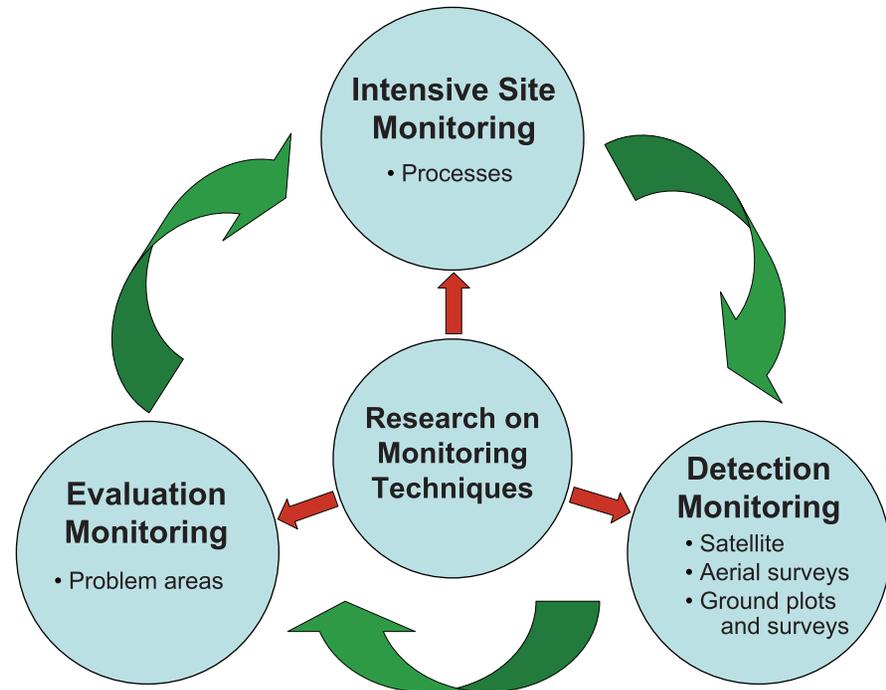


Figure 1.3—The design of the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture (FHM 2003). A fifth component, Analysis and Reporting of Results, draws from the four FHM components shown here and provides information to help support land management policies and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

- 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 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 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—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. These reports may be produced with FHM

partners, both within the Forest Service and in State forestry and agricultural departments. Some examples include reports on disturbance and forest conditions (Steinman 2004), urban monitoring methods (Lake and others 2006), health conditions in national forests (Morin and others 2006), urban forest health monitoring (Cumming and others 2006, 2007), crown conditions (Randolph 2010, Randolph and Moser 2009), and ozone monitoring (Rose and Coulston 2009). The Forest Health Highlights report series, available on the FHM Web site at [www.fs.fed.us/foresthealth/fhm](http://www.fs.fed.us/foresthealth/fhm), is produced by the FHM regions in cooperation with their respective State partners.

The FHM program and its partners also produce reports 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), crown-condition classification (Schomaker and others 2007), sampling and estimation procedures for vegetation diversity and structure (Schulz and others 2009), and the overall forest health indicator program (Woodall and others 2010). For more information, visit the FHM Web site at [www.fs.fed.us/foresthealth/fhm](http://www.fs.fed.us/foresthealth/fhm).

This FHM national report is produced by national forest health monitoring researchers at the Eastern Forest Environmental Threat Assessment Center, which was established under the Healthy Forest Restoration Act to generate knowledge and tools needed to anticipate and respond to environmental threats. For more

information about the research team and about threats to U.S. forests, please visit [www.forestthreats.org/about](http://www.forestthreats.org/about).

## LITERATURE CITED

- Bailey, R.G. 1995. Descriptions of the ecoregions of the United States. 2<sup>d</sup> 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.
- 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., Jr. [and others]. 2007. Ecological subregions: sections and subsections for the conterminous United States. Sloan, A.M., tech. ed. Gen. Tech. Rep. WO-76. Washington, DC: U.S. Department of Agriculture Forest Service. Map, presentation scale 1:3,500,000; Albers equal area projection; colored. Also as a GIS coverage in ArcINFO format on CD-ROM or at [http://fsgeodata.fs.fed.us/other\\_resources/ecosubregions.html](http://fsgeodata.fs.fed.us/other_resources/ecosubregions.html). [Date accessed: March 18, 2011].
- 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.
- 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. Low resolution: [http://www.na.fs.fed.us/pubs/fhm/pilot/pilot\\_study\\_wisconsin\\_02\\_lr.pdf](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](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.
- Forest Health Monitoring. 2003. Forest health monitoring: a national strategic plan. [http://fhm.fs.fed.us/annnc/strategic\\_plan03.pdf](http://fhm.fs.fed.us/annnc/strategic_plan03.pdf). [Date accessed: August 24, 2011].
- Forest Health Monitoring. 2011. Program description. Forest health monitoring fact sheet series. <http://www.fhm.fs.fed.us/fact/>. [Date accessed: August 24, 2011].
- Homer, C.; Dewitz, J.; Fry, J. [and others]. 2007. Completion of the 2001 national land cover database for the conterminous United States. Photogrammetric Engineering and Remote Sensing. 73: 337-341.
- Kolb, T.E.; Wagner, M.R.; Covington, W.W. 1994. Concepts of forest health: utilitarian and ecosystem perspectives. Journal of Forestry. 92: 10-15.
- 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, State and Private Forestry. <http://www.fhm.fs.fed.us/pubs/ufhm/indianaforests02/indianaforests02.html>. [Date accessed: November 6, 2007].
- 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](http://www.fs.fed.us/ne/newtown_square/publications). [Date accessed: November 6, 2007].
- Montreal Process Working Group. 1995. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests. [Online]. [http://www.rinya.maff.go.jp/mpci/rep-pub/1995/santiago\\_e.html](http://www.rinya.maff.go.jp/mpci/rep-pub/1995/santiago_e.html). [Date accessed: June 21, 2012].
- 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-GTR-258. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Research Station. 53 p.
- 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. 187 p.
- PRISM Group. 2010. 2.5-arcmin (4 km) gridded monthly climate data. <ftp://prism.oregonstate.edu/pub/prism/us/grids>. [Date accessed: September 16, 2010].
- 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. 2010. Equations relating compacted and uncompact live crown ratio for common tree species in the South. *Southern Journal of Applied Forestry*. 34(3): 118-123.
- 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.
- 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.
- 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](http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs077.pdf). [Date accessed: November 6, 2007].
- 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.
- 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](http://fhm.fs.fed.us/pubs/tp/dist_cond/dc.shtml). [Date accessed: December 8, 2009].
- U.S. Department of Agriculture Forest Service. 2004. national report on sustainable forests—2003. FS-766. Washington, DC: U.S. Department of Agriculture Forest Service, Washington Office. 139 p.
- U.S. Department of Agriculture Forest Service. 2011a. 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 Forest Service. 2011b. MODIS Active Fire Mapping Program: Continental United States Fire Detection GIS Data. <http://activefiremaps.fs.fed.us/gisdata.php>. [Date accessed: March 18, 2011].
- 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: United States 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.
- 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: United States Department of Agriculture Forest Service, Rocky Mountain Research Station. 336 p.