Forest Health Monitoring in the United States: Focus on National Reports

Kurt Riitters[1*], Kevin Potter[2], and Borys Tkacz[3]

[1]*US Department of Agriculture, Forest Service, Research Triangle Park, NC, USA*

[2]*Department of Forestry and Environmental Sciences, North Carolina State University, Raleigh, NC, USA*

[3]*US Department of Agriculture, Forest Service, Washington, DC, USA*

Introduction

Forests cover approximately 304 million ha, or one-third of the total land area of the United States (Smith et al. 2009). That area represents 45% of North American forest cover and 8% of global forest cover (UNFAO 2010). While the forests possess substantial ecological and socioeconomic importance, both their ecological integrity and their continued capacity to provide goods and services are of concern because of a long list of threats, including insect and disease infestation, fragmentation, catastrophic fire, invasive species, and the effects of climate change. Forest health monitoring provides some of the information needed to manage forests in a sustainable way, thereby helping to ensure the continued production of a variety of benefits including ecological diversity, water, recreation, wildlife habitat, timber and other forest products.

The health and sustainability of United States forests have been evaluated for many years from several different perspectives (Tkacz et al. 2008). Here we focus on a national perspective and the information needs at that scale. The early attention on national timber inventories was supplemented later by efforts to monitor specific forest threats such as pests, diseases, and air pollution effects (Riitters and Tkacz 2004). Several decades ago, international frameworks such as the 1995 Santiago Agreement (Anonymous 1995) brought attention to new forest issues such as biodiversity, as well as a "criteria and indicator approach" to national assessments (e.g., USDA Forest

Service 2004, 2011). The most recent United States national assessments are now framed in terms of potential impacts from climate changes and socio-economic drivers such as increasing human population (e.g., USDA Forest Service 2012). Forest health monitoring has evolved to meet the changing needs for national analyses and assessments.

The Forest Health Monitoring (FHM) Program was established in 1990 by Federal and State agencies to develop a national system for monitoring and reporting on the status and trends of forest ecosystem health (www.fs.fed.us/foresthealth/fhm). The rationale, approach, and implementation of the FHM Program have been described in detail elsewhere (e.g., Riitters et al. 2004; Bechtold et al. 2007; Tkacz et al. 2008, 2013). In addition, a set of "fact sheets" describing various aspects of the FHM Program is available (http://www.fs.fed.us/foresthealth/fhm/fact/). Briefly, the FHM Program consists of five major components:

- *Detection Monitoring* – nationally standardized aerial and ground surveys to establish baseline forest health conditions and to evaluate status and change in the condition of forest ecosystems (http://www.fs.fed.us/foresthealth/fhm/fact/pdf_files/fhm_dm_2009.pdf);
- *Evaluation Monitoring* – special projects to determine the extent, severity, and causes of undesirable changes in forest health which are identified through Detection Monitoring (http://www.fs.fed.us/foresthealth/fhm/fact/pdf_files/fhm_em_2009.pdf);
- *Intensive Site Monitoring* – special projects to improve the understanding of cause-effect relationships and to link Detection Monitoring to ecosystem process studies at multiple spatial scales (http://www.fs.fed.us/foresthealth/fhm/fact/pdf_files/fhm_ism_2009.pdf);
- *Research on Monitoring Techniques* – research to develop or improve monitoring databases, field measurements, and analysis techniques (http://www.fs.fed.us/foresthealth/fhm/fact/pdf_files/fhm_rmt_2009.pdf), and;
- *Analysis and Reporting* – synthesis of information from various data sources within and external to the FHM Program to produce issue-driven reports on status and change in forest health at National,

Regional, and State levels
(http://www.fs.fed.us/foresthealth/fhm/fact/pdf_files/fhm_reporting_2009.pdf)

In this paper, we describe and illustrate the annual national reports which are one aspect of the Analysis and Reporting component of the FHM Program.

Evolution of FHM National Reports

The Analysis and Reporting component of the FHM Program provides for the periodic reporting of forest health conditions in a consistent way over time and space (Tkacz et al. 2013). The original rationale for periodic reporting was to achieve the goal of Detection Monitoring, that is, to identify the type and location of apparently abnormal forest health conditions and trends, which could then be investigated through Evaluation Monitoring. Those analyses and reports are prepared primarily by regional experts, and it was anticipated that those expert regional reports would be compiled and integrated into national reports. However, that approach proved infeasible because of the intractable variety of analysis and reporting protocols among regions.

As a result, the national analysis and reporting strategy evolved to better contribute directly to a wide range of national assessments both within and external to the FHM Program. Starting in 2001, a framework known as the FHM National Technical Report (NTR) served to summarize data in a "criteria and indicator" format that was needed by the US Forest Service for international reporting. For example, the 2001 NTR (Conkling et al. 2005) used FHM data to provide an overview of forest health based on the criteria and indicators of sustainable forestry framework of the Santiago Declaration, and some of that information appeared in the official United States Reports on Sustainable Forests (USDA Forest Service 2004, 2011). A similar format was used for the NTRs produced from 2002 through 2008 (Coulston et al. 2005a, 2005b, 2005c; Ambrose and Conkling 2007, 2009; Conkling 2011; Potter and Conkling 2012a).

In 2005, the production model for the NTR was changed to broaden the scope of information which could be included. Before 2005, all the national analysis and reporting was done by a small group of FHM analysts, who naturally could report only on the set of topics within their capabilities. Beginning in 2005, the work of the FHM analysts was supplemented by contributions from authors from other scientific disciplines throughout the FHM Program. As a result, the NTR production model changed to an edited volume of chapters contributed by more authors.

In 2008, another change was made to broaden the scope of information included in the NTR. Before 2008, there was not a convenient reporting framework for the results of the Evaluation Monitoring special projects which were funded by the FHM National Program Office to address specific forest health issues. Evaluation Monitoring projects completed from 1998 through 2007 were synthesized by Bechtold and others (Bechtold et al. 2012). Since the NTRs were already being compiled as contributed chapters with a national focus, it was decided to include the results of Evaluation Monitoring projects completed since 2008 in the NTRs in the form of short chapters contributed by the recipients of Evaluation Monitoring funding. Many Evaluation Monitoring special projects are also summarized in poster format for presentation at national FHM meetings (http://www.fs.fed.us/foresthealth/fhm/em/index.shtml).

In 2009, the "criteria and indicator" format was dropped, and the reporting framework became much more flexible and dynamic with three general objectives:

- present forest health status and trends from a national perspective using a variety of data sources from within and outside the FHM Program;
- introduce new techniques for analyzing forest health data, and;
- report results of completed Evaluation Monitoring projects.

In comparison to earlier reports, this framework explicitly recognized contributions related to the component of FHM known as Research on Monitoring Techniques. The 2009 and 2010 national reports (Potter and Conkling 2012b, 2013) utilized the new framework.

In 2010, the FHM Program revised the printing process because the actual printing and release of the reports was occurring after the nominal date of the report. This unacceptable delay led to requests for shorter and more timely summaries (e.g., Ambrose et al. 2008), but the production of those documents did not result in faster printing of the main reports, and the printing of the shorter summaries was also time-consuming. Instead, the production problem was addressed in 2010 by simplifying the technical review process, by giving chapter authors more editorial control over their contributions, by setting and adhering to firm deadlines for contributions, and by releasing a draft version of a report online as soon as the technical and policy reviews were completed. Since then, these versions of the reports have been available by the end of the same year in which they were prepared, but another year or two will be needed to reduce the backlog of reports that are ready for the physical printing process. For example, the 2011 and 2012 reports (Potter and Conkling, in press) are now available online (http://www.fs.fed.us/foresthealth/fhm/pubs/index.shtml).

The current year's (2013) report (Potter and Conkling, in prep.) is the 13th national report produced by the FHM Program. The contents of FHM national reports has certainly evolved during the past 13 years (Table 1), and future years will likely witness more changes in response to the changing needs for monitoring, analysis, and national reporting.

Table 1. Major topics included in United States FHM national reports from 2001 to 2010.

Report year	Major topics included
2001	Biological diversity, productive capacity, health and vitality, conservation of soil, carbon cycling, multivariate analysis of indicators, quality assurance report
2002	Disturbances (biotic, abiotic, anthropogenic), air pollution exposure, tree mortality, crown condition, tree damage, multivariate analysis of forest indicators
2003	Landscape structure, biotic and abiotic factors, forest condition
2004	Forest fragmentation, insect and disease surveys, crown condition, tree mortality, drought, fire
2005	Forest fragmentation, drought, fire, air pollution bioindicators, insect and disease surveys, carbon pools, soil quality, soil carbon

2006	Drought, lightning and fire, air pollution deposition and exposure, insect and disease activity, exotic insect pests, crown condition
2007	Landscape context of forest and grassland, lichen diversity, understory species diversity, invasive and introduced species, tree mortality, ozone injury risk, spread modeling using host/pest distribution and climate matching, monitoring and analyses of sudden oak death
2008	Phylogenetic approach for assessing the health of forest communities from an evolutionary perspective, public retrieval of high-resolution maps of land cover patterns, methods for comparing moisture conditions between different geographical areas and time periods, hotspots of insect and disease activity, geographic clustering of forest fires, tree mortality, risk mapping, soil chemistry trends, change in woody carbon stocks, evaluation monitoring projects
2009	Landscape patterns, biotic disturbances, geographic patterns of insect and disease activity, geographic patterns of nonnative tree species occurrence, tree mortality, risk mapping temporal analysis of abiotic agents, geographic clusters of forest fires, moisture conditions pattern analysis, evaluation monitoring projects
2010	Geographic patterns of insect and disease activity, geographic patterns of fire, tree mortality, fragmentation of grassland, forest, and shrubland, moisture condition analysis, standing dead tree resources, impacts of climate change on forest soil critical acid load limits, evaluation monitoring.

Current Practice

The national reports are now called the National Status, Trends, and Analysis Reports in recognition of their more flexible and dynamic format. A convenient way to describe the current practice of national reporting by the

FHM Program is to summarize the contents of the 2013 report (Potter and Conkling, in press.). The analyses and results outlined in sections 1 and 2 of the report offer a snapshot of the current condition of US forests, incorporating baseline investigations of forest ecosystem health, examinations of change over time in forest health metrics, and assessments of developing threats to forest stability and sustainability. For datasets collected on an annual basis, analyses are presented from 2012 data. For datasets collected over several years, analyses are presented at a longer temporal scale. Individual chapters describe new techniques for collecting and analyzing forest health data as well as new applications of established techniques. Section 3 of this report presents summaries of results from recently completed Evaluation Monitoring projects that have been funded through the FHM national program to determine the extent, severity and/or causes of specific forest health problems.

Section 1. Forest health status and trends

Chapter 2. Insect and Disease Activity (K.M. Potter and J.L. Paschke) Monitoring the occurrence of forest pest and pathogen outbreaks is important at regional scales because of the significant impact insects and disease can have on forest health across landscapes. National insect and disease survey data (FHM 2005) collected in 2012 by the Forest Health Protection Program of the Forest Service identified 82 different biotic mortality-causing agents and complexes on 1.67 million ha in the conterminous United States, and 81 defoliating agents and complexes on approximately 3.64 million ha. Geographic hot spots of forest mortality were associated with mountain pine beetle in the West. Hot spots of defoliation were associated with western spruce budworm, aspen defoliation, pine butterfly, and larch needle cast in the West, and with fall cankerworm in the East. Mortality was recorded on a very small proportion of the surveyed area in Alaska, while aspen leaf miner and willow leaf blotch miner were the most important identified agents of defoliation.

Chapter 3. Forest Fire (K.M. Potter) Forest fire occurrence outside the historic range of frequency and intensity can result in extensive economic and ecological impacts. The detection of regional patterns of fire occurrence density can allow for the identification of areas at greatest risk of significant impact and for the selection of locations for more intensive analysis. In 2012, more satellite-detected forest fire occurrences (Justice et al. 2002; USDA Forest Service 2013) were recorded for the conterminous States than for any other since the beginning of data collection in 2001. Ecoregions in Idaho, Wyoming, Nebraska, Montana, and South Dakota experienced the most fires per 100 km^2 of forested area. Geographic hot spots of high fire occurrence density were detected throughout the Interior West. Ecoregions in the Interior West, Northwest, Great Lakes States, Northeast, and Middle Atlantic States experienced greater fire occurrence density than normal compared to the 11-year mean and accounting for variability over time. Alaska experienced low fire occurrence density in 2012.

Chapter 4. Drought (F.H. Koch, W.D. Smith, and J.W. Coulston) Most U.S. forests experience droughts, with varying degrees of intensity and duration between and within forest ecosystems. Arguably, the duration of a drought event is more critical than its intensity. A standardized drought indexing approach was applied to monthly climate data from 2012 (PRISM Group 2012) to map drought conditions across the conterminous United States at a fine scale. It was a very dry year relative to historical data. Most of the Central United States, including much of the Great Lakes and Southwest regions, experienced at least mild drought conditions. A large contiguous area of extreme drought extended from the northwestern portion of the Great Plains and into the eastern portion of the Central and Northern Rocky Mountains. Areas with a moisture surplus were limited to the Pacific Northwest and northern California, New England, and coastal areas of the Southeast. Longer-term moisture deficits existed in the Interior West, the South Central and Great Lakes States, and Florida.

Chapter 5. Tree Mortality (M.J. Ambrose) Mortality is a natural process in all forested ecosystems, but high levels of mortality at large scales may indicate that the health of forests is declining. Data collected by the Forest Inventory and Analysis (FIA) Program of the Forest Service (http://www.fia.fs.fed.us/) offer tree mortality information on a relatively spatially intense basis of approximately 1 field plot per 6,000 acres. An analysis of FIA plots from 37 States found that the highest ratios of annual mortality to gross growth occurred in ecoregion sections located in the northern Plains and the southern Mississippi alluvial plain. In Plains ecoregions with the highest mortality relative to growth, tree growth is quite low, and most of the species experiencing the greatest mortality are commonly found in riparian areas. The exception was high ponderosa pine mortality in one ecoregion. In the Southern Mississippi Alluvial Plain, meanwhile, several hardwood species experienced high mortality.

Section 2. New techniques for analyzing forest health

Chapter 6. ForWarn (S.P. Norman, W.W. Hargrove, W.M. Christie, and J.P. Spruce) National-scale satellite-based forest monitoring can provide uniform and timely insights into forest health. ForWarn (Hargrove et al. 2009), a satellite-derived change detection system operating across the conterminous United States, has been used since January 2010 to detect a wide array of environmental threats to forests. ForWarn disturbance detections rely on changes in the timing of vegetation "greenness," as measured by the Normalized Difference Vegetation Index (NDVI) derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite sensors. Of its four detection capabilities—occurrence, severity, progression and recovery—ForWarn's ability to monitor and track forest recovery may be among the most significant for aiding forest management in the future. ForWarn's multiple baselines and cross seasonal product lines provide a rich context for understanding the duration of disturbance effects and the cumulative effects of management in the months to years that follow.

Chapter 7. Monitoring Forest Disturbance (J. Ellenwood, F. Sapio, J. Mai, and V. Thomas) While effective as standalone applications, the value of individual forest health protection technologies can be dramatically improved if developed in concert or as part of an organized system. A conceptual organization of existing and future technologies aims to support and improve the monitoring of forest health. Additionally, a strategic solution may be needed to integrate monitoring assessments. As a one-stop shopping system, the Forest Health Protection (FHP) Mapping and Reporting Portal (FMRP) combines inventory, real-time tracking, and reporting tools to allow for better planning and integration of separate technologies. As part of FMRP, the Forest Disturbance Mapper (FDM) is a Web-based data delivery system designed to enhance efforts to allocate resources and plan forest health surveys. Additionally, a new approach to Insect and Disease Survey (IDS) will prioritize operator safety, maximize the quality and value of aerial sketch mapping, and improve other data streams.

Chapter 8. Invasive Plants (C.Oswalt and S. Oswalt) Long-term monitoring and assessment of invasive plant species on the forest landscape is necessary to managers and policy-makers for the obligation and direction of funds and other resources. Given the importance of monitoring invasive plants, units in the FIA Program have implemented efforts to track invasive plants in their regions ((http://www.fia.fs.fed.us/). Here, a national map of invasive species infestation was presented; this map may be used to identify potential hot spots of invasion and could serve as a baseline for future monitoring efforts. Nationwide, 39 percent of sampled forested subplots contained at least one invasive species. In general, excluding Hawaii, invasive species were more prevalent on forest subplots in the East than in the West. In Northern States, multiflora rose, reed canarygrass, garlic mustard, and Japanese honeysuckle were the most commonly detected. In Southern States, Japanese honeysuckle, Chinese/European privets, nonnative roses and Chinese lespedeza were the most common.

Chapter 9. Crown Conditions (K. Randolf) Tree crown conditions are visually assessed by the FIA Program (http://www.fia.fs.fed.us/) as an indicator of forest health. These assessments are useful because an individual tree's photosynthetic capacity is dependent upon the size and condition of its crown. In general, crown conditions across the United States were stable during the last decade. Though some changes in crown condition were observed, many statistically significant changes were relatively small and likely biologically unimportant. Notable exceptions to this were the declining crown conditions among the hardwoods, western hemlock, and true firs in the West

Coast region. The 2010 crown density moving averages for lodgepole pine, ponderosa pine, and Jeffrey pine in the West Coast region were substantially lower than the average conditions observed between 1996 and 1999. The ash group has maintained a high mean level of crown dieback in the northern U.S. since the late 1990s.

Section 3. Evaluation Monitoring Project Summaries

Five recently completed Evaluation Monitoring projects address a wide variety of forest health concerns at a scale smaller than the national or multi-State regional analyses included in the first sections of the report. These projects:

- Identified potentially beech bark disease-resistant trees and established permanent plots in four Mid-Atlantic States to monitor general health conditions of beech trees;
- used large-scale forest inventory data to describe the quality of wildlife habitat in the forests of Maine, particular to several wildlife species;
- Provided a scientific basis for managing the white pine blister rust invasion in Arizona and New Mexico by extending previous research on southwestern white pine ecology and documenting the distribution and effects of the disease on it;
- Characterized forest attributes and fuel loads of riparian and upland forest stands in southern Rocky Mountain watersheds infested by mountain pine beetle, and;
- Identified the extent to which non-native sawflies and alder canker contribute directly and synergistically to alder dieback in Alaska.

This summary of the 2013 National Status, Trends, and Analysis Report illustrates how forest health specialists and researchers inside and outside the Forest Health Monitoring Program continue to investigate a broad range of issues relating to forest health using a wide variety of data and techniques. The 2013 report presents some of the latest results from ongoing national-scale detection monitoring and smaller-scale environmental monitoring efforts by FHM and its cooperators.

The Future

The annual national reports produced by the FHM Program have evolved considerably since production began 13 years ago. The evolution of the contents of the reports reflects changes in the information needs not only for policy formulation and resource allocation at national scale, but also for meeting international reporting requirements, and to address new resource assessment questions. The production process has evolved from a traditional publishing model to a distributed, near real-time publishing model. In the future, we expect there will be new information requirements for non-traditional forest lands such as urban and riparian forests. Monitoring systems will continue to improve with the incorporation of more remotely sensed and biophysical databases. Evaluating forest health responses to climate changes, human population increases, and disturbances due to fire and insects is expected to remain a high-priority assessment goal.

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Abstract

The health and sustainability of United States forests have been monitored for many years from several different perspectives. The national Forest Health Monitoring (FHM) Program was established in 1990 by Federal and State agencies to develop a national system for monitoring and reporting on the status and trends of forest ecosystem health. We describe and illustrate the annual national reports which are one aspect of the Analysis and Reporting component of the FHM Program. The evolution of the content and format of reports from 2001 through 2013 has followed from changes in information requirements. Current practices are illustrated by using material drawn from the 2013 report which includes three sections covering forest health status and trends (insect, disease, fire, drought, and tree mortality), new techniques in forest health monitoring (disturbance mapping, invasive plants, and tree crown conditions), and special investigations to evaluate the possible causes or consequences of observed forest health conditions.

Key words : FHM, insect, disease, fire, drought, mortality, disturbance, invasive plants, crowns

* **Corresponding author :** kriitters@fs.fed.us