Forest health monitoring in the United States: a program overview

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Summary

The Forest Health Monitoring Program in the United States is a science-based, comprehensive monitoring system that provides statistically precise and accurate baseline and forest health trend information to determine detrimental changes or improvements that occur in our forests over time. This program, initiated in 1990 to provide information on forest health and sustainability, consists of four separate, interrelated activities, including detection monitoring, evaluation monitoring, research on monitoring techniques, and intensive site monitoring. Descriptions and examples are provided for each activity.

Keywords: forest health; surveillance; methodologies; monitoring; pest management; forest management; United States of America

Introduction

The United States Forest Health Monitoring (FHM) Program was initiated in 1990 to provide information on the status, changes and trends in forest health and sustainability across all of the approximately 304 million ha of forested land in the United States. Information derived from this program is used by land managers and policy makers and it affects all citizens of the United States, directly or indirectly.

Specific objectives of this Forest Health Monitoring Program are to:

- determine detrimental changes or improvements in our forests over time
- provide baseline and trend information that is statistically precise and accurate
- report annually on status and changes to forest health.

The program consists of four separate, interrelated activities (Fig. 1): detection monitoring, evaluation monitoring, research on monitoring techniques, and intensive site monitoring.

Forest Health Monitoring Program

Detection monitoring

Detection monitoring, the most extensive of the three monitoring activities, is designed to provide data to determine baseline or current conditions of forest ecosystems and to detect changes and trends over time. Our detection monitoring system consists of a nationwide grid of permanent sample plots that are integrated with our Forest Inventory and Analysis (FIA) plots. Aerial detection damage surveys and special ground surveys are also used to provide valuable monitoring information.

Monitoring the health of forest ecosystems requires an integrated approach at multiple scales including airborne hyper-spectral scanners, classical aerial photography, low-level aerial detection surveys, and more intensive ground surveys. This integrated approach involves three distinct phases (Fig. 2).

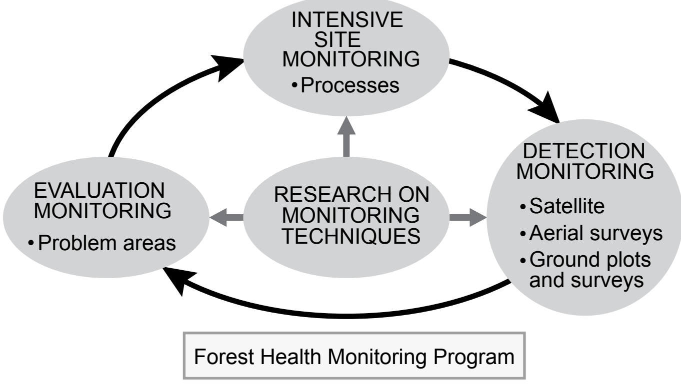

Figure 1. The interrelated activities of the US Forest Health Monitoring Program

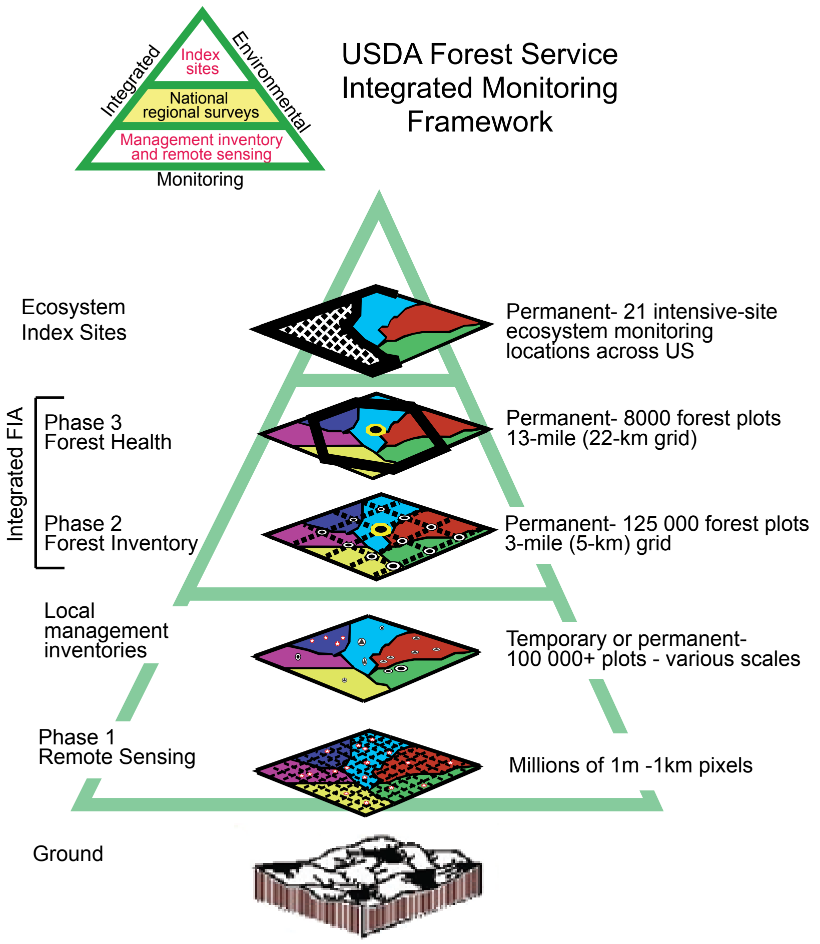

Figure 2. The USDA Forest Service integrated Forest Health Monitoring Program framework

Phase 1 is the aspect of data collection related to remote sensing. In this phase aerial photographs and more recently satellite images are used to characterise sample areas as forest or non-forest. A subset of these sample areas is then selected for field data collection (Phase 2).

Phase 2 is the field data collection activity. Forested plots are installed and measured regardless of intended use or any restrictive management policy. Plot installation takes place after permission is granted by the landowner. It is on these field locations that most data collection activities occur. Specific measurements include tree species, diameter, length, crown class, damage and cull; seedling species, counts and condition class; and general stand characteristics such as forest type, stand size, stand age, regeneration status, tree density and disturbance. A detailed explanation of these specific measurements can be found in the *FIA Field Guide for Phase 2 Measurements*, located at www.fia.fs.fed.us/library/field-guides-methods-proc/. These measurements are collected on about 125 000 plots, each representing about 2428 ha.

Phase 3 plots are a subset of Phase 2 plots, designed to measure forest ecosystem function, condition and health. Measurements on the Phase 3 plots are grouped into the following categories: tree crown condition, lichen community monitoring, ozone bioindicator plants, down woody debris, vegetation structure and soil condition. These forest health monitoring indicators are measured on about 8000 subplots, each representing about 38 850 ha. Each plot is measured once every 5–10 y.

Figure 3 shows the rotating panel design of a hexagon plot grid that we use in the random selection of these plots (Scott *et al.* 1993; Brand *et al.* 2000). This system is designed to cover the entire globe, so the spatial distribution is uniform everywhere, regardless of scale. Use of this grid facilitates the statistical design to conduct area-based analyses.

Phase 3 plot-measured categories

Tree crown condition is a measurement of vigour class, uncompacted live crown ratio, crown light exposure, crown position, crown density, foliage transparency and crown dieback. These variables, used alone or in combination with others, add to the overall tree crown condition rating for each tree. Trees that score high for uncompacted live crown ratio and density, and low for dieback and foliage transparency, are considered to have increased potential for carbon fixation, for nutrient storage and for survival and reproduction (www. fia.fs.fed.us/library/field-guides-methods-proc/). The tree crown information we collect is important in understanding forest ecosystem attributes, including biodiversity, sustainability, aesthetics, forest environment and wildlife habitat.

Lichen community monitoring is included in our forest health monitoring survey program in order to address key assessment issues such as the impact of air pollution on forest resources, spatial and temporal trends in biodiversity and the sustainability of timber harvesting. We know that lichens are very responsive to environmental stressors in forests, including changes in forest structure, air quality and climate (Stolte *et al.* 2002), and that there is a close relationship between lichen communities and air pollution, especially sulphur dioxide and acidifying or fertilising nitrogen and sulphur-based pollutants (Neitlich *et al.* 2003). Their sensitivity results from their total reliance on atmospheric sources of nutrition. Because lichens are so sensitive to these air pollutants, they are useful as early indictors of improving or deteriorating air quality.

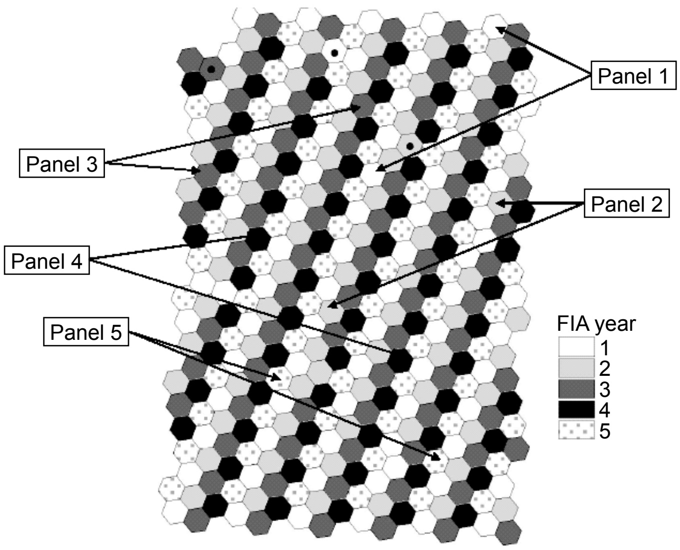

Figure 3. A representative example of the Forest Health Monitoring hexagon-shaped plot grid

An **ozone bio-indicator evaluation** is conducted on a separate nation-wide grid of ozone bio-monitoring plots (Fig. 4) from which ozone-induced foliar injury data are collected to detect and monitor ozone stress in the forest environment (USDA-FS 2002). Possible impacts of ozone on forest species include reduced growth and seed production and increased susceptibility to insects and disease (Miller *et al.* 1996; Chappelka and Samuelson 1998; USDA-FS 2003). Long-term ozone stress may lead to changes in species composition and biodiversity.

The ozone bio-indicator sampling intensity varies across the landscape according to differing air quality regimes and perceived risk to ozone-sensitive forest types. That is, the sampling intensity is greatest in areas of higher ozone concentration, such as highly populated industrial regions of the US, and in areas where moist humid conditions favour ozone and ozone-caused damage on susceptible plants. Examples of indicator plants include *Rubus* spp., *Asclepias* spp., *Prunus serotina*, *Fraxinus americana* and *Liriodendron tulipifera* in the eastern US and *Vaccinium membranaceum*, *Symphocarpus oreaphilus*, *Pinus ponderosa*, *Populus tremuloides* and *Alnus rubra* in the western US (USDA-FS 2000).

The **down woody material indicator** is designed to estimate the biomass of forest ecosystem components not sampled during the Phase 2 inventory. These biomass components include coarse woody debris, fine woody debris, duff, litter, shrubs or herbs, slash piles and fuelbed depths. The presence, size and condition of down woody material is measured on each plot to assess fuel loading and fire behavior, quality and status of wildlife habitats,

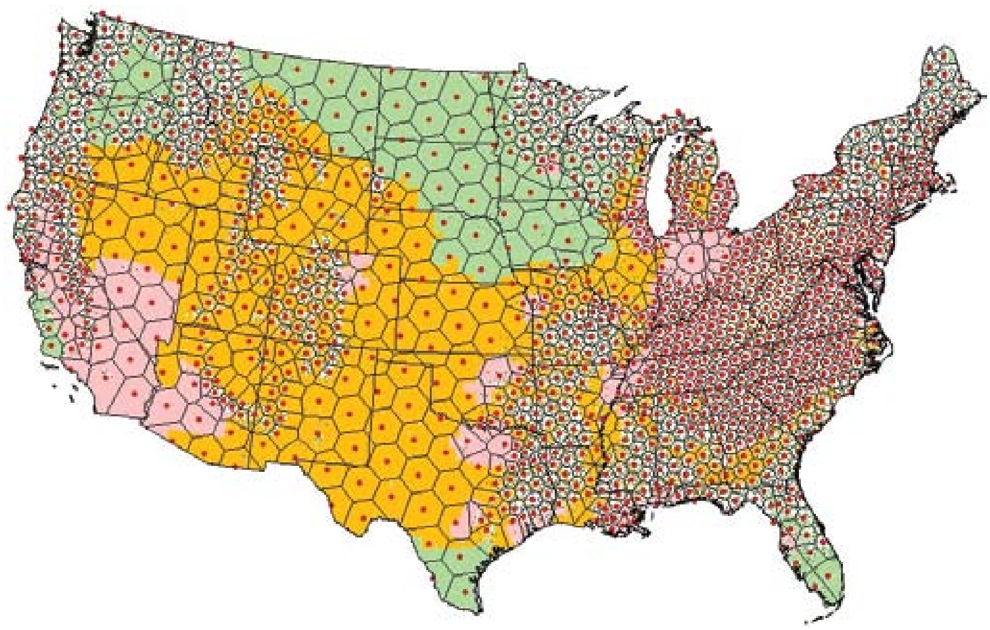

Figure 4. The nationwide grid of ozone biomonitoring plots

structural diversity within a forest, carbon sequestration, and storage and cycling of nutrients and water.

The **vegetation structure indicator** is designed to assess the type, abundance and spatial arrangement of all trees, shrubs, herbs, grasses, ferns and fern allies (horsetails and club mosses) occurring in the plots. Measuring vegetation allows us to report on the relative diversity of both native and introduced species. Information about the abundance and arrangement of species (structure) allows us to classify plots into community types. By remeasuring plots over time, we can monitor for change outside expected rates.

Soil condition represents the basic support system for terrestrial ecosystems. Soils provide nutrients, water, oxygen, heat and mechanical support to vegetation. Any environmental stressor that alters the natural function of the soil has the potential to influence the productivity, species composition and hydrology of forest systems. Therefore, we measure soil erosion and compaction at each Phase 3 plot. Soil samples are also collected for analysis of physical and chemical properties, including estimates of site fertility (USDA-FS 2003).

Aerial detection surveys

Forest health data collected from our FHM ground plots is augmented with aerial detection survey (see Johnson and Wittwer 2008) data regarding biotic and abiotic damage to forested ecosystems. These surveys, conducted by Forest Health Protection staff and their state cooperating partners for over 50 y, provide annual information on forest insect, disease and weather related damage. The information derived from these surveys is used for national and regional reporting on forest insect and disease conditions and trends, and to evaluate tree damage that may be missed on periodically visited ground plots.

Special detection surveys

In addition to our annual aerial detection and ground monitoring surveys, we also conduct special detection surveys as the need arises. For example, in 2003 we conducted special aerial and ground surveys over 6 million ha of pinyon/juniper forested land in the south-western US to detect and aid in evaluating the extent and intensity of mortality caused by an extended, multi-year drought and the subsequent outbreak of bark beetles.

Sudden oak death, caused by *Phytophthora ramorum*, is the focus of another special detection survey currently being conducted in the US. The objectives of this special survey are to determine the distribution, incidence and impact of sudden oak death in California; to determine the effectiveness of eradication efforts in Oregon; and to detect new infestations in forests outside the known infested areas of California and Oregon. The intensity of survey sampling is directly related to the risk of invasion. Risk factors include known or suspected tree hosts, likely pathways of introduction (rhododendron nurseries) and climatic factors (Swiecki and Bernhardt 2002; Rizzo 2003; Rizzo and Garbelotto 2003; Swiecki and Bernhardt 2006). Sample sites include general forested areas and forested areas around nurseries. At each site, suspected host plants are sampled. In 2004, surveys were conducted in 37 states. Over 4500 samples were collected from nearly 1000 locations. All were negative except two follow-up samples from the San Francisco area. These were the first reports of the disease in that county. Additional states were added to this special survey in 2005 and 2006. No other infested areas have been detected and confirmed.

Evaluation monitoring

Evaluation monitoring is the second component of the Forest Health Monitoring program and is designed to determine the extent, severity and causes of undesirable changes in forest health that are identified through detection monitoring and other means. This component addresses cause-and-effect relationships, identifies associations between forest health and forest stress indicators, identifies management consequences and alternatives for reducing the effects of forest stress, and identifies research needs.

One such evaluation monitoring project has investigated ozone-induced foliar injury in the south (Rose 2005). Examples of other evaluation monitoring projects include investigating lichen distribution in the Allegheny National Forest (Morin *et al.* 2004) and determining the distribution and effects of balsam woolly adelgid in Washington and Oregon (Ragenovich *et al.* 2002). Analysis of lichen data collected from the Allegheny National Forest project resulted in a list of lichen species present on the Forest, and a special distribution of the most common lichen species. This baseline assessment of lichens can be used for future monitoring. Results from the balsam woolly adelgid survey in Washington and Oregon showed higher mortality on wet sites and at lower elevations; considerable resistance in some host species at high elevations; and susceptibility of other species at all locations.

Research on monitoring techniques

The third component of FHM entails research on monitoring techniques. The purpose of this component is 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. One recent research project has developed a much-needed method of sampling and inventorying sparse, linear and widely-distributed riparian environments on a large scale (Ruefenacht *et al.* 2005). Another recent research project analysed FHM survey methods in urban forest areas of Indiana. Based on this analysis, the investigators refined FHM sampling techniques and data collection procedures for use in urban areas (Lake *et al.* 2006). Being able to effectively monitor forest health in these settings will strengthen our ability to monitor the health of all forested lands in the US and to aid in urban forest management and planning.

Intensive site monitoring

Intensive site monitoring is the fourth component of the Forest Health Monitoring Program. This component is designed to enhance understanding of cause–effect relationships by linking detection monitoring to ecosystem process studies and assessing specific issues, such as calcium depletion and carbon sequestration, at multiple scales.

The Delaware River Basin Collaborative Environmental Monitoring and Research Initiative is a good example of intensive site monitoring (Stolte *et al.* 2003). This initiative addresses the effects of forest cover changes on water quality of the Delaware River; changes in forest biomass and productivity; forest fragmentation and associated ecosystem changes; causes, consequences and regional extent of calcium depletion; and the identification and monitoring of forests vulnerable to non-native invasive pests.

FHM reporting

Data collected from these various components of our FHM program are analysed and synthesised into issue-specific reports on the status and change in forest health at national, regional and state levels. Examples include *Forest Health Monitoring in the Interior West* (Rogers *et al.* 2001), *Lichen Communities Indicator Results from Idaho: Baseline Sampling* (Neitlich *et al.* 2003), *A National Ozone Biomonitoring Program — Results from Field Surveys of Ozone Sensitive Plants in Northeastern Forests (1994–2000)* (Smith *et al.* 2003), *Forest Health Monitoring in the Northeastern United States, Disturbances and Conditions During 1993–2002* (Steinman 2004) and *Forest Health Monitoring: 2004 National Technical Report* (Coulston *et al.* 2005). Information included in these reports is used by policy makers, land managers, researchers and the general public to identify forest health concerns, to develop and implement appropriate action, and to monitor changes in forest health conditions over time.

The United States FHM program continues to evolve and improve, but also faces challenges regarding timely detection, analysis and reporting of adverse changes in forest health that can be used to facilitate an effective management response. Future program opportunities include looking back to analyse trends and integrate diverse data sources; looking forward to forecast future conditions and analyse forest health risks; designing new approaches for the timely and effective detection of invasive species; and utilising additional local survey data to enhance forest health analyses at regional and local levels.

Acknowledgements

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Additional information on our Forest Heath Monitoring Program can be found at: www.fhm.fs.fed.us www.fia.fs.fed.us

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