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산사랑 국민운동
한국산지보전협회
KOREA FOREST CONSERVATION MOVEMENT

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The Historical Background, Framework, and Application of Forest Health Monitoring in the United States

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Forest monitoring systems have historically been designed to obtain data needed for timber management, but in the past few decades forests have been increasingly viewed as holistic systems that are best monitored with an integrated approach which includes the ecological and social aspects of forests(Riitters and Tkacz 2004). The demand for more comprehensive and science-based information has led the U.S. Forest Service to assemble a monitoring program that is based on a cooperative and integrated approach to gathering and reporting information on many aspects of forest health. This paper provides a brief history of the U.S. Forest Health Monitoring (FHM) Program, a summary of the conceptual approaches, and a description of current operations. Additional details are available on the Program's web site at http://fhm.fs.fed.us/.

HistoryofForestHealthMonitoring

Beginning in the late 1970's, widely reported declines in the health of European forests spawned much debate that similar symptoms observed in the U.S. might be attributed to air pollution and acid rain (Peterson and Shriner 2004). The lack of science-based information necessary to respond to these allegations led the U.S. Congress to create an interagency task force to study the issue. The National Acid Precipitation Assessment Program (NAPAP) was thus established in 1980. The NAPAP task force spent a decade studying atmospheric deposition and its effects on aquatic and terrestrial ecosystems. The resulting summary report (Irving 1991) was a major contribution to the technical understanding of acid rain. In 1984, the U.S. Forest Service, the U.S. Environmental Protection Agency (EPA), and private forest industry combined resources to create the Forest Response Program (FRP) to conduct research on forested ecosystems for NAPAP (U.S. Department of Agriculture 1989). As part of its contribution to this cooperative research effort, the Forest Service launched the

National Vegetation Survey (NVS). One objective of the NVS was to design a long-term approach to forest health monitoring. While the Forest Service and EPA were collaborating in the Forest Response Program, the EPA Science Advisory Board initiated the Environmental Monitoring and Assessment Program (EMAP) to monitor the condition of the nation's major ecological resources by using a series of ecological indicators (Thornton et al. 1993; Hunsaker and Carpenter 1990). EMAP targeted seven ecological resources for monitoring, one of which was forests. Facilitated by the pre-existing collaborative relationship between the Forest Service and the EPA, the NVS and EMAP-Forest programs were combined in 1990 to create the U.S. Forest Health Monitoring Program. A comprehensive monitoring strategy was published the following year (Palmer et al. 1991), with many design features that still apply.

Early efforts focused on reviewing existing programs (Hazard and Law 1989), identifying candidate indicators of forest health (Riitters et al. 1991), and acquiring potentially useful auxiliary data such as weather records. Numerous sampling procedures and candidate indicators were reviewed and tested (Alexander et al. 1991). The pilot tests facilitated the development of operational tools such as field manuals (Tallent-Halsell 1994), quality assurance plans (Palmer 1992), and information management systems (Liff et al. 1994). Initial implementation started with the establishment of field plots in six northeastern states in 1990; additional states were added gradually over subsequent years (Alexander and Palmer 1999). To date, thousands of permanent field plots have been established in 45 states.

Early efforts also focused on air pollution, but the scope soon expanded to include the internationally sanctioned Criteria and Indicators from the Montreal Process(Montreal Process Working Group 2006). In 1993, the Canadian government hosted an international seminar in Montreal to discuss the sustainable development of temperate and boreal forests. An international Working Group known as the Montreal Process was commissioned to develop Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. Criteria are categories of forest values to be preserved, such as biodiversity and productive capacity; indicators are measurable aspects of these criteria. The Montreal Process Working Group consists of 12 countries on five continentsincluding the Republic of Korea. Participating countries account for 90 percent of the world's temperate and boreal forests.

The Montreal Process was further advanced in 1995, when participating countries met in Santiago, Chile, where they issued a declaration of 7 criteria and 67 indicators to guide policy makers, forest managers, and the general public in the sustainable management of temperate and boreal forests. The seven Criteria are:

1. conservation of biological diversity;
2. maintenance of the productive capacity of forest ecosystems;
3. maintenance of forest ecosystem health and vitality;
4. conservation and maintenance of soil and water resources;
5. maintenance of forest contributionsto global carbon cycles;
6. maintenance and enhancement of long-term socio-economic benefits; and
7. the legal, institutional, and economic framework for forest conservation and sustainable management.

In combination with our national forest inventory system, the U.S. FHM program currently addresses the first 5 Criteria and monitors 16of the 67 Indicators (Reams et al. 2004). Techniques are being developed to monitor an additional 10 Indicators. Adoption of the Montreal Process with its internationally sanctioned indicators has helped to standardize the analysis and reporting of forest health data. The national reports produced by our FHM program are organized to address the Montreal Process Criteria and Indicators.

Various federal agencies, state agencies, and universities have been involved in the U.S. FHM Program since its inception in 1990. The EPA, which was heavily involved in the early design and implementation of the Program, withdrew in 1995. Today, the dominant cooperators are the State and Private (S&PF) Deputy Area of the U.S. Forest Service, the Research and Development (R&D) Deputy Area of the Forest Service, and individual state forestry agencies. S&PFis involved primarily through its Forest Health Protection (FHP) Program. FHP has a long history of working with state agencies to manage and protect forests from insects, diseases, and other damaging agents. For more than 50 years, FHP has conducted extensive aerial surveys to identify insect, disease, and weather damage (Ciesla 2006). These aerial surveys produce maps of problem areas and are occasionally supplemented with ground surveys. Most of this survey work, along with the emphasis on state collaboration, was integrated with the FHM Program in the mid 1990's. The R&D Deputy Area of the Forest Service contributes in two ways. First, in 2000, the FHM plot network was incorporated into ournational forest inventory system--the Forest Inventory and Analysis (FIA) Program (Bechtold and Patterson 2005). Second, in 2002, a formal Research Work Unit was established to analyze forest health data, produce reports, and conduct research on monitoring techniques. State participation is important because it keeps the Program relevant and responsive to local issues, which in turn helps to keep local forest health problems from becoming regional or national problems. State involvement ranges from field work to Program management.

The U.S. FHM Program is currently organized under two main levels of internal management. A national Steering Committee that includes two members appointed by the National Association of State Foresters (NASF) and one representative from each of the three main Deputy Areas of the U.S. Forest Service (i.e., the National Forest System, State and Private Forestry, and Research and Development). The Steering Committee sets broad strategic goals and directions. The second level of management, the FHM Management Team, has operational responsibilities for implementing these goals in 5 administrative regions (Figure 1). TheManagement Team is headed by the National Program Manager and includes 15 state and federal partners who provide technical oversight and implement the program regionally. The Program Manager has final authority over major operational and budgetary decisions.

Conceptual Approaches to Forest Health Monitoring

Detection, Evaluation, and Intensive Site Monitoring

The study of forest health is a complicated endeavor. Forests are exposed to a changing array of natural and human stresses that produce both normal and unexpected changes in forest health. The response to a given stress depends upon the species involved, the geographic location, and local conditions. Stresses also interact with each other, and they change over time. Responses to stress occurat multiple scales, and may be delayed rather than immediate. These complications make it difficult to establish appropriate standards of forest health. They also make it difficult to recognize departures from normal ecosystem functions, many of which are only poorly understood.

The U.S. Forest Health Monitoring system has three main objectives (Riitters and Tkacz 2004):

1. to identify forest ecosystems where conditions might be deteriorating in subtle ways over large areas. This objective calls for consistent, large-scale, long-term monitoring of key indicators
2. to define the *extent* of resources where conditions are deteriorating, and to develop management strategies for those events. This objective calls for more focused surveys and monitoring; and
3. to understand the detailed processes that cause forest health problems so that strategies can be developed for problem mitigation and prevention.

To match these objectives, the Program uses a 3-tiered (or 3-level) approach by which progressively more detailed studies are conducted to evaluate forest health (U.S. Department of Agriculture Forest Service 2003). The first tier is Detection Monitoring (DM), the second is Evaluation Monitoring (EM), and the third is Intensive Site Monitoring (ISM).

In Detection Monitoring, forests are systematically sampled in space and time. Initial measurements establish the "baseline" forest conditions existing at the onset of sampling. Repeated measurements over time then provide the data for assessing change. The group of forest health "indicators" selected for Detection Monitoring must be chosen carefully to achieve a proper balance between practicality and the many dimensions of forest condition. Ideally, some small set of indicators can be used to quantify important aspects of forest health such as biological response, exposure to stressors, and habitat suitability. Attention to Montreal Process Criteria and Indicators should guide the indicator selection process to promote international consistency.

Detection-Monitoring surveys are primarily designed to document status and trends. They can suggest plausible mechanisms for observed changes, but are not intended to resolve many important questions about the cause or significance of change. This explains the use of generalized integrative indicators inDetection Monitoring. Too much attention to diagnosing known causeeffect relationships requires highly specific measures that are more appropriate for evaluating known problems. The goal of Detection Monitoring is to identify subtle or previously unknown problems.

Scale is also important. The successful detection of change depends on the scale of the sample design relative to the scale of the phenomena of interest. When searching for slow changes that affect large areas (e.g., climate change or air pollution), the sampling frame should incorporate widely distributed measurements and relatively long measurement cycles. Knowledge of small-scale temporal and spatial variability typically yields little information about long-term and large-scale changes. Model-based extrapolations from a few intensely studied research sites cannot reliably predict regional changes, and small-scale intensive surveys say nothing about areas beyond those surveys. With our approach to Detection Monitoring, small-scale intensive studies are not usually deployed until after a problem is suspected.

Detection Monitoring accepts a high rate of false positives as the price of not overlooking change. The false positives are resolved through the more detailed studies that take place in the Evaluation tier of the program.

The details of this follow-up research naturally depend on circumstances, so

Evaluation Monitoring protocols cannot be fully defined in advance, as they are with Detection Monitoring. The Evaluation tier is designed to investigate the extent, severity, and potentialcauses of undesirable changes in forest health.

The third tier, "Intensive Site Monitoring", enhancesour understanding of cause and effect relationships by linking Detection Monitoring indicators to process-level research such as calcium depletion and carbon sequestration studies (Stolte et al. 2004). Ideally, such research is accomplished in conjunction with ongoing process-level studies at long-term research sites. Intensive Site Monitoring can also be used to establish indicator thresholds, and to develop strategies to prevent or mitigate forest health problems once they are identified.

The three tiers of monitoring do not necessarily have to occur in the order presented above. Sometimes a problem comes to our attention by means other than Detection Monitoring. For example, *Phytopthora ramorum*, which causes sudden oak death (SOD), was first observed about 10 years ago in commercial nurseries in California in 2000 (Rizzo et al. 2002). This non-native pathogen is fatal to at least some oak species, and has the potential to decimate the oak forest ecosystems of the eastern U.S. The prospective impact of such phenomena isso large that it makes sense to conduct an immediate evaluation, and not wait for signs and symptoms to manifest through the Detection tier of the system.

In summary, the conceptual approach to forest health monitoring in the U.S. includes a component to detect long-term regional changes, a component to assess the practical importance and impact of observed changes, and a component to conduct process-level research. Detection Monitoring is largely statistical and relies on multiple indicators of condition. Evaluation Monitoring focuses additional study on potentially important problems that come to our attention through Detection Monitoring or other sources. Intensive Site Monitoring links to the other components by allowing a more rigorous evaluation of cause and effect relationshipsby establishing thresholds for indicators of forest health, by investigating strategies for prevention and mitigation, and by linking to studies on the fundamental processes that shape ecosystems.

Current Application of Forest Health Monitoring

Detection Monitoring

Sampling Framework for Phase2/Phase3 Field Plots

The permanent field plots used for Detection Monitoring are integrated with our national forest inventory systemthe FIA Program. The FIA sampling framework is based on a systematic network of ground plots (Bechtold and Patterson 2005). The systematic sample was obtained by dividing the Country into a series of 2,400-hectare hexagons (figure 2). The hexagonal shape was selected because of its resistance to spatial distortion from the curvatureof the earth. One permanent ground plot is randomly located inside each hexagon. The network of hexagons is divided into 5 panels, where all plots in one of the panels are measured each year. Each panel represents full spatial coverage across the population, and panels are scheduled for measurement on a rotating basis. The result is a forest inventory that has a 5-year remeasurement cycle, with annual panels that can be analyzed separately or combined in various ways to strengthen the estimates. Starting in year 6, when the first panel is remeasured, we then have continuous annual change estimates from remeasured plots.

We note here that the number of panels and sampling intensity are permitted to deviate among administrative regions. The number of panels may be as high as 10 in regions where change occurs slowly (e.g., Alaska), and the sampling intensity of plots may be increased in regions that are willing to pay for the additional data. We also notethat deviations from the standard design complicate data processing and analysis.

Standard forest inventory data are recorded at each ground plot. Additional forest health indicators are measured on a 1/16th subset of these plots. The standard forest inventory data are called Phase 2 data; the additional forest health data from the 1/16th subset are called Phase 3 data. Our national forest inventory system thus consists of Phase 2 plots where each plot represents 2,400 hectares, and Phase 3 plots where each plot represents 39,000 hectares. The Phase 3 plots are part of the FHM Detection Monitoring system.

Phase 2 Plot Configuration

Here we describe the details of the Phase 2 plot design. Keep in mind that Phase 2 data include common inventory data such as tree volume, growth, mortality, and timber harvesting, and that Phase 2 data are collected on both Phase 2 and Phase 3 plots.

The Phase 2 plot design consists offour points spaced 37 meters apart and arranged as shown in figure 3. A cluster of pointswas selected because this configuration covers more territory than a single point of equal area. This reduces between-plot variation, so fewer plots are needed to achieve a given standard of accuracy. The overall size of the plot is based on the amount of Phase 2 data that a two-person field crew can collect in one day.

Each point is surrounded by a 7.3-m fixed-radius subplot where trees 12.7-cm and larger are sampled. Each subplot contains a 2-m fixed-radius microplot for sampling trees less than 12.7 cm. Each subplot is surrounded by an 18-m fixed-radius macroplot, which can be useful for sampling in regions where large trees are common. The macroplot feature is optional; it is used by only one administrative region.

In addition to the trees measured on these plots, data are also gathered about the area in which the trees are located. Area classifications are useful for grouping the data into meaningful categories for analysissuch as stand age class, ownership group, or tree density class.

Some important indicators of forest health can be derived directly from the Phase 2 inventory data, such as forest extent, regeneration, growth, and mortality rates. This is why it was convenient to integrate Detection Monitoring with our national forest inventory system.

Phase 3 Forest Health Indicators

The additional forest health data recorded on Phase 3 plots include tree crown condition, lichen communities, forest soils, vegetation structure, down woody material, and ozone. Each indicator has been assigned to a technical specialist who is responsible for developing data collection protocols and analytical procedures. The locations of these various measurements on Detection Monitoring ground plots are illustrated in figure 3. Detailed information regarding the field protocols associated with each indicator is available in the national field guide (U.S. Department of Agriculture Forest Service 2006). Links to additional information about these indicators are available at the web site: (http://www.fia.fs.fed.us/program-features/indicators/). A brief description of each Phase 3 Indicator follows below.

Crown Condition-Tree crowns are an important component of net primary production. They convert solar radiation into usable energy for tree growth andmaintenance. Large, dense crowns are correlated with vigorous growth rates. Trees with sparse foliage suggest unfavorable conditions such as competition from other trees, drought, insect damage, disease, weather, or air pollution. Trees with deteriorating foliage show visible signs of stress that often precede reduced growth and mortality. Unexpected reductions in crown vigor occurringin spatial clusters or tree crowns that degrade over time warrant further investigation.

Crown measurements are recorded on all sampled trees greater than 12.7 cm dbh. Individual crown measurements include crown ratio, crown diameter, crown density, foliage transparency, crown dieback, light exposure, and canopy position. These measurements can be analyzed individually, or they can be combined to calculate crown volume or surface area.

Lichen Communities-Lichens are fungi that live in close association with algae. Lichens are extremely sensitive to environmental stressors in forests, including changes in forest structure, air quality, and climate. The composition of an epiphytic lichen community is a good biological indicator of air pollutionbecause lichens rely totally on atmospheric sources of nutrition. Lichens can be used to evaluate air quality impacts on forest health that are difficult to measure directly, especially with respect to nitrogen and sulfur pollutants. Long-term observation of lichen community change provides an indication of corresponding changes in air quality.

Field crews are trained to observe the presence of lichen species, to estimate the abundance of each species, and to collect specimens for identification by a specialist. Lichen community measurements are made within a 37-meter radius of each plot center, where one field person spends two hours searching for lichen species.

Forest Soils-Soils provide water, minerals, and mechanical support to vegetation. Any environmental stressor that interferes with soil function has the potential to influence the productivity, species composition, and hydrology of forest ecosystems. The soil indicator evaluatessoil physical and chemical properties. The purpose is to gather baseline data about the status of forest soils and then check for unusual temporal or spatial trends.

At each plot location, field crews collect 5 soil samplesthree forest floor samples to measure organic matter and carbon content, and twomineral soil cores down to 20 cm. Samples are sent to the laboratory immediately after collection where they are stabilized by air drying. Field crews also estimate the percentage and type of soil compaction or erosion observed on the plot.

Vegetation Structure-The vegetation-structure indicator is designed to evaluatethe abundance and spatial arrangement of all vascular plants occurring on the plots. This indicator allows us to calculate the relative diversity of native and non-native species. It also permits us to identify forest ecosystems that are most prone to invasion by non-native species, and habitats that are likely to contain rare species. Upon remeasurement we can assess trends in species diversity over time and examine forest communities' response to disturbance.

Field measurements are recorded by experienced botanists. All vascular plants are identified and quantified on each of the four subplots according to the percent cover they occupy in three different height zones (0-2 meters, 2-5 meters, and 5+ meters). More refined sampling is done in the 0-2 meter height class on twelve permanent 1-meter-square quadrats located across the plot.

Down Woody Material-The DWM Indicator is designed to estimate non-living above-ground biomass in the form of coarse woody material, fine woody material, litter, and duff. The purpose is to address important fire, wildlife, and carbon issues. Fire applications include assessment offire risk, estimation of fuel loading, creation of national fuels maps, and monitoring the effects of fuel reduction projects.

Coarse woody material (greater than 7.5 cm in diameter) is sampled on a series of transects across the plot totaling 88 meters. Fine woody material between 2.5 and 7.5 cm is sampled on a series of transects totaling 12 meters. Fine woody material less than 2.5 cm is sampled on a series of transects totaling 7 meters. Duff and litter depth measurements are taken at 12 points located on the plot.

Ozone Injury-Ozone is a widely dispersed pollutant that has been shown to reduce tree growth, change species composition, and predispose trees to insect and disease attack. Because ozone causes direct foliar injury to certain forest plant species, such species can be used as "bio-indicators" to identify the presence and severity of local air pollution. If the trees in a given locality exhibit signs of stress and the presence of ozone has been detected, then further investigation of ozone as a possible causal agent is warranted. Ozone bio-indicator data can also be used to identify which ecosystems are most vulnerable to ozone damage, and whether or not regional air quality has been changing over time.

Ozone is the only Phase 3 indicator that is not observed directly on the plot network. This is necessary because bio-indicator species are not always present on Phase 3 plots, and openings in the canopy are necessary to obtain useful results. Also, the measurement window for ozone sampling is narrower than the 4-month sampling season for other indicators. For these reasons, the ozone indicator is sampled on a separate network. At each field site, crews evaluate up to 30 individual plants for amount and severity of ozone damage.

Aerial Surveys

Besides permanent field plots, Detection Monitoring also includes aerial surveys and special ground surveys. Aerial Detection surveys have been widely used for 50 years by our Forest Health Protection Program to gather information on insect, disease, and weather damage (Ciesla 2006). As our forest inventory has become part of the FHM Detection Monitoring System, so have aerial surveys. These annual surveys supply tree damage data that might be missed on periodically measured and sparsely distributed ground plots. Each state is responsible for conducting annual surveys of forested lands within their jurisdiction. The data are collected by forest health specialists who fly over the region of interest in a systematic pattern, drawing polygons on a map to show the locations of affected areas, and making notes of the observed signs and symptoms. Maps are digitized into Geographic Information Systems (GIS) and the data are forwarded to a national processing center for compilation and reporting. Much of this sampling is now done with automated sketch-mapping systems that link to aircraft global positioning systems. Like the plot measurements, aerial surveys are supported by national training and data quality assurance programs.

Special Ground Surveys

Special ground surveys for monitoring invasive plants, insects, and diseases are becoming an increasingly important part of Detection Monitoring. When potentially dangerous invasive species are identified, a risk-based sampling approach is applied that incorporates knowledge of pest biology, susceptible hosts and likely pathways of introduction. For example, *Phytophthora ramorum*, which causes the Sudden Oak Death mentioned above, is already a severe threat to oak forest ecosystems in California and Oregon (Rizzo and Garbelotto 2003), where areas with known infestations have been quarantined (Goheen et al. 2006). There are dozens of alternate host species, including ornamental species that have the potential for wide distribution through commercial nurseries. In 2003, it was discovered that nurseries in California and Oregon had shipped thousands of infected plants to more than 30 states. As a result, more than 21 States have confirmed infections in nursery stock.

In an effort to identify infected areas and initiate early eradication measures, the FHM Program produced a national map where sampling efforts were based on risk factors (Tkacz et al. 2006) that include:

- o presence of known host species
- o locations of nurseries receiving infected plants
- o locations with adequate rainfall to sustain the fungus; and

o areas within the temperature extremes tolerated by the fungus.

Sampling protocols were then implemented to check the perimeters of nurseries to determine if the pathogen had escaped into nearby forest (Oak et al. 2006). Recently, it has been discovered that this pathogen is waterborne, and more effective sampling protocols have been developed to monitor streams in high risk areas. After three years of testing and sampling we have been able to conclude that:

o *P. ramorum* is not native to the U.S.
o it has been widely distributed to nurseries throughout the Country
o it has been detected in ornamental species in urban settings in CA, OR, GA, and SC
o it has spread into natural forest ecosystems only in CA and OR; and
o eradication efforts in CA and OR offer hope that early detection and eradication can prevent this pathogen from spreading into areas where it does not yet occur.

Remote Sensing

Remote sensing with satellite imagery is another tool used in Detection Monitoring to identify potential problems. For example, fragmentation, which refers to the division of forested land into smaller pieces, is one aspect of forest health that can be quantified with satellite imagery. Although the actual extent of forest has increased in some areas of the U.S., a closer look at spatial patterns reveals extensive forest fragmentation. Fragmented forests often result in decreased habitat suitability, fewer corridors for wildlife to move through the landscape, and the spread of invasive species from disturbed edges.

A study of high-resolution land cover maps (Riitters et al. 2002) derived from satellite images indicates that forest is usually dominant where it occurs, with three-fourths of all forest land in forest-dominated landscapes. At the same time, fragmentation is so pervasive that half of all forestland is within 100 m of forest edge. Historic patterns of forest clearing have left relatively few large blocks of forest along major rivers, near urban areas, or in fertile agricultural areas. Fragmentation caused by roads is of special interest because the effects of roads extend way beyond the roads themselves, altering drainage patterns, disrupting wildlife movement, introducing exotic plants, and increasing noise. Only 18 percent of the continental U.S. land area is more than 1 kilometer from a road (Riitters and Wickham 2003).

Evaluation Monitoring

So far we have emphasized the Detection Monitoring tier of the Program. The Evaluation tier is designed to investigate the severity and possible causes of undesirable changes in forest health that are identified through Detection Monitoring or other sources. Evaluation Monitoring can also be used to study improvements such as increased plant vigor from air pollution control. Unlike Detection Monitoring, Evaluation Monitoring Projects are designed to study specific issues.

Project proposals are submitted through each of the five administrative regions and later selected through two separate competitionsFire Plan EM Projects and Base EM Projects. Fire Plan Projects are funded with money from our Fire Program and concentrate on fire-related forest health issues. Studies of interest include risk reduction, fuel loading, ecological impacts of fires, fire-related invasive species, and ecosystem restoration. Base EM Projects may addressany forest-health related issue.

EM Projects may extend from one to three years in duration and are funded at an average about $30,000 per study per year. A committee headed by the National Program Manager selects proposals based on four criteria:

1. linkage to Detection Monitoring surveys
2. significance in terms of geographic scale
3. biological and political importance and
4. the probability that the study can be completed in 3 years or less.

A total of 19 Base Projects and 16Fire Projects were selected for funding in 2006. Previously funded multi-year proposals from past years are given priority if the investigators report sufficient progress. Upon completion investigators are required to submit a final published report, and present a poster at the national FHM meeting. Posters presented over the past five years can be viewed at the following web sites:

http://www.fhm.fs.fed.us/posters/posters02/posters02.htm
http://www.fhm.fs.fed.us/posters/posters03/posters03.htm
http://www.fhm.fs.fed.us/posters/posters04/posters04.htm
http://fhm.fs.fed.us/posters/posters05/posters05.shtm
http://fhm.fs.fed.us/posters/posters06/posters06.shtm

Intensive Site Monitoring

Intensive Site Monitoring is the least developed tier of the Program. So far, we have established only one such site in the Delaware River Basin. This particular study is a collaborative effort between the FHMProgram and the Water Resources Division of the U.S. Geological Survey (Stolte et al. 2004). Initiated in 1999, the research conducted there has several unique features:

- it integrates the monitoring of vegetation, soil, water, and air
- it links process-level research occurring at this site with Detection Monitoring sampling efforts and
- it supports issue-driven data collection and analysis techniques.

The measurement protocols implemented there have been enhanced to study several important issues, namely:

- the causes and consequences of calcium depletion
- the ability of forest ecosystems to absorb and retain nitrogen pollutants
- the effect of forest cover changes and fragmentation on forest ecosystems and water quality and
- the characterization and quantification of carbon sources and sinks.

Research on Monitoring Techniques

All aspects of our FHM Program are supported by a formal component to conduct research on monitoring techniques. The goal of this component is to develop or improve indicators, monitoring systems, and analytical techniques. Much of this is accomplished through the established national FHM research team, but some research is conducted by others when additional assistance or special skills are required. For example, the risk-based sampling protocols developed for Sudden Oak Death began under this component of the Program.

Another example of research on monitoring techniques is urban forest health monitoring. The plot design used for sampling trees in forest conditions is not efficient for sampling trees in urban environments, so it became necessary to develop alternative sampling procedures for trees in nonforest conditions. A plot design based on linear transects was subsequently implemented for use along streets in urban areas (Cumming et al. 2006). Similar linear sampling techniques are being developed for sampling vegetation in riparian areas. Specialized riparian sampling techniques are important in arid regions where trees are mostly confined to long, narrow stream margins.

Reporting

The U.S. FHM program has generated hundreds of reports and scientific articles on subjects ranging from monitoring techniques to comprehensive analyses of emerging problems. Many of these papers originate from Evaluation Monitoring Projects, and many others are prepared by Program cooperators. Aside from these, the Program has a Reporting Plan that prescribes a series of regular reports to be produced at the national, regional, and state levels (U.S. Department of Agriculture Forest Service 2004a). At the national level, the Program publishes a national technical report every year (Conkling et al. 2005; Coulston et al. 2005a, 2005b, 2005c). The main framework used for these reports is The Montreal Process Criteria and Indicators for Temperate and Boreal Forests. The topics discussedinclude the indicators deployed on the Detection Monitoring network, as well as additional indicators derived from ancillary data. One example of the latter is the measure of forest fragmentation from satellite imagery (Riitters et al. 2004). Ancillary datasets are also used to interpret indicators. For example, tree crown data from the plot network have beeninterpreted with respect to regional weather patterns as reported by the National Oceanic and Atmospheric Administration (NOAA) (Coulston et al. 2005b).

In addition to the national technical reports directly sponsored by the FHM Program, FHM data and results are often included in other important national reporting efforts. Some noteworthy reports in this category include:

- The Forest Service 2003 National Report on Sustainable Forests (U.S. Department of Agriculture Forest Service 2004b)
- The Heinz Center's State of the Nation's Ecosystems (available at http://www.heinzctr.org/ecosystems/report.html) and
- The EPA's US/Canada Air Quality Agreement Progress Reports (available at http://www.epa.gov/airmarkets/usca/index.html).

Regional reports are periodic compilations of information to address issues covering multiple states. These reports usually relate to one of the 5 Program administrative regions, but some forest health issues will define other multi-state areas that do not follow administrativeor political boundaries. One such issue is the decline of aspen forest types in the Southern Rocky Mountains of the western U.S. (Rogers 2002)

At the State level, the Program produces annual Forest Health Highlight reports that are published annually on the internet to address local issues (available at the website: http://fhm.fs.fed.us/fhh/fhmusamap.shtm). These are usually authored by our State collaborators andinclude summaries of the annual plot data, aerial surveys, and special pest surveys. Some States produce more comprehensive reports on a less regular basis (e.g., Keyes et al. 2003). Our national forest inventory (the FIA Program) analyzes Phase 3 data as part of the comprehensive inventory reports that they produce for each state at 5-year intervals (e.g., Conner et al. 2004).

Conclusion

As it has matured, the U.S. Forest Health Monitoring Program has shifted emphasis from data collection to analysis, reporting, and research on monitoring techniques. The Program has surpassed expectations in its mission to provide information on the status, changes, and trends of forest condition in the U.S. on an annual basis. It is the only entity whose entire function is to integrate forest health information from many data collection agencies to produce reports of forest health. It has improved overall efficiency by becoming the focal point for many programs, agencies, and studies that independently addressed forest health issues prior to 1990. More than this, it has served to standardize several national efforts that were only loosely organized prior to the FHM Program. The aerial surveys conducted by individual states have become much more standardized now that they are required to supply information for regional and national assessments. The sampling framework and plot design used by our national forest inventory, the FIA Program, were originally developed and implemented by the FHM Program. And finally, attention to the Montreal Process Criteria and Indicators has raised the scope of the Program to international relevance.

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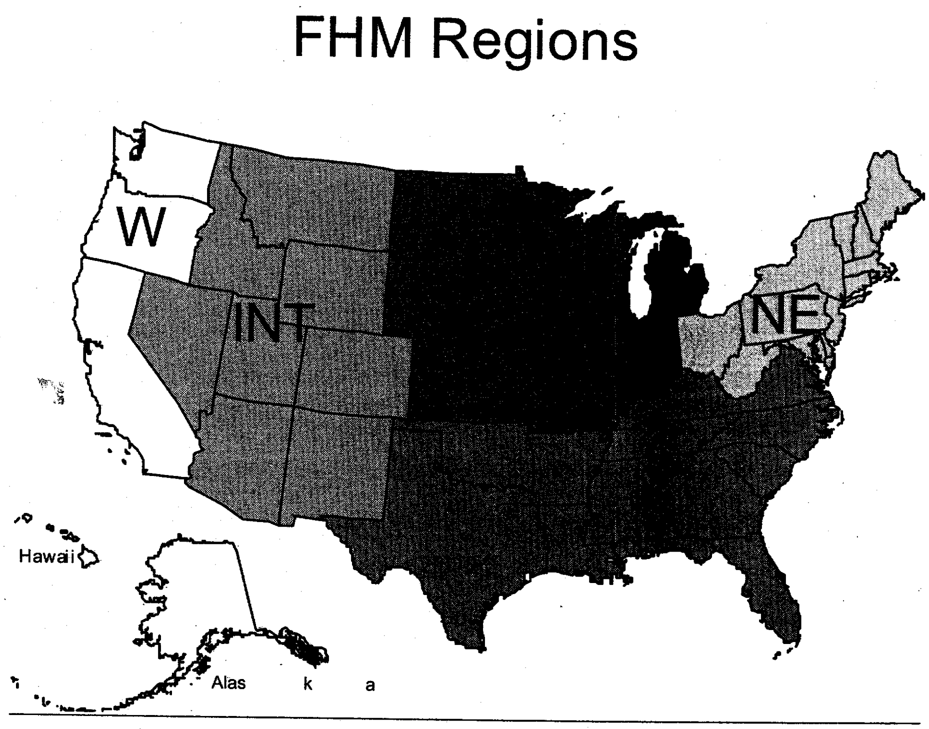

Figure 1. Five Forest Health Monitoring Administrative Regions: Northeast (NE), North Central (NC), South (S), Interior West (INT), and West Coast (W).

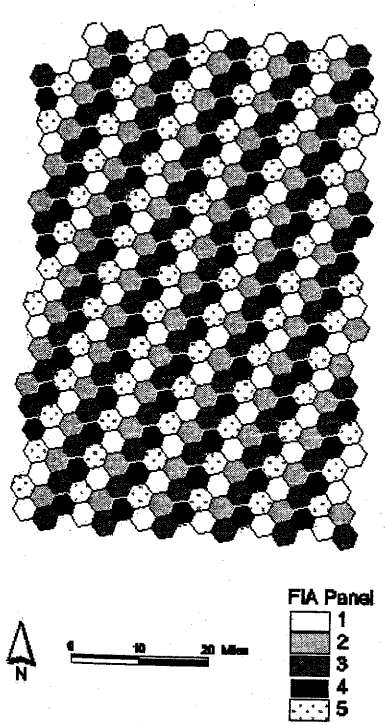

Figure 2.The FIA sampling framework, which is based on a tessellation of 2,400-hectare hexagons. The hexagons are systematically divided into 5 panels, where one panel is visited every year. Each hexagon contains 1 ground plot, where standard forest inventory data are collected. Additional forest health indicators are measured on a 1/16th subset of these plots. (Adapted from USDAForest Service, Forest Inventory and Analysis Sampling Hexagon Fact Sheet. Available at: http://www.fia.fs.fed.us/library/fact-sheets/data-collections/Sampling%20and%20Plot%20Design.pdf).

Phase 2/Phase 3 Plot Design

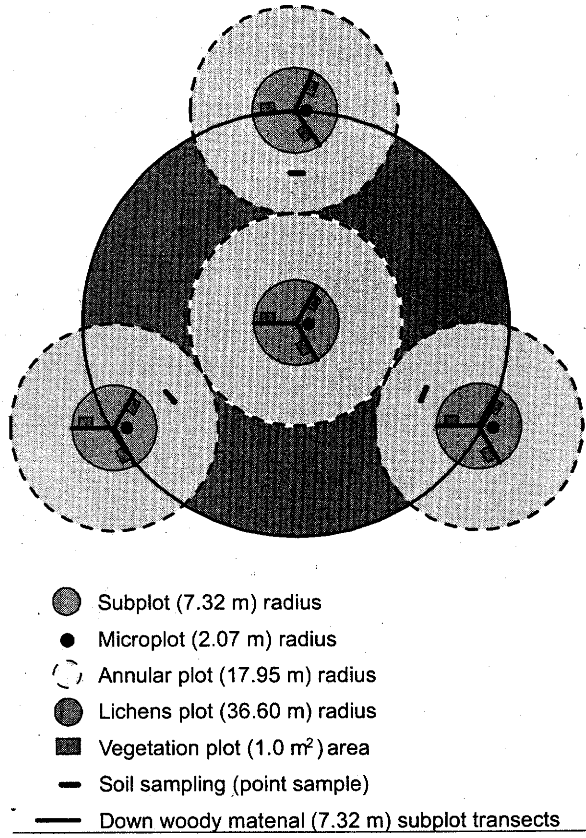

Figure 3. Field plot layout for Detection Monitoring plots. (From USDA Forest Service, FIA Sampling and Plot Design Fact Sheet at: http://www.fia.fs.fed.us/library/fact-sheets/data-collections/Sampling%20and%20Plot%20Design.pdf).