CHAPTER 7.

Working towards an Integrated Approach for Monitoring Forest Disturbance at Multiple Scales and Frequency

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INTRODUCTION

Forest Health Protection and its cooperators have a long history of technological development. Many applications regarding pesticide application technology, data collection technology, pest modeling technology, and remote sensing technology have all been developed independently without regard for integration. While effective as stand-alone applications, the value of these individual technologies can be dramatically improved if developed in concert with or as part of an organized system. Integration of design with regard to efficiency and optimization of natural resource management can dramatically improve the utility of individual software programs, Web sites, databases, models, and monitoring activities. The purpose of this paper is to describe a conceptual organization of existing and future technologies that would support and ultimately improve the monitoring of forest health as well as provide a framework for developing new technologies.

FOREST DISTURBANCE AND FOREST HEALTH MONITORING ACTIVITIES

Forest disturbance refers to changes in the forest structure, composition, or density that have occurred either through natural, human-caused, or catastrophic events. Disturbance intensity can vary from low intensity over a small area to severe intensity over a large area. While disturbance is a natural process in healthy forests, patterns of disturbance—i.e., source, size, and frequency—are difficult to assess in relation to the range of natural variability.

Forest Health Monitoring (FHM) is a national program designed to determine the status, changes, and trends in specific forest damage agents, as well as indicators of forest condition. The present national program began as an amalgam of national and regional programs. As it has evolved, the emphasis has been on building consistency among regional programs and efficient integration of national activities. This conceptual paper describes recent and ongoing improvements to provide an integrated strategy for monitoring forest disturbance at multiple scales and frequencies.

FHM incorporates the following activities:

- Detection Monitoring (DM) is intended to be a nationally standardized aerial and ground inventory program to evaluate status and change in conditions of forest ecosystems.
- Evaluation Monitoring (EM) activities are used to determine extent, severity, and causes of undesirable changes in forest condition identified through DM.
- Intensive Site Monitoring (ISM) activities are used to enhance understanding of cause–effect relationships at multiple spatial scales by linking DM to studies of ecosystem processes and assessments of specific issues, such as calcium depletion and carbon sequestration.
- Research on Monitoring Techniques (RMT) activities are used 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.
- Analysis and Reporting (AR) activities are used to synthesize 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.

PREDISPOSED CONDITIONS—RISK/HAZARD ASSESSMENT

Disturbance can occur anywhere on the landscape; however, the likelihood of disturbance varies. A priori knowledge of disturbance agents along with knowledge of existing forest conditions can yield information that would be conducive to the monitoring of anticipated disturbances. A collection of information about known insect and disease disturbance agents, hosts, ranges, and environmental conditions has been developed, along with a suite of tools, to facilitate the production of risk/hazard assessments nationally.

Predisposed risk/hazard assessment involves a thorough understanding of the disturbance agents' hosts, range, and impacts. Until recently, there has been no organized effort to document pest ranges nationally. A simple query of the Web will produce multiple conflicting range maps for any given species. In 2010, the Forest Health Technology Enterprise Team (FHTET) began a project to develop an authoritative database of pest ranges. For a limited though ever-increasing number of pests, the outward expression of this database is the Forest Pest Conditions Portal (USDA Forest Service 2013a). This portal provides access to the Pest Range geospatial dataset and Pest Host database, which incorporates published literature and reported occurrences of individual pests. The portal also incorporates nationwide forest pest mapping and reporting on an annual basis. These maps, which locate specific pests on the landscape, are a fundamental basis for forest pest risk assessments.

2012 National Insect and Disease Risk Map

To aid in the development of risk and hazard assessments, the Risk Modeling Application (RMAP) was developed to support the development of risk models using state-of-the-art knowledge for individual pests. Data from the Spatial Data Library (SDL) were improved from various national datasets to provide a set of predictor layers for generating geospatial risk products. This suite of tools and data was used in the 2012–27 National Insect and Disease Forest Risk Assessment (Krist and others 2014), which identified the potential impact of both endemic and non-endemic forest pests in the conterminous United States, Alaska, and Hawaii. The collection of each individual agent–host risk assessment is an effort to provide a 5-year strategic appraisal of the risk of tree mortality due to major insects and diseases.

The National Insect and Disease Risk Map (NIDRM) report contains a nationwide strategic assessment of the hazard of tree mortality due to major insects and diseases, displayed as a series of maps. The risk in NIDRM is defined as the potential that, without remediation, 25 percent or more of the standing live basal area (BA) of trees >1 inch in diameter will die over the next 15 years due to insects and diseases.

The NIDRM represents the integration of 186 individual insect and disease hazard models, all constructed within a common GIS-based multi-criteria framework that can account for regional variations in forest health concerns. The 2012 modeling process, applied to all 50 States, provides a consistent, replicable, transparent, peer-reviewed process through which interactive spatial and temporal hazard assessments can be conducted. Each individual model is based upon the best science and data known to the developers. The modeling process allows for flexible analysis to produce hazard assessments for specific insects and diseases. For the underlying host tree conditions, the National Tree Species Extent and Parameter geospatial dataset was developed to support NIDRM and utilizes Forest Inventory and Analysis (FIA) field data along with predictor layers from the SDL and remotely sensed imagery. The NIDRM can support the prioritization of regional plans and can possibly be implemented to support forest and project plans for project-level support. In addition to NIDRM, individual pest species risk assessments have been developed for a number of anticipated and recently introduced invasive species (USDA Forest Service 2013c) such as Sirex woodwasp (*Sirex noctilio*) and emerald ash borer (*Agrilus planipennis*).

The predisposed risk/hazard assessment details risk in relation to the health of the forest; however, the ability to observe forest health conditions can pose a risk to the observer. An assessment of aerial safety risk was developed as the Spatial Tool for Aviation Risk (STAR) project. The STAR project prioritizes the safety of areas based upon weighted factors of known pest risks, topography, land cover, and distance to landing sites. Coupled with NIDRM, STAR-based analysis may reveal that—due to landscape characteristics, road density, and other factors—changes to flight mission profiles, aircraft selection, or detection methods are required in order to ensure safe coverage of high priority forested landscapes.

MULTI-SCALED MONITORING—A SPATIAL CONTEXT

Given a priori knowledge of known disturbance agents, improvements in efficiency can be realized by creating targeted and more focused monitoring activities. To assist in the allocation of monitoring resources, inventory designs that alter the intensity and frequency of samples would achieve better utility of monitoring resources. The use of risk/hazard assessments can be used as a tool to focus and prioritize monitoring areas. The predisposing risk assessments can be considered an initial Tier 1a monitoring effort.

Risk assessments show *potential* for disturbance, while Detection Monitoring (DM) and Evaluation Monitoring (EM) measure actual disturbances. Different DM and EM activities can be organized hierarchically (fig. 7.1 and table 7.1). At the top of the spatial hierarchy, broad-scale disturbance detection monitoring is achieved through Synoptic Surveillance and

Figure 7.1—Hierarchical organization of Forest Health Monitoring and Forest Disturbance Monitor activities. DM= Detection Monitoring; EM= Evaluation Monitoring.

can be referred to as Tier 1b monitoring. Using large-area monitoring systems, disturbances are mapped and tracked through periodic surveys. The monitoring of the extent, severity, and causes of undesirable changes is achieved through Focused Surveillance (Tier 2a monitoring). Directed Monitoring (Tier 2b monitoring) is used for fine-scale mapping to validate or invalidate positive detections from Tiers 1b and 2a. Project Assessment (Tier 3 monitoring) is needed to identify site-specific existing and desired conditions for project implementation (e.g., National Environmental Policy Act, pest management or State planning and analyses, decisions and implementation, and ecosystem restoration).

Table 7.1—Organizational hierarchy of Detection Monitoring and Evaluation Monitoring activities

	Tier	Decadal	Annual	Seasonal	Monthly	Daily	Hourly
Spatial	0-Risk Assess	National Insect and Disease Risk Map					
	1-Synoptic	Landscape change	Harvest and development				
	2-Focused	LandTrendr recovery	Burn severity		Defoliation from insects and diseases		
	3-Directed		Mortality from insects and diseases	Mortality and defoliation from insects and diseases	Defoliation from insects and diseases	Active large fire	
	4-Project					Active fire	Fire behavior

Detection Monitoring/Synoptic Surveillance: Tier 1b

Survey intelligence regarding ongoing forest disturbances comes from multiple sources. Often the best source of information regarding a pest outbreak or forest decline comes from the public. These reports can be more timely than regular survey methods, but they typically lack information regarding the scale or scope of the problem. The public may see a stretch of defoliation along a roadside but may not be able to comment on the overall extent, which may occur over several counties or multiple regions. Public reports often lack proper identification of the causal agent of a forest disturbance event. Informal observations from trained specialists yield more accurate determinations of causal agents; however, due to the nature of limited, localized observations, they may not identify the full extent of the disturbance agent. More extensive observational systems from aerial detection surveys allow for better overviews of disturbance agents, although these sacrifice some of the determination accuracy since observations are limited to areas and times flown, which may not coincide with the peak signature of the disturbance event.

Real-time forest disturbance mapping technology from coarse spatial resolution satellite imagery allows for a consistent and replicable assessment of the extent and magnitude of disturbances. The Forest

Disturbance Monitor (FDM) Web site (USDA Forest Service 2013b) was developed to host the near real-time forest disturbance (RTFD) mapping data as a first-cut disturbance monitoring system. By tracking interseasonal changes, early-detected disturbances can be monitored subsequently using finer scale remote sensing applications. Though Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery is collected twice daily, frequent cloud contamination limits the ability to gather adequate samples to produce timely composites. Even with compositing periods of 16 and 24 days, RTFD is somewhat limited in producing a consistently reliable early-warning system. Due to the coarse resolution of the imagery, the system is not sensitive to all types of forest disturbance. These shortcomings limit the utility of this system as a stand-alone system; however, when integrated with casual observations, data analysis, and aerial and ground survey, there is the potential to create a more robust sound and timelier survey system.

Insect and Disease Survey (IDS) is the main focus of the Tier 1b monitoring effort and currently relies largely on aerial detection surveys (ADS). For this data stream, information is collected using a hardware/software system called the Digital Aerial Sketchmapping System (DASM) (USDA Forest Service 2013a). Though this system is designed for aerial observation of pest damage, it can be used to capture areas of damage from the ground. Tier 1a and Tier 1b monitoring can be utilized to prioritize IDS missions.

DASM Next Gen is a redesign of the Digital Aerial Sketchmapping System. This computer tablet-based data-collection system will retain much of the original functionality but will be based upon less-expensive technology and will be designed to fully support both ground-based survey and aerial observations.

Detection Monitoring/Focused Surveillance: Tier 2a

Sadly, in 2010 FHP lost a survey crew, consisting of a pilot and two aerial surveyors, in a crash. This tragedy forced FHP to examine the value of information gained versus the risk of conducting aerial surveys, and the methods by which it collects insect and disease information. The FHP staff director and management team concluded that whereas aerial survey remains a key data-collection tool, FHP needs to decrease its reliance on flying. While FHTET and FHP have been working on multiple tools for collecting field data in a consistent fashion for some time, this tragedy reinforced the need to develop an integrated strategy. As no one technique offers a complete assessment of forest health on a national scale, an integration of existing technologies and an identification of new opportunities seem warranted. A remote sensing strategy and new tools are being developed by FHTET to help focus monitoring and evaluate the extent of forest disturbances.

The following is a list of existing forest pest reporting technologies that are being integrated into FHP's monitoring system:

- The Early Detection and Rapid Response (EDRR) database was developed to support State cooperators and FHP personnel for early detection of key invasive pests using traps, periodic collections, and taxonomist expertise.
- Pest Event Reporter (PER) supplements IDS and standardizes the data entry process across the regions to allow local experts to integrate and interpret pest observations from multiple sources and enter the records into the database.
- The Southern Pine Beetle Information System (SPBIS) has survey, management, and cost reporting functions for the management of southern pine beetle (*Dendroctonus frontalis*) on Federal lands.
- The Southern Pine Beetle Portal (SPB portal) application focuses on southern pine beetle survey on all lands, including both trap counts and spot delimitation.
- Pest Observations (PestOBS) allows users to capture forest pest damage locations, typically based on ground observations. While PER operates at the scale of a pest event that typically involves many observations over a multi-county area, PestOBS records individual observation sites and may eventually include crowd-sourced data.
- Operationalizing Remote Sensing for Forest Health Protection (ORS) has the potential to be a companion, alternative, and gap-filler for aerial survey, and to facilitate the evolution of aerial survey to a more reliable insect and disease survey. The increased availability of imagery, combined with lower imagery costs, makes operational remote sensing a practical opportunity. Finer-scaled remotely sensed products can gap-fill missing coverages from aerial survey and serve as an alternative survey where aviation safety concerns are high and where potential pest impacts are of high concern.

For Tier 2 monitoring, FHTET proposes a multi-staged system that takes advantage of synoptic sensors for phenological trend and high resolution sensors for detecting damage and mortality. Extension of FDM products to incorporate interseasonal trend data with finer-scaled imagery can be utilized to track on-going mortality and defoliation extents. At a resolution of 22 m, the Disaster Monitoring Constellation (DMC) collects imagery every three to five days over any given point during the growing season (Bethel 2013). Alternative imagery from U.S. Geological Survey Landsat 8 (now operational) can also be utilized, as can the European Space Agency's future Sentinel satellite constellation.

Evaluation Monitoring/Directed Monitoring: Tier 2b

ORS in a second stage can be implemented to create a Directed Monitoring production environment. The production environment can be conducted as a stand-alone environment as an extension of Detection Monitoring or in conjunction with ground investigations in support of Evaluation Monitoring efforts. In a stand-alone environment, ORS can be used as fine-scale Detection Monitoring by utilizing available remotely sensed high-resolution data as a surrogate for field data collection. High-resolution imagery from WorldView-2 and other high-resolution satellites can be utilized for individual tree counts for both recent and older mortality and can serve as an alternative surveying technique or for gap-filling missing aerial survey coverage areas. Automation of this process can be refined through the development of object-recognition algorithms.

When combined with ground investigations, Directed Monitoring ORS can be used to determine extent, severity, and causes of disturbance. A team of specialists working closely with regional aerial survey programs can conduct damage assessments. In areas where the causal agent cannot be determined through remote sensing alone, aerial and ground observers can augment the image analysis with appropriate attribution.

Project Assessment and Implementation: Tier 3

FHTET also develops treatment technologies for direct control of forest health concerns. Bio-control technologies are used to limit the biological processes of the targeted species. Aerial spray technologies are designed to aid in the dispersal of chemical and biological control agents. Semiochemicals (pheromones, anti-aggregation chemicals) can be utilized to protect or concentrate localized populations of pests.

OBSERVATION AND REPORTING FREQUENCY (TEMPORAL CADENCE)

Surveys of disturbance events are temporally limited in that the duration of an observation is, in effect, a snapshot of the conditions at a given point in time. Ephemeral disturbance events can be entirely missed if the observation snapshots are too far apart, while persistent disturbance events can be observed through multiple observation periods.

Intraseasonal (short cadence) needs for tracking short-duration (e.g., defoliators) and multi-generation-per-year disturbance agents (e.g., southern pine beetles) require frequent observations. Ground observations, multiple aerial survey flights, and frequent remote sensing collections can be utilized to track the extent of a known ephemeral disturbance agent.

In an effort to differentiate between persistent and ephemeral disturbances, two FDM persistence products were developed. The 3-year and 5-year FDM Persistence of Disturbance (POD) products track deviations from prior season normals by looking for deviations over three consecutive overlapping 16-day compositing periods (spanning 32 days). This reduces some of the system noise; however, it does not track subtle changes due to the large class bins. A cumulative seasonal product may be able to track some of the more subtle changes, but this has not been developed. Additional noise reduction efforts to aid in tracking more subtle, but persistent, changes might be achieved through developing a drought-normalized adjustment based upon current monthly drought indices.

Interseasonal (moderate cadence) needs for tracking longer duration disturbance agents (e.g., mortality) require less frequent observation. *ForWarn* (chapter 6) produces several products that track these disturbance agents: full-archive change detection, 5-year change detection, 3-year change detection, and annual change detection (Hargrove and others 2009). Each dataset is a 24-day gap-filled composite of daily imagery produced every 8 days. FDM also produces two products that track longer duration disturbance agents: 5-year trend analysis and 3-year change detection products, where each dataset is a 16-day non-filled gap composite of daily imagery produced every 8 days. While the differences between the *ForWarn* and FDM approaches are subtle, the systems have significantly different intents. *ForWarn* is predicated on creating an absolute deviation from normal for quantitative assessments, while FDM is predicated on creating a user-oriented system to allow for direct interpretation of disturbance events to facilitate an observational survey and create a refined extent for the disturbance through IDS.

Annual reporting needs for area impacted by damage agents are currently being met with the IDS program. However, concerns over safety as well as customer needs for damage intensity information are driving the development of a revised system. A grid-based organization of geospatial data will be incorporated in the DASM Next Gen system, which will allow for better estimates of damage intensity over limited extents. The grid-based organization also will allow for the transition to an ORS-based system and a ground-based survey. It may be possible to incorporate sampling strategies, but this is not currently being considered.

Periodic national assessments, such as the 2010 National Report on Sustainable Forests (USDA Forest Service 2011), focus on semi-decadal tracking (long cadence) and are accomplished through a compilation of the FIA State reports and an aggregation of the annual IDS survey data. Though most States' inventory schedules data are annualized, mortality estimates are based upon observed recent mortality on plot samples (recent mortality within the last 5 years), which does not fit well with the annualized sample design. Mortality estimates can be improved using an intermediate assessment of mid-scale disturbance products. Possibilities exist to develop a calibrated dataset based upon the MODIS phenology dataset (2001–12) together with two separate archives from the USGS/Earth Resources Observation and Sciences (EROS) Data Center phenology dataset (at 250-m resolution) and the NASA/Stennis phenology dataset (a 232-m resolution dataset for 2001 through 2009). FHTET utilized the NASA/Stennis phenology dataset to calibrate against remeasured FIA plots to adjust the NDIRM host layers and bring the dataset to a 2011 vintage (Ellenwood and others [in press]).

Additional tools under development would allow for the compilation of long-term disturbance monitoring assessments. Trends in Canopy Change (TCC) is part of the National Land Cover Dataset to track decadal change in forest canopy (Coulston and others 2012). Monitoring Trends in Burn Severity (MTBS) utilizes the historical Landsat archive to map burn severity of large fires (Eidenshink 2007). A more complete method that tracks all disturbances throughout the Landsat archive is the LandTrendr/TimeSync (Cohen and others 2010). Though currently existing for the West Coast and a few isolated Landsat scenes, this dataset tracks disturbance at a 30-m scale throughout the 28-year historic record and allows for the characterization of the initial disturbance impact as well as the subsequent recovery. The long-term implications and utility of this dataset have yet to be fully realized. The ability to calibrate these disturbances can yield benefits for modernizing our estimates of existing conditions and the potential of future impacts of disturbance agents.

STRATEGIC SOLUTION

An overarching strategy is needed to integrate each piece of the monitoring assessments. As a one-stop shopping system, the FHP Mapping and Reporting Portal (FMRP) combines the inventory, real-time tracking, and reporting tools to allow for better planning and the potential for better integration of these separate technologies (fig. 7.2). The applications are independent of one another and operate at disparate scales. The integration of the toolsets requires skilled analysis to produce statistically robust and viable projects.

One path to better integration is to establish a standard evaluation grid. This grid framework would accommodate all survey methods (ground, aerial sketchmapping, and remote sensing), integrate with other geospatial data layers (tree species distribution, pest ranges, land cover, etc.), and provide set resolutions. FHTET is in the process of developing a national fixed grid at a 240-m cell resolution (approximately 6 ha) as a basis for all survey reporting. This 240-m grid aligns with key national, geospatial datasets, including National Land Cover Database (NLCD) and LANDFIRE. The 240-m standard has already been utilized to build and align a comprehensive Spatial Data Library of Geographic Information System (GIS) layers (soils, climate, species-specific tree host parameters, etc.) for NDIRM. By tying all forest health survey observations (ground survey points, sketch-mapped polygons and sample surveys) to the 240-m cells on which pest events occur, FHP can standardize the scale of its own data. By establishing a framework that borrows from a widely accepted national standard, FHTET has established a convenient basis for integrating forest health surveys, the NIDRM, remotely sensed data, and other important datasets and new reporting technologies such as HTML5/mobile device-based platform software.

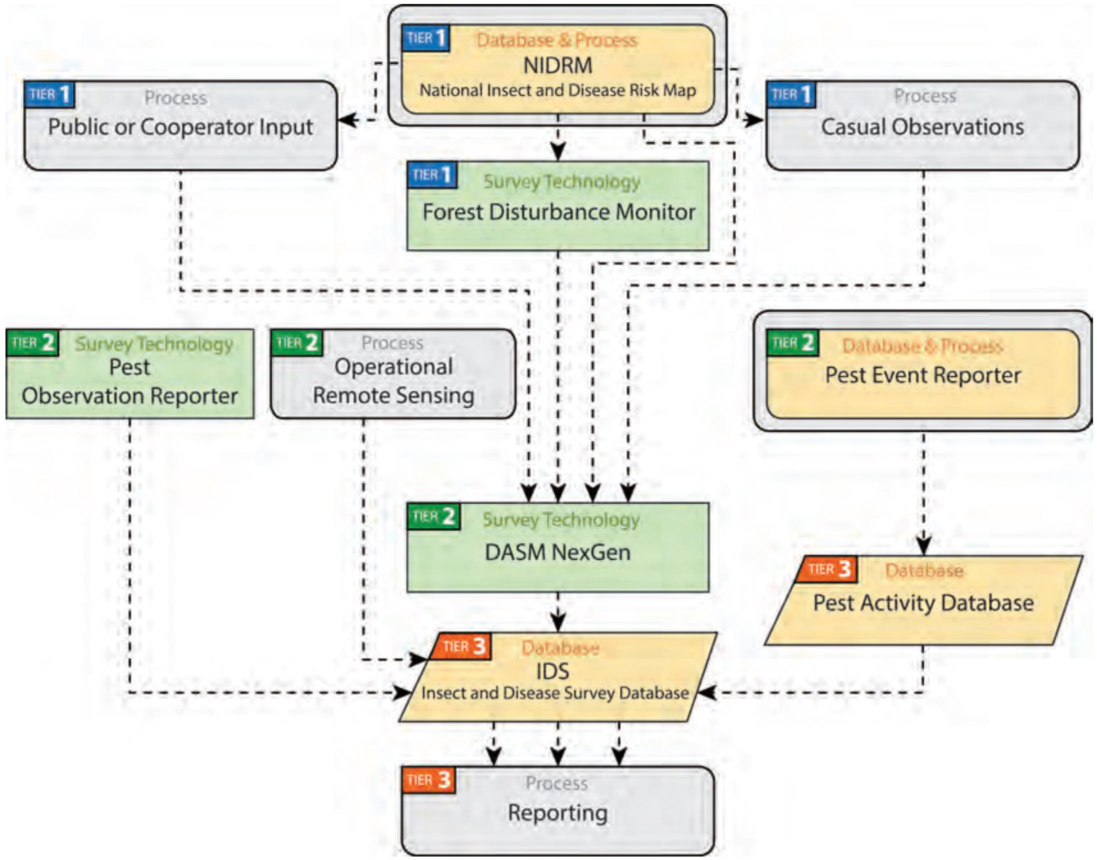

Figure 7.2—The Forest Health Protection Mapping and Reporting Portal combines the inventory, real-time tracking, and reporting tools to allow for better planning and the potential for better integration of these separate technologies. DASM= Digital Aerial Sketchmapping.

CASE STUDY 1—FOREST DISTURBANCE MONITOR

Forest Disturbance Monitor (FDM) is a Web-based forest disturbance data delivery system that was specifically designed for integration with IDS. FDM is designed to enhance the ability of forest health personnel to allocate resources and plan missions for aerial and ground forest health surveys.

The forest disturbance products used in the FDM are based on 240-m MODIS satellite data and are created from 16-day (RSAC) or 24-day (NASA) composites updated every 8 days. FDM utilizes two main types of forest disturbance products: the 3-year Real Time Forest Disturbance (RTFD) data, produced by both RSAC (Nielson 2008) and NASA (Hargrove and others 2009), and the 5-year Trend Disturbance Data (TDD) produced by RSAC (Chastain and others 2013). Collectively these are referred to as the Disturbance Composites. The 3-year RTFD dataset is a change-detection product that compares the current RTFD Normalized Difference Vegetation Index (NDVI) to a 3-year baseline of NDVI. RTFD is sensitive to defoliation events in deciduous forests, such as those caused by gypsy moth. The 5-year TDD is derived from a regression analysis of the past 5-year NDVI data with the slope parameter normalized. The TDD is sensitive to longer-term disturbances in coniferous forests such as those caused by mountain pine beetle.

Persistence of Disturbance

In addition to the composites, FDM produces 240-m 3-year and 5-year Persistence of Disturbance (POD) products. The POD is created by combining the negative departure values from normal NDVI values of the latest three Disturbance Composite products. The 3-year persistence is defined as those pixels whose NDVI values are significantly below normal as compared to the 3-year baseline and whose NDVI have remained substantially below normal for at least the latest two of the last three or all three RTFD composite periods (32 total days). The 5-year POD is defined as those pixels whose 5-year regression trend of forest NDVI have had a negative regression slope for at least the latest two of the last three or all three RTFD composite periods. A 5-year POD would indicate significant changes in forest structure.

Histogram Threshold Tool

The FDM is designed to allow the user to directly interact with the 3-year RFTD and 5-year TDD products using the FDM Histogram Threshold Tool. This tool is used to develop forest disturbance signatures by reclassifying the continuous Disturbance Composite data in real time. The Disturbance Composite data use only the reduced (below-normal) NDVI values of the disturbance data and exclude the above-normal NDVI values. This enhances the signal for the negative departures from normal and allows finer thresholding for the classification of the disturbance. Different levels of departure from normal NDVI are located at different positions within the Disturbance Composite histogram. The FDM Histogram Threshold Tool allows the user to select specific threshold ranges that best represent a potential forest disturbance. The severity of forest damage varies for different types of forest disturbances, as does the threshold range that best captures these disturbances in the MODIS-based Disturbance Composite data. This is illustrated in figure 7.3, where locations represented on the left side of the histogram have a much greater departure from normal NDVI and represent areas of severe disturbance such as fires, storm damage, and extreme insect and disease activity. Similarly, moderate severity disturbance values are typically found within the shoulder of the histogram, and the more subtle or less detectable disturbances are associated with the right side portion of the histogram. FDM also includes important ancillary data such as IDS data for

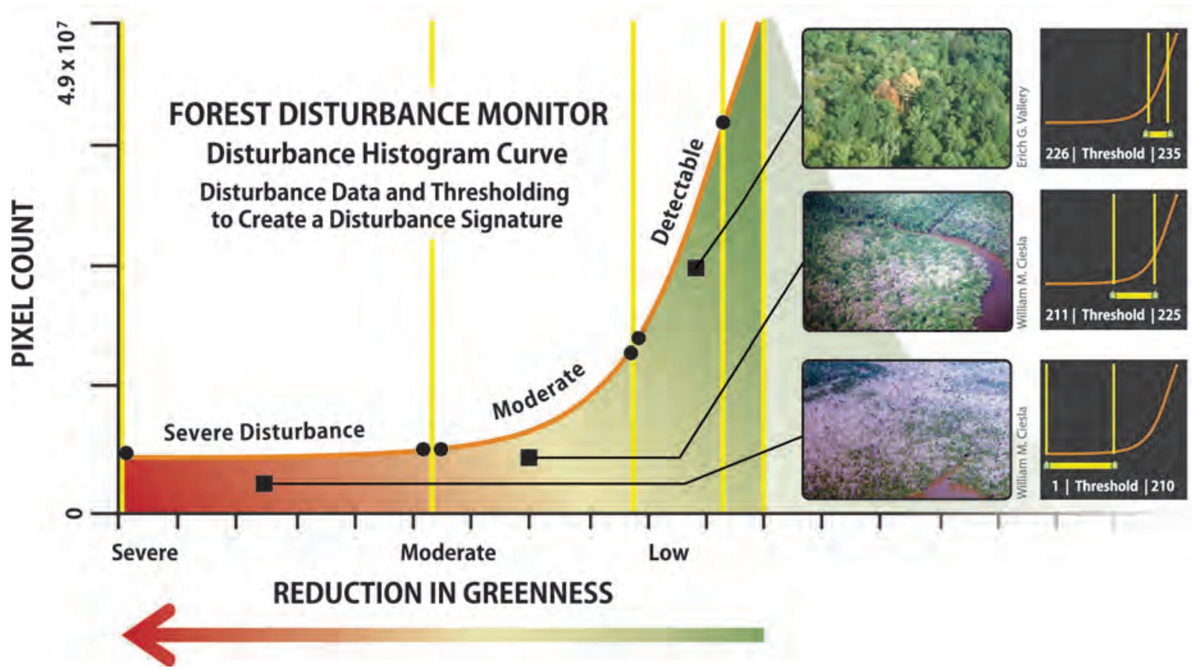

Figure 7.3—Examples of the application of the Forest Disturbance Monitor Histogram Threshold Tool and the degree to which the disturbances are reflected by departures from the normal Normalized Difference Vegetation Index.

the previous 5 years (dominant tree species, recent drought severity data, and past fire data) that allow the user to eliminate non-insect and disease forest disturbances.

FDM Process Procedures

The FDM system incorporates an intuitive three-step process that allows the user to (1) quickly scan and assess large areas for potential forest disturbances, (2) create spatial forest disturbance signatures using the FDM Disturbance Composite threshold tool, and (3) create downloadable datasets (polygon and raster) that can be used in aerial and ground survey missions and in subsequent GIS analyses (fig. 7.4).

The first step in the FDM process is to examine the Persistence of Disturbance data. The persistence data are designed as the initial targeting layer, allowing the user to quickly locate potential forest disturbance over a wide area. Compared to the Disturbance Composite data, the Persistence of Disturbance is a more conservative spatial estimate of a potential forest disturbance. The persistence data have other important advantages including reducing the amount of false positives due to atmospheric contamination from clouds and haze, and work as a reference guide when thresholding the Disturbance Composite data. The Persistence of Disturbance data are made up of three basic classes: (1) disturbance that is detectable, (2) moderate disturbance, and (3) severe disturbance. These classes are based on a combination of the temporal persistence and the degree of departure from normal NDVI. The second step in the FDM process involves creating forest disturbance signatures using the Histogram Threshold Tool and the selected current Disturbance Composite data. The thresholding is accomplished by adjusting the left and right slider located just under the histogram graphic tool. Any adjustment made to the histogram slider is updated immediately in the viewer, allowing the user to quickly create a disturbance signature that best represents the potential disturbance area. All pixels that fall within the adjusted range between the left and right slider will be visible in the viewer frame. The recommended starting thresholds are 100 and 225, which primarily capture moderately severe disturbances. The user can adjust the thresholds until the desired extent is reached. In the third step, the user creates polygons using the disturbance thresholded areas as a guide. These polygons are downloaded and utilized in the DASM system. These polygons contain attribute data based on the disturbance data including the creation date, the data source (RSAC or NASA), the name and date range of the Disturbance Composite, and the threshold range. The user may also assign additional attributes, such as the rationale for the polygon's delineation and the hypothesized (or verified) causal agent of disturbance, among other data needs.

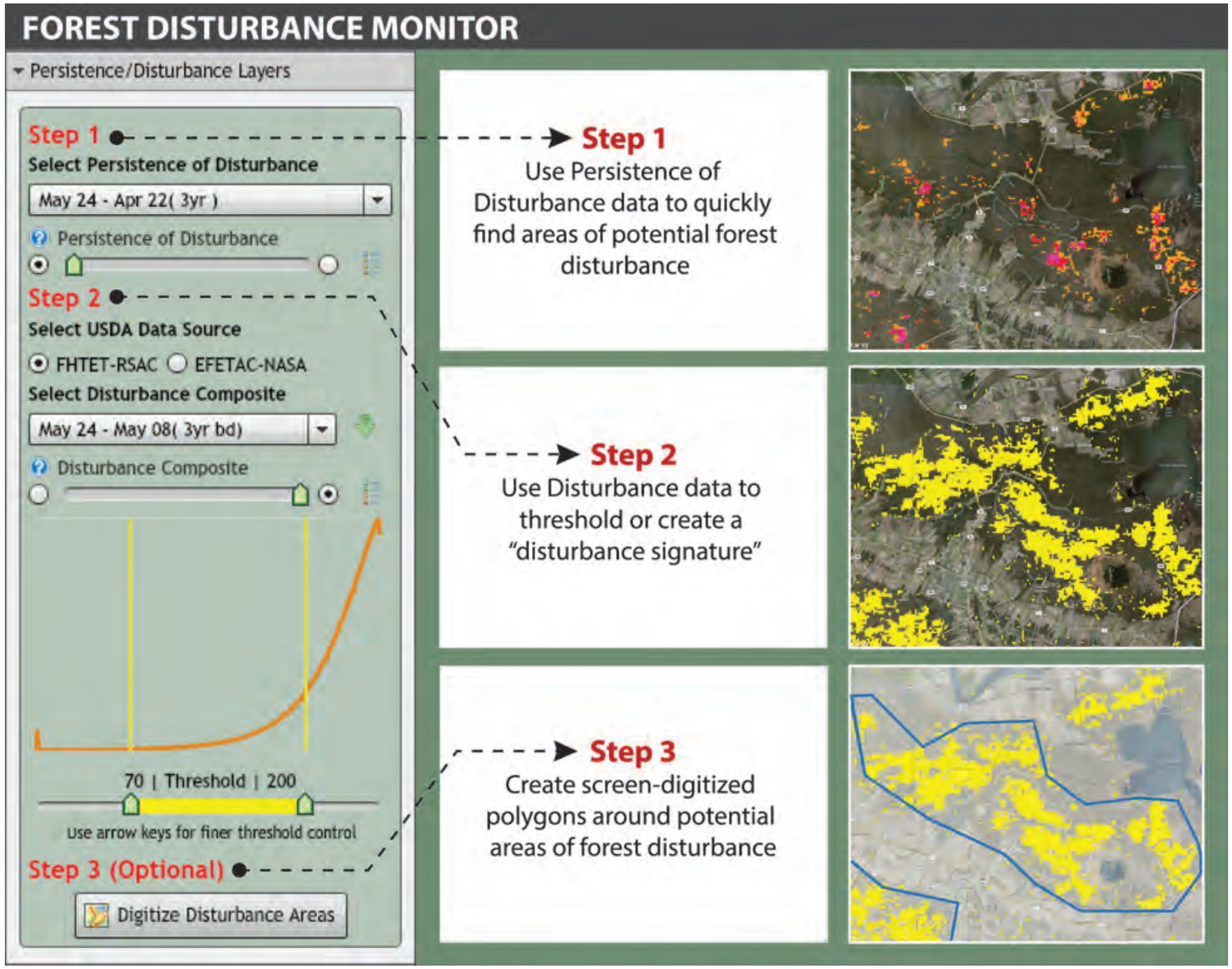

Figure 7.4—The Forest Disturbance Monitor (FDM) system incorporates an intuitive three-step process that allows the user to (1) quickly scan and assess large areas for potential forest disturbances, (2) create spatial forest disturbance signatures using the FDM Disturbance Composite threshold tool, and (3) create downloadable datasets that can be used in aerial and ground survey missions and in subsequent geographic information system analyses.

Example 1: Charles County, Maryland

In Charles County, MD, a fall cankerworm (*Alsophila pometaria*) outbreak occurred in April and May 2013. The FDM was used to create apparent forest disturbance signatures using the April 22 RSAC Disturbance Composite data using thresholds of 100–210. Screen-digitized polygons were created over the general area of the disturbance signature. An aerial survey was flown (by Biff Thompson, Forest Health Technician, Maryland Department of Agriculture) on May 15, 2013, using a DASM system. The resulting IDS polygons were then spatially assessed with the Disturbance Composite data (fig. 7.5). The results show good general spatial congruency of the disturbance signatures and the resulting IDS polygons.

An analysis of the Disturbance Composite data and the IDS data with Charles County, MD, shows 51 total IDS polygons, of which 33 polygons (65 percent) correctly overlay areas identified as potential forest disturbances using the FDM and the Disturbance Composite data. Eighteen of the 51 IDS polygons (35 percent) did not overlay any disturbance identified with FDM. This indicates that the forest disturbance data do not consistently detect all forest disturbances and are dependent on the severity and size of the disturbance. In addition, there were also areas that were identified as having forest disturbance but where no IDS polygons were generated. Overall, the results of this assessment show the FDM system performed as designed and successfully located a majority of the disturbance in an area verified as affected by a fall cankerworm outbreak.

Figure 7.5—A good general spatial congruency was found between Insect and Disease Survey polygons and apparent forest disturbance signatures created by the Forest Disturbance Monitor for a fall cankerworm outbreak in Charles County, MD, in April and May 2013.

Example 2: Atchafalaya Valley Area, Louisiana

An outbreak of forest tent caterpillar (*Malacosoma disstria*) began west and southwest of Lake Pontchartrain and New Orleans, LA (in St. James, Assumption, Lafourche and Terrebonne Parishes), in April and May 2013. The FDM was used to create apparent forest disturbance signatures using the April 30 RSAC Disturbance Composite data using thresholds of 100 and 220. Screen-digitized polygons were created over the general area of the disturbance signature. An aerial survey was flown by Region 8 personnel on May 6, 2013, using a DASM. The resulting IDS polygons were then spatially assessed with the Disturbance Composite data (fig. 7.6). The results show excellent spatial congruency between the disturbance data and the IDS polygons and indicated the FDM screen-digitized polygons adequately indicated the general areas of disturbance that required survey.

An analysis of the 114 total IDS polygons shows that 69 percent overlaid the thresholded forest disturbance signatures. There was an area of disturbance commission where forest disturbance was indicated by FDM but not by IDS to the west of Baton Rouge (West Baton Rouge Parish). This signature is most likely due to phenological responses of later-than-normal leaf-out in the dominant sugarberry forest type. Approximately 31 percent of the area had cankerworm (as identified by IDS) that the thresholded forest disturbance signature did not detect. Based on the IDS data, this was because these areas had light defoliation disturbance that was not detected by the disturbance data. This indicates that the forest disturbance data do not consistently detect all forest disturbances and are dependent on the severity and size of the disturbance event. Overall, the system performed as designed and indicated that disturbance was occurring in the area, providing data that the aerial surveyor could use as information when flying the overall affected area.

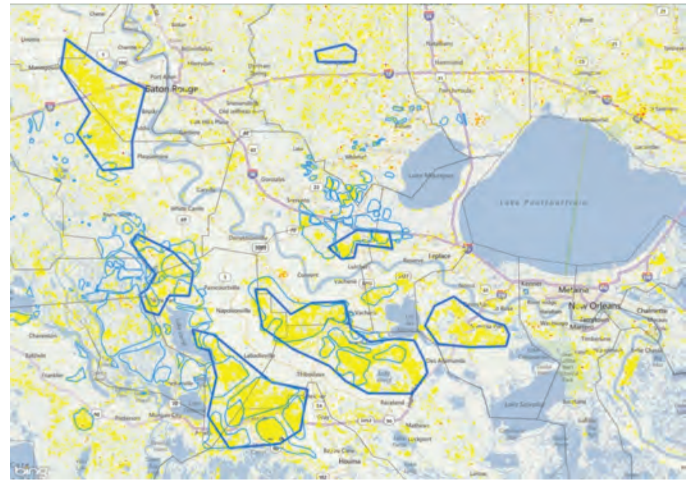

Figure 7.6— Excellent spatial congruency was found between Insect and Disease Survey polygons and apparent forest disturbance signatures created by the Forest Disturbance Monitor for a forest tent caterpillar outbreak near New Orleans, LA, in April and May 2013.

CASE STUDY 2—INSECT AND DISEASE SURVEYS

From 2000 through 2011, FHP's Insect and Disease Survey (IDS) program mapped and reported more than 18 million ha across the United States with significant tree mortality, with additional areas of other damage types as well. At a national scale, this mortality information is relatively coarse: areas mapped as having tree mortality can range from landscape-level epidemics to pockets of dead trees or widely scattered mortality intermixed with areas of healthy trees, and to lands that are not forested (USDA Forest Service 2009). Natural resource managers need more specific, consistently mapped, and appropriately scaled information about where dead trees exist. Other damage surveys are also warranted. Meaningful damage assessments that can be derived from focused post-processing of the national data are difficult because of different and uncertain spatial and temporal scales of the source data. Business needs can vary within each monitoring tier and at all administrative levels of the agency. There is not only a need to measure damage intensity but also an increasing interest in more specific information regarding the residual standing live trees remaining in pest-infested areas. To meet those needs, FHP is evaluating whether to shift from capturing data from "areas *with* tree mortality," to "areas *of* tree mortality," and to more accurately and usefully represent data about relative loss expressed as percentages of forest.

Digital Aerial Sketchmapping is FHP's primary method to survey the presence and impacts of forest insects, diseases, and other disturbances that lead to tree mortality or other damage impacting growth, health, and vigor. A network of FHP crews and State partners conducts aerial and ground-based surveys across State, private and Federal lands. Regional IDS data are edited to meet national reporting standards and transmitted to FHTET on an annual basis. FHTET then integrates the data into the FHP national Insect and Disease Survey (IDS) database and creates regional and national maps detailing forest mortality and other damage.

Data Standards and Guidelines

The data and methods FHTET uses to produce these maps and analyses are well documented, but due to the increasing importance, utility, and client base of the data, there is a national interest in improving accuracy and meeting data standards. However, despite significant investments to develop new standards, provide compliance training, and enhance technology, national standards are still too broad and provide surveyors too much latitude in how damage is recorded.

The Benefits of Insect and Disease Survey

FHP partners derive considerable benefit from their own aerial survey and pest-damage maps because they have an intimate understanding of both the pest patterns in their local landscapes and of the idiosyncrasies and tendencies of the mapping crews who observe and record the data. These benefits include:

- Assisting managers in meeting requirements for reporting on the status of forest insects and diseases on an annual basis (USDA Forest Service 1997)
- Summarizing disturbance events and trends for Forest Monitoring Reports and Biological Evaluations

- Contributing to regional and State highlights reports
- Detecting and mapping outbreaks of native and exotic insects and diseases (within limits of aerial surveys and levels of effort to investigate developing threats)
- Communicating with the public and elected officials
- Describing landscape-level impacts over time (within the statistical and biological constraints of these data)
- Locating studies to determine causal agents, extents, and severity of disturbance events
- Providing an approximate (first cut) at extent and severity of disturbance events in support of salvage and suppression projects
- Linking to risk-rating systems (appropriate when used as trend data and not for precise locations)
- Providing dynamic visual representations of insect/disease disturbance over time
- Providing timely disturbance information to assist land managers in prioritizing work
- Estimating acres impacted summarized by jurisdictional boundaries (e.g., Forests, State districts, State lands, and counties)
- Estimating snag densities at appropriate scales
- Training remotely sensed data

These benefits produce significant challenges when FHP aggregates regional data nationally. The sheer scale of uncertainties within, and inconsistencies between, the regional-level surveys inhibits FHP's ability to collaborate and share reliable information with its research partners. The uncertainties and inconsistencies restrict how the data can be (1) used to validate the NIDRM models and (2) integrated with cell-based, remotely sensed imagery or ground-based surveys.

Geospatial Technology

FHP is a leader in the collection and dissemination of geospatial data about forest health and, as such, recognizes the need to make significant improvements to the data. FHP understands that aerial survey data cannot reliably answer some basic management questions. Often, the IDS estimate of damage area is overestimated and the severity of mortality (dead trees per acre) is underestimated. Inconsistencies among datasets exist with regard to (1) spatial resolution of the delineated polygon, (2) thresholds of damage severity used to designate an area as damaged, (3) variability among damage signatures from region to region, and (4) variation with host/agent relationships among regions.

FHP has a need and an opportunity to better quantify the extent and severity of many of the most significant insect and disease outbreaks of the past decade, including the mountain pine beetle, beech bark disease, and emerald ash borer epidemics. ADS struggles with accurately estimating higher levels of damage associated with epidemic pest events. The ability to track multiple-year pest trends is often limited due to lack of consensus as to what areas will be flown in a particular year. A more cohesive structured program of work that considers priority lands regardless of ownership, predisposed conditions, and a monitored seasonal trend can improve the ability to track pest trends. New remote sensing methods can provide more accurate spatial location and disturbance intensity measurements; however, cost and timeliness are not comparable to the current aerial survey.

The Path to Better Insect and Disease Survey

With the rapid evolution of GIS technology and the Internet, it has become significantly easier to distribute geospatial data in general, and for FHP to collect, combine, and analyze information from a multitude of sources. Coincidently, these advances are coming at the same time as demands and expectations on FHP to improve the quality of its IDS data are increasing and as aviation risk management is pressuring surveyors to fly less due to concern for employee safety. The path to a better insect and disease survey includes a new survey strategy, refreshed DASM hardware and software, and a more centralized and coordinated national planning effort.

New survey strategy—FHP is considering developing a forest health survey strategy that gives top priority to operator safety, maximizes the quality and value of aerial sketchmapping, and improves other data streams. For example, to overcome limitations on aerial sketchmappers to observe, identify, and record pest events accurately during flight, the system needs to do a better job of accommodating data from ground observations. To address safety concerns, FHP is considering a new survey strategy that:

1. Combines remote sensing, risk modeling techniques, and local expertise to prioritize areas where sketchmapping flights are most needed;
2. Identifies modifications to mission profile (pattern, altitude, maneuvers) and/or choice of aircraft; and,
3. Augments aerial surveys with remote sensing wherever possible and prudent (e.g., where alternative technology can be shown to capture useful forest health data such as mountain pine beetle damage in remote, high-altitude terrain).

Refresh Digital Aerial Sketchmapping hardware and software— FHTET is upgrading the DASM and will deliver a mobile data-collection platform and back-end process that integrates aerial detection, ground survey, and remote sensing data with a standard spatial resolution. Current DASM technology allows for the delineation of forest-pest damage as well as the (1) identification of a causal agent, (2) damage type, (3) damage intensity, and (4) host type. Delineation of damage is done through on-screen digitizing, using a pen-tablet personal computer. FHTET is examining possible improvements to this delineation process within the DASM refresh. Improvements may include the introduction of a new delineation method based on the selection of predefined areas, or grid cells, at fixed resolutions. This new data-collection platform needs to be mobile and compatible with both aerial and ground surveys.

The refreshed DASM will utilize the standardized grid as its back-end framework. For example, instead of sketchmappers making rapid, and typically flawed, trees-per-acre (TPA) mortality estimates, they would simply attribute selected grid cells from a list of percent-of-trees-affected categories (e.g., 1-3 percent, 4-10 percent, 11-29 percent). Then, by applying that percent-class selection to TPA information already loaded in its grid-aligned GIS, DASM will be able to calculate a much more reliable and consistent measure of tree mortality. This will be accomplished by providing the forest cover and host layers used as a baseline to indicate whether an area is "forested," as well as by providing the presence and correct stocking of specific species, regularly maintained to reflect current composition/basal area over time.

The need for more centralized and coordinated national planning—State and regional partners have considerable leeway as to where, when, and how much area to survey. Although FHTET expects its partners to submit spatial data about the areas flown and not flown within their jurisdictions, it does not have adequate information to assess whether a decision not to fly certain areas was based on the local knowledge that these areas are likely pest-free, or based on information or evidence unrelated to pest biology (e.g., funding, aircraft availability, travel restrictions, and weather limitations). Recent experience shows that local flight planning decisions can subvert the ability of the national IDS database to track trends of major outbreaks, such as the mountain pine beetle epidemic. FHTET and the aerial survey standards committee are working to revamp a survey coding system that, in order to accommodate a variety of region-specific concerns, has grown too complex, inconsistent, and inflexible. Each of these potential developments suggests the need for a more centralized and coordinated national planning program.

SUMMARY

Effective use of limited financial resources is driving the need to increase efficiencies at all levels of natural resources management. In this era of data overload, the complex processes of information management are a distraction from the real need to focus information analysis into useable knowledge and decision support. Disturbance is a natural process, but sorting out which disturbances are significant can be burdensome. Does a single tree dying constitute a significant impact? It does if it is the start of an outbreak. Gathering historical data, analyzing current conditions, and projecting future issues is a sound pathway toward the endeavor of providing useable knowledge. The development of the technologies to support each step of the pathway has been highlighted in this chapter. It is important that future development focuses on incorporating new pathways to better integrate these individual technologies.

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