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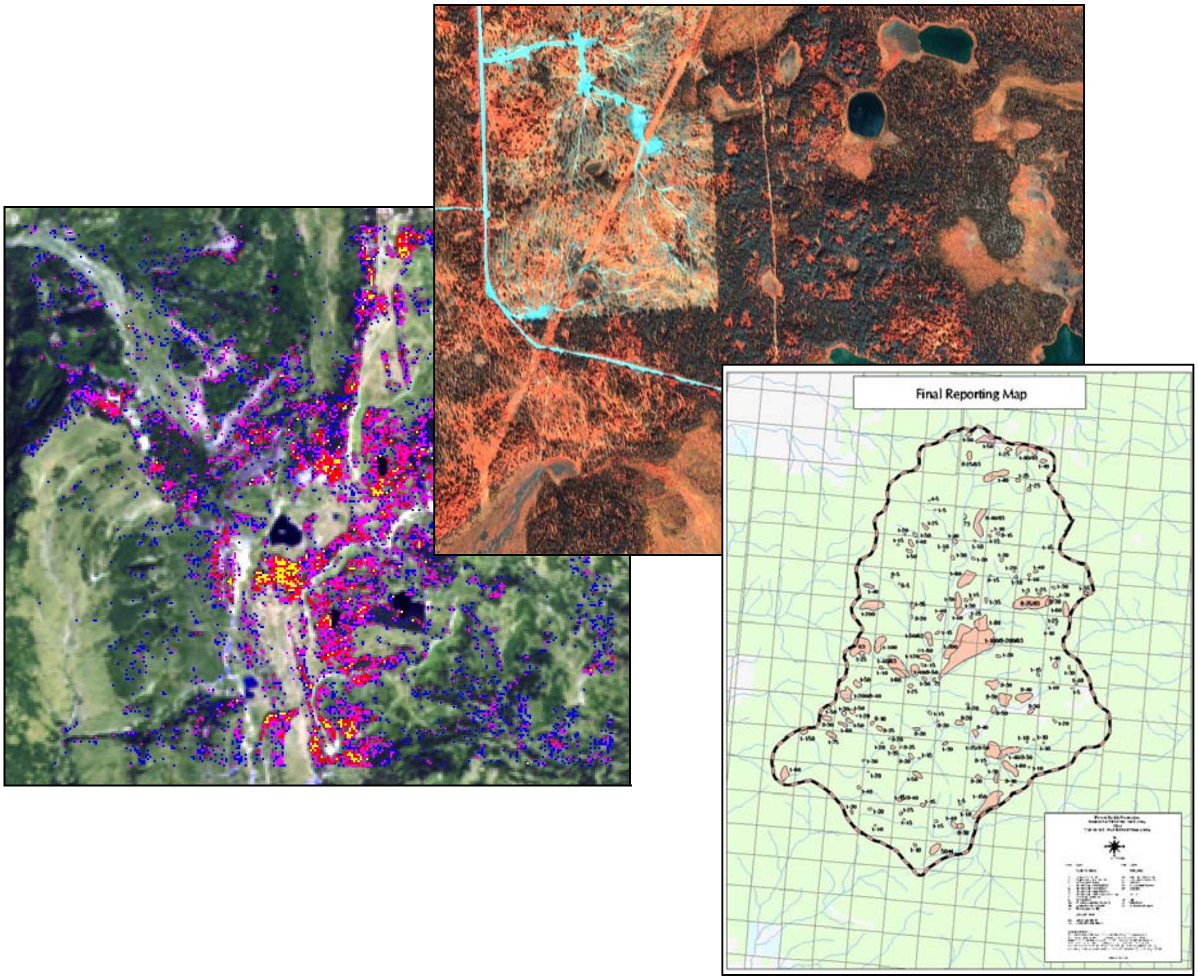
Aerial Detection Overview Surveys Futuring Committee Report



The Aerial Detection Overview Surveys

Futuring Committee Report

Submitted to

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***"You've got to figure out where it is
so you don't spend your money
on detection."***

Paul Ishikawa, 2002

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EXECUTIVE SUMMARY

Aerial Detection Overview Surveys Futuring Committee

August 2003

A review of current and potential remote sensing techniques including satellite sensors, airborne sensors, photography and aerial sketchmap surveys was undertaken over the past year with the assistance of Forest Health Protection (FHP) specialists (committee), remote sensing specialists, and the Remote Sensing Application Center. The effort began with the chartering and meeting of the committee in November 2002. The group developed national and regional pest specific considerations to help focus in on the many forest health issues nationally to reduce the immensity of the task. Once an examination of the current and potential remote sensing methods was done, it quickly became apparent that costs become prohibitive when the need for large scales and higher resolution increase.

Although such descriptions such as “intriguing”, “promising”, “optimistic potential” have been used with today’s remote sensing technologies, forest health information needs requiring higher resolutions over large areas of land makes the application of these technologies cost prohibitive.

Some satellite sensors (MODIS, LANDSAT, and SPOT) provide relatively inexpensive images over large areas for analysis that can be done at the National Forest level, but the resolution is too coarse to provide the information that current aerial overview surveys provide.

Some higher resolution satellite sensors (Ikonos, Quick Bird) provide much better spatial resolution that can detect small groups of dead trees but each scene covers such a small area (foot print) and the cost per scene is so expensive making a large area analysis cost prohibitive.

Airborne sensors using hyper-spectral and multi-spectral scanners is relatively new to the forest health remote sensing community and shows potential detection capabilities, but it too is expensive and the analysis technology lags behind what is currently available at the National Forest level.

Aerial photography, including imagery from digital cameras and scanned analog (film) photography, has provided valuable forest health information at medium to large-scale images. While the costs of acquiring this imagery are quite variable, the associated interpretation and geo-referencing of this imagery requires a great deal amount of labor. For a large area this is cost prohibitive. The advantage of aerial photography over aerial survey is that geo-positioning of identified forest health concerns are much more accurate and may provide information for project-level planning. Additionally, the imagery acts as a permanent record and can be utilized for long-term forest health monitoring. Disadvantages for aerial photography are costs and manual photo interpretation is subjective and tied to the skill of the interpreter. Because of the human factor of making a “call” on what is observed, it is much the same as aerial sketchmapping. Recent developments with “automated” interpretation/classification through software packages such as “Feature Analyst” and “3Cognition” offer the ability for repeatable ”objective” interpretation. Application of this technology holds some promise for the future.

Aerial overview sketchmap surveys can cover large areas in only a few days. It is a matter of processing priority that determines turn around time for this product, not its processing of paper maps into digital data. Meeting the minimum Forest Health Aerial Survey Standard of 1:100,000 scale basically states that high resolution (accuracy) is not critical to the data collection process of overview surveys. It has been long known that a land manager should never plan a timber sale from solely information off of an aerial survey map. The goal of sketchmapping is to detect and document visible mortality, defoliation and other visible forest change events only. The accuracy concerns are scale related, in that the aerial overview survey is for detection, not project level information needs. If greater information is desired, forest health specialists or land managers can determine what level of accuracy is needed to meet project demands. A combination of sketchmapping, imagery and ground data utilized in a multi-tiered sampling scheme can be utilized in large areas with forest health concerns.

Currently, FHP and its Remote Sensing Program in the Forest Health Technology Enterprise Team in Fort Collins, Colorado, in cooperation with the Remote Sensing Application Center in Salt Lake City, Utah work together on a variety of projects that continue to look into current and potential new remote sensing technologies in support of forest health needs. This effort should continue as new technologies develop and become more affordable.

Aerial sketchmap overview surveys are currently the staple to forest health information nationally and should continue with an emphasis on training, quality assurance and safety. Aerial survey coverage of forested areas continues to increase as does flight time and commitment to a useful product. Support for the digital sketchmap system has improved “turn-around time” for aerial survey data and in places revitalized the sketchmapping chore. This support should continue as technological improvements are applied to this system. Aerial sketchmap overviews surveys detect and monitor visible forest health issues; they document the event and get the forest health specialist to the affected area. It was never meant to be an analysis tool. Currently there is no other cost-effective detection process available. The Forest Health Technology Enterprise Team will publish the full report of the futuring of aerial detection overview surveys in the fall of 2003.

Table ES-1. Remote sensing methods table

Remote Sensing Systems	COST	TIME			SKILLS				
	Acquisition to Project Completion	Acquire/ Deliver Data	Processing/ Analysis	Total Project Time	Image Processing	Image Interp.	GIS	Traditional Sketchmap	Digital Sketchmap
SATELLITE SENSORS									
o Coarse Spatial Resolution									
MODIS	low	1 day	days	days	basic-adv	yes	yes	n/a	na
o Intermediate Spatial Res.									
LANDSAT	low	1-2 days	days	days	basic-adv	yes	yes	n/a	n/a
SPOT	low	3-5 days	weeks	days-weeks	basic-adv	yes	yes	n/a	n/a
o High Spatial Resolution									
Quick Bird	high	1 week	months	weeks-months	basic-adv	yes	yes	n/a	n/a
Ikonos	high	3 days	months	weeks-months	basic-adv	yes	yes	n/a	n/a
AIRBORNE SENSORS									
o Hyperspectral									
AVIRIS	moderate	weeks-months	months	months-year	advanced	yes	yes	n/a	n/a
Probe-1	high	weeks-months	months	months-year	advanced	yes	yes	n/a	n/a
o Digital Still Frame & Video									
35mm size cameras	moderate	days	weeks	weeks	basic	yes	yes	n/a	n/a
Medium format size cameras	moderate	days	weeks	weeks	basic	yes	yes	n/a	n/a
Full frame mapping camera	moderate	days	weeks	weeks	basic	yes	yes	n/a	n/a
Digital video camera	moderate	days	weeks	weeks	basic	yes	yes	n/a	n/a
AERIAL PHOTOGRAPHY									
o Film									
Small Scale (1:40,000 - 1:70,000)	moderate	days	weeks	weeks	basic	yes	yes	n/a	n/a
Med. Scale (1:12,000 - 1:24,000)	moderate	days	weeks	weeks	basic	yes	yes	n/a	n/a
Large Scale (1:8,000 or less)	moderate	days	weeks	weeks	basic	yes	yes	n/a	n/a
o Tape									
Analog videography	moderate	days	days	days	basic	yes	yes	n/a	n/a
AERIAL SKETCHMAPPING									
Traditional Sketchmapping	low	days	week	week	no	no	no	yes	n/a
Digital Sketchmapping	low	days	days	days	no	no	yes	yes	yes

Table ES-1. Remote sensing methods table (continuation)

Remote Sensing Systems	ACCURACY	EXTENT	EASE OF METHOD USE			TECHNOLOGICAL FEASIBILITY				
	Location (Spatial)	Footprint/ Swathwidth	Difficulty	Interpretability	Repeatability/ Consistency	Temporal Availability	Agent Bio-Window	Climatic Cloud Cover	Project Area	Damage Area
SATELLITE SENSORS										
o Coarse Spatial Resolution										
MODIS	250/500 m	2330 km	low	mod	high	10	10	6	>1M acres	200 acres
o Intermediate Spatial Res.										
LANDSAT	15/30 m	183 km	mod	mod	high	4	2	2	1M acres	5 acres
SPOT	2.5/10-20 m	60 km	mod	mod	high	6	4	4	100K acres	2.5 acres
o High Spatial Resolution										
Quick Bird	0.6/2.4 m	16.5 km	high	high	high	6	5	3	10K acres	< 1 acre
Ikonos	1/4 m	13.8 km	high	high	high	6	5	3	10K acres	< 1 acre
AIRBORNE SENSORS										
o Hyperspectral										
AVIRIS	20 m	10.5 km	high	high	high	7	6	7	10K acres	< 1 acre
Probe-1	5 m	6 km	high	high	high	8	7	7	10K acres	< 1 acre
o Digital Still Frame & Video										
35mm size cameras	+/- 12 m	< 1 km	mod	mod	mod	9	8	8	10K acres	point
Medium format size cameras	+/- 12 m	1 km	mod	mod	mod	9	8	8	10K acres	point
Full frame mapping camera	+/- 12 m	2-5 sq km	mod	mod	mod	9	7	7	10K acres	point
Digital video camera	+/- 12 m	< 1 km	mod	mod	mod	9	8	8	10K acres	point
AERIAL PHOTOGRAPHY										
o Film										
Small Scale (1:40,000 - 1:70,000)	+/- 12 m	9.1-16 sq km	mod	mod	mod	8	7	6	100K acres	< 1 acre
Med. Scale (1:12,000 - 1:24,000)	+/- 12 m	2.7-5.5 sq km	mod	high	mod	9	8	7	10K acres	point
Large Scale (1:8,000 or less)	+/- 12 m	< 2 sq km	mod	high	mod	9	8	8	10K acres	point
o Tape										
Analog videography	+/- 12 m	< 1 km	mod	low	low	9	5	8	10K acres	< 1 acre
AERIAL SKETCHMAPPING										
Traditional Sketchmapping	+/- 50 m	4 km	low	high	low	10	10	9	1M acres	point
Digital Sketchmapping	+/- 50 m	4 km	mod	high	low	10	10	9	1M acres	point

Note: Scale from 1 to 10 with
10 being most feasible and
1 being least feasible

BACKGROUND

This report is in response to the chartering (Appendix A) of the Forest Health Protection (FHP) Aerial Detection Overview Surveys Futuring Committee in 2002. The desired outcome from this effort was that the FHP Directors will: 1) Understand the costs and benefits of alternative ways to provide information from forest health overview surveys, including aerial sketchmapping, airborne sensors and satellite imagery; and be able to determine the preferred option(s) for provide forest health overview information in the future that address pest-specific, local, regional and national needs.

This effort was not intended to be a management review of the Aerial Survey or Forest Health Monitoring Programs, rather a look at other alternatives, costs and advantages, both now and in the future (5 to 10 years).

During the presentation of the executive summary at the August 2003 FHP Directors meeting in Anchorage, Alaska the issues of expense, cost versus risk, and FHP expertise were raised and were to be a part of the final report.

The following sections discuss the results of comparing some remote sensing methods for forest health detection and monitoring.

AUGUST 2003 COST RESPONSE SUMMARY

Due to differences in project, data, and remote sensing system specifications, as well as the variables of project scale and cost, it is impossible to propose a single data-collection method as the most cost-effective technology for use in supporting forest health detection and monitoring. Table ES-2 (below), an extension of the “Remote Sensing Methods Table” Table ES-1 (above), summarizes selected remote sensing methods based on three major features of comparison (costs, quality, and scope) that were used as the base of comparison for FHP Directors’ meeting questions. These summaries were prepared based on literature review, discussions with vendors, experts’ familiarity with the systems, and personnel experience to qualitatively define forest pest’s detection, recognition, and identification. (Note that actual costs are subject to change, and are provided here only for comparison purposes).

It is important to point out that Table ES-2 results **are not** site-specific forest pest detection analysis to assess the differences among the remote sensing methods under study. In other words, no field evaluations or remote sensing analysis were conducted per se. On the contrary, comparison is qualitative in nature and uses the standard approach for camera systems to measure their resolving power for feature detection, after Lillesand and Kiefer (1979) guidelines. Besides, this comparison does not take into consideration the extrinsic or intrinsic remote sensor factors like atmospheric conditions, flights motion or any other problems during data acquisition. Simply, we are interested in the ability of remote sensing systems to detect, recognize, and identify individual dead trees or defoliation damage based on area of analysis established by the committee. See Aerial Detection Survey Technologies Comparison section (page 14).

Table ES-2. A cost, quality, and scope features comparison of remote sensing methods and their ability to detect, recognize, and identify forest pest damage.

Remote sensing methods	Features to be compared			Sensor Capabilities to: *Detection (D), Recognition (R) and Identification (I) of forest pests
	Costs based on a Million acre	Quality imagery pixel size (in meters)	Scope	
MODIS	$2,000	Low spatial 250/500	Large area analysis	Detect and recognize objects if they happen over very large areas, no identification
LANDSAT	$3,000	Low-Med spatial 10/30	Large area analysis	Detect and recognize objects if they happen over large areas, no identification
SPOT	$35,000	Medium spatial 2.5/10 or 20	Med-Large area analysis	Detect and recognize objects if large areas, but no identification of individual dead trees
QuickBird	$292,000	High spatial 0.6/2.4	Small-Med area analysis	Detect, recognize, and identify individual dead trees, but low spectral resolution
Ikonos	$270,000	High spatial 1/4	Small-Med area analysis	Detect, recognize, and identify individual dead trees (10 meters tree crown diameter)
AVIRIS	$44,000	High spatial 20	Small-Med area analysis	Detect, recognize, and identify individual dead trees, and high spectral resolution
Probe-1	$308,000	High spatial 5	Small-Med area analysis	Detect, recognize, and identify individual dead trees, and high spectral resolution
9x9 camera	$252,000	High spatial 0.15-2	Small-Med area analysis	Detect, recognize, and identify individual dead trees, but low spectral resolution
645C camera	$232,000	High spatial 0.15-2	Small-Med area analysis	Detect, recognize, and identify individual dead trees, but low spectral resolution
Video Camera	$152,000	High spatial 0.5-2	Small area analysis	Detect, recognize, and identify individual dead trees, but low spectral resolution
Sketchmapping	$3,000	Depend on map scale	Small-Large area analysis	Detect, recognize, and identify individual dead trees, but no spectral resolution

*Detection discern separate objects discretely; Recognition determine kinds of objects, e.g., grass from trees; and Identification identify specific objects, e.g., live from dead trees (after Lillesand and Kiefer, 1979).

For example, MODIS and Landsat are the least expensive alternatives, and their footprint (coverage) is large; however, each pixel covers an area larger that a single tree crown, which makes identification difficult. Though more expensive, AVIRIS and Probe-1 provide high spectral resolutions at a cost competitive with aerial photograph.

Ultimately, the selection of the method can be done only after taking into consideration many factors, but most importantly: the type of data necessary for forest health detection. Identification, which is based upon textural characteristics, such as crown form/damage, are best met with higher spatial resolution sensors, while identification based upon spectral reflectance, such as faders, may be best met with higher spectral resolution sensors.

INTRODUCTION

A BRIEF HISTORY OF AERIAL DETECTION SURVEYS

The USDA Forest Service Forest Health Protection (FHP) and its State cooperating partners have been conducting aerial detection surveys for over 50 years. These overview surveys have provided essential information on insect and disease occurrence and other forest disturbance agents, and have been used for cost-effective and timely reporting and response to forest health conditions and trends. Users of aerial detection survey information include land managers and forest health specialists from federal, state, and tribal agencies, private industry, and the public. To conduct these aerial detection overview surveys, FHP sketchmappers fly over 2,500 hours, annually, covering hundreds of millions of forested acres. While all possible safety precautions are routinely exercised, there are inherent risks in using aircraft to collect data.

Recent advances in remote sensing technologies and image analysis techniques suggest there may be alternatives to aerial detection overview surveys that should be considered. Remote sensing has been applied to many natural resources detection needs, including methods used to classify vegetation and analyze data. However, remote sensing systems vary by temporal, spatial, and spectral resolution; in terms of forest pest detection, it has been difficult to develop guidelines with respect to “the best method” because it involves new technology, high costs, and expertise. Aldrich (1979) presents a review of remote sensing technology based on Forest Service user requirements, including sensor parameters, data quality, and cost-effectiveness, as a tool for wildland management.

SCOPE OF THIS STUDY

Forest change events, such as conifer mortality or defoliation, must have a significant visible damage signature to be detected either with the naked eye, visible in a photograph, or discernable from surrounding vegetation in a digital image. Damage from insects, diseases, and other causal agents that do not produce highly visible signatures will not be detected by any commonly used remote sensing method at a landscape scale; however, digital enhancement and spectral analysis—in conjunction with spectroradiometer data from ground-truthing—can reveal early signs of an outbreak where it is not otherwise visible. Use of an appropriate remote sensing method is thus critical for detection of agents of concern across a project area.

Remote sensing technologies have extended the ability of resource specialists to assess forest conditions, and these technologies are increasingly used to address natural resource management questions. But data acquisition and analysis in any form still requires the investment of time and money: use of digital and ancillary data must be well planned to gain the needed benefit (Bobbe et al. 2001). The Forest

Service continues to improve its suite of hardware and software tools for processing and analyzing remotely sensed data; most National Forest District and Field Offices included now have such hardware and software, but have limited expertise in processing and analysis of geospatial data sets using Geographic Information Systems (GIS) or remote sensing software, and less in selecting appropriate remote sensing technologies to address their data needs.

While various remote sensing methods have long been used in the Forest Service, new technologies are also being investigated for forest health assessment and damage detection. Each technology has its advantages and disadvantages. This report is not a complete or comprehensive comparison of all methods available, but a general discussion of options that may address the variables of scale, resolution, delivery time, and cost for natural resource assessment. Before continuing, the following paragraphs address some basic concepts central to this study.

Scale and Resolution

Two interdependent factors, scale and resolution, are central to every decision concerning data collection and analysis. Scale refers to the relative geographical coverage of a single image, and resolution refers to the level of detail in that image: the two factors generally have an inverse relationship (greater coverage yields less detail). Scales closer to 1:1 are considered larger scales, with less coverage on the ground; scales progressively further from 1:1 (for example, 1:20,000 or greater) are progressively smaller scales, with correspondingly greater coverage. These types of scales are usually referred as coarse or low-resolution methods that cover a large area (footprint), but do not provide the detail needed to identify dead trees or defoliation. High-resolution methods can support such identification, but only cover a small area (foot print), and may not be suitable for large landscape assessments because of cost and time requirements for data collection.

According to Bobbe et al. (2001), as the need for larger scales AND greater resolution increases, the cost of the data increases as well. The required level of detail of remotely sensed data needed in forest health surveys is relatively fine, which brings an expensive price tag in this day of expensive data acquisition and optimistic analysis efforts. The choice of a particular method must take into account the data quality requirements.

Geographic Accuracy

Two aspects of geographic accuracy of importance are geographic reference (spatial accuracy) and point-specific location of data. Regarding the first of these, all remotely sensed data that is registered by latitude and longitude or some other locator method, spatial accuracy is not an issue when data collection is conducted. It is only in aerial photography and aerial sketchmapping in which there is no geographic reference that accuracy is a potential issue. But even aerial photography that has been scanned and registered can be highly accurate for geographic location.

The second issue in geographic accuracy lies in location of specific point data, which favors high-resolution technologies over coarse ones, including aerial sketchmapping. Given the data collection variables in sketchmapping surveys (airspeed and map scale), for instance, it is understood that sketchmapping overview surveys are not expected to yield stand-specific data, but more a general, landscape-oriented representation of current forest health events. Because of the coarseness of such surveys, management activities such as a harvest or sanitation efforts cannot be planned from the resulting aerial survey maps: such data collection is primarily intended to indicate the general area of an event. Higher resolution ground surveys and mapping efforts must be subsequently accomplished guided by information from aerial surveys for management activity planning.

OBJECTIVES OF THIS REPORT

This report attempts to answer specific questions from the August 2003 Aerial Detection Overview Surveys Futuring Committee executive summary Directors':

1. How much more expensive are other remote sensing tools?
2. What are the costs and risks of aerial survey compared to other remote sensing tools?
3. Do we (FHP) have the skills to interpret other types of remote sensing data?

It is important to keep focus on the ability of remote sensing methods to quantify forest pest problems at local, regional, and national levels.

To answer these questions, the following plan was undertaken:

- Use existing information sources and/or local experts' knowledge on remote sensing methods including aerial sketchmapping as related to costs, data quality, and scope to be used as comparison factors to detect, recognize, and identify forest pest problems;
- Associate potential pest-specific considerations to the information from the previous item, focusing on various choices of remote sensing and aerial detection overview surveys to assess costs and risks to provide information for forest health decision-making;
- Generate a discussion regarding remote sensing availability, adaptability, and acceptability of preferred option(s) tailored to set ideas on needed skills for future forest pest management at local, regional and national levels; and
- Make some conclusions about the findings.

Because these items are interrelated, results are presented thematically. Definitions of some of the terms used in the report can be found at the end of the paper.

AERIAL DETECTION SURVEY TECHNOLOGIES COMPARISON

For classification purposes, land resources data can be acquired through “hands-off” systems, such as cameras and other sensors, or “hands-on” methods, such as maps generated by sketchmappers. The former can be further divided according to coverage, period, and the types of imagery generated, such as “high global coverage,” “regular global coverage,” “continuous coverage,” hyperspectral applications (Nieke et al. 1997), and various types of photography. Each method of acquisition has its own costs. The following sections detail the characteristics of each type of sensor—its strengths and weaknesses—and its relative costs for forest pest detection.

TEST AREA, SUBJECTS, AND SPECIFICATIONS

In November 2002, the committee met in Salt Lake City, Utah, to decide what remote sensing methods should be explored and what important regional specific forest health pests should be considered as examples for comparison. Along with important regional pests were damage patterns and three working area sizes were chosen for comparison of remote sensing methods. Aerial Survey Standards specified defoliation classifications for comparison was light (less than 50 percent) or heavy (greater than 50 percent), and tree mortality to have assigned tree counts or trees per acre estimates in conifers.

The agreed-upon regional pest categories and damage pattern categories to be used for comparison and evaluation of remote sensing systems are typical of common forest health issues. Since no comparison study was conducted, a literature review of existing remote sensing methods was substituted for the study. The committee developed the following guidelines for pest specific considerations.

Working Area Size Categories

Size of detection and/or classification area was simplified to three landscape size categories:

1. 10,000 acres or 15.6 square miles (m^2) (project size),
2. 100,000 acres or 156.3 square miles (m^2) (watershed size), and
3. 1,000,000 acres or 1562.5 square miles (m^2) (National Forest size).

These scales represent the range of most typical to most comprehensive study areas that may be covered by a remote sensing survey or analysis project area.

Forest Damage (Causal) Agents and Signatures

Knowing that the scope of the study was to be national, but conducted with regional and pest-specific considerations, the committee decided on the following important regional damage agents for detection: **East:** gypsy moth defoliation (in hardwoods); **South:** southern pine beetle (pine mortality; foliage faded to red); and **West:** bark beetles, including Douglas-fir beetle (fir mortality; foliage faded to red), mountain pine beetle–ponderosa pine (pine mortality; foliage faded to red), mountain pine beetle–lodgepole pine (pine mortality; foliage faded to red), and western spruce budworm and Douglas-fir tussock moth defoliation. It is expected, as in aerial overview surveys, that remote sensing tools must detect at a minimum these damage agents. If the damage is not detected, the specific tool is considered to be ineffective and not adaptable to forest health detection and monitoring needs.

Damage Types and Patterns

Damage Types. Damage types for study were consolidated to two types: defoliation and conifer tree mortality. Defoliation was categorized as “light” (less than 50 percent susceptible foliage) and “heavy” (greater than 50 percent susceptible foliage). Only gypsy moth defoliation was considered in the eastern hardwoods and spruce budworm and only Douglas-fir tussock moth defoliation was considered in the western conifers. Mortality was considered only for western and southern conifers: southern pine beetle in the South and Douglas-fir beetle and mountain pine beetle in ponderosa pine and lodgepole pine in the West. The damage signature for recent conifer mortality is tree foliage fading to a red hue, which makes it identifiable.

Damage Patterns. Damage patterns were important for defining impact across the landscape. Although no field tests were conducted for the report, the committee developed the following matrix to display hardwood and conifer forest damage patterns in order to compare remote sensing tools across various landscapes. The damage patterns were categorized as follows: a) WS (widely scattered)—several thousand acres of the same general damage across the landscape; b) WW (wall-to-wall)—damage goes for as far the eye can see; c) SC (small clumps)—1 to 50 acres in size; and d) LC (large clumps)—50 to several thousand acres in size. Table 1 illustrates these landscape damage patterns.

Table 1. Hardwood and conifer forest pest damage patterns across the East, South, and West, identified by their shape and continuity in the landscape.

DAMAGE	**Type of damage classified by its shape and continuity**							
	WS/SC		**WS/LC**		**WW/SC**		**WW/LC**	
	*Hardwood	**Conifer	Hardwood	Conifer	Hardwood	Conifer	Hardwood	Conifer
Light Defoliation		DFTM, SBW		SBW		DFTM, SBW		DFTM, SBW
Heavy Defoliation	GM	DFTM, SBW	GM	DFTM, SBW	GM	DFTM, SBW	GM	DFTM, SBW
Tree Mortality		SPB, BB	GM	SBP, BB,		SPB, BB		SPB, BB

*Hardwoods: GM (gypsy moth defoliation)
**Conifers: SBW (spruce budworm), DFTM (Douglas-fir tussock moth), SPB (southern pine beetle) and BB (bark beetles include Douglas-fir, ponderosa pine, and lodgepole pine)

REMOTE SENSORS CLASSIFICATION AND CHARACTERISTICS

For practical purposes, this report will concentrate on remote sensing systems that are being used or that have the potential for use within the Forest Service for forest pest detection. Such systems are both spaceborne and airborne, and operate at different spectral and spatial resolutions.

One thing to remember about satellite sensors is that they must "see" through the earth's atmosphere to collect ground-level data: cloud cover and other atmospheric disturbances can easily degrade the quality of the data. Another thing to remember is that most remote sensing images are often derived—the product of a translation of digital data to visual output. In these cases, the information is really in the data domain, not in an image visible to the human eye (like an aerial photograph), until the image is processed into pixel format. Therefore, often more data is available than can be readily seen.

Following is a short description of the different systems considered.

High Global Coverage (Low or Coarse Spatial Resolution)

<u>MODIS (Moderate Resolution Image Spectrometer</u>. This satellite-based sensor covers the United States twice a day, and the data is free of charge. Scientists created it to monitor aspects of global environmental change. It used Vegetation Cover Conversion (VCC) for large area change detection. Each image covers a large area (2330 km swath width by 10 km at nadir), and has 36 bands. The spatial resolution is 250 meters, 500 meters, and 1 km, depending on the band. Little work has been done to adapt these data to the forest health arena to date.

MODIS has had some success in determining percent of tree cover (in 10 percent increments). Its coarse resolution makes it unsuitable for typical conifer mortality (faders) detection unless it occurs in several thousand contiguous acres. Its success has been mapping the large fires of 2000 and 2002 in the western United States (see Figure 1) and to develop a global percentage of tree cover (Hansen, no date). It also provides a good background image on which to drape other layers, such as fires and map features.

Figure 1. MODIS terra satellite, 1 km. true color: western wildfire application.

Regular Global Coverage (Medium or Intermediate Spatial Resolution)

LANDSAT Thematic Mapper (TM). This intermediate spatial resolution method (30-meter pixel size) has a long history of providing digital data, and has an extensive archive dating back 30 years. Landsat has a footprint of 183 km x 70 km, with a repeat coverage of the same area every 16 days. Data has eight spectral bands: a panchromatic band (15 meter or 49 feet); one near infrared (IR), two mid-IR (indicating water absorption)—good for change detection; visible blue, green, red bands (30 meter or 98 feet); and a thermal infrared band (60 meter or 197 feet). Landsat TM is often used for image classification and vegetation mapping for large areas (e.g., 183x170 km—an area of 12190 m^2) (EO library, 2003) (see Figure 2). A mechanical problem with the Scan Line Corrector (SLC) has been detected since May 2003, and that unit is beyond repair. New software is trying to correct for the problem and corrected data was to be available in November 2003 (Space News 2003). In the meantime, Landsat 5 is still operational and providing this intermediate spatial resolution data.

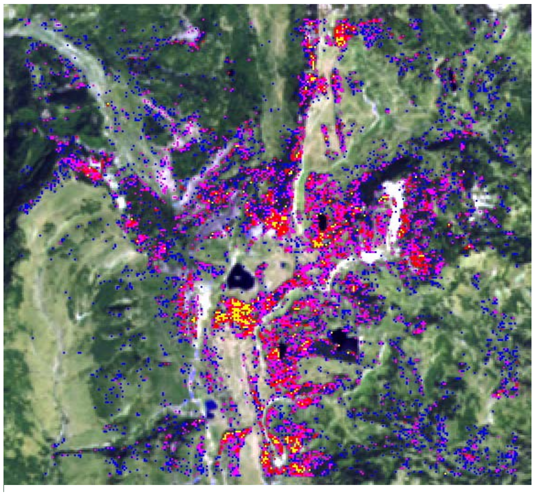

Figure 2. Landsat 5 TM subpixel analysis, Manti-LaSal NF, UT (Jan Johnson).

Mountain pine beetle-caused lodgepole pine mortality was estimated using Landsat and Ikonos imagery (Bentz and Endreson 2003). They found that Landsat data was useful to detect pine beetle outbreaks level in clumps of dead trees, but not so for endemic level populations of the species. Spectral discrimination was difficult to achieve using Landsat data, but Ikonos data offered a better alternative to detect small clumps of dead trees, as well as individual tree mortality from mountain pine beetle attacks.

SPOT (Satellite Pour l' Observation de la Terre). SPOT is a French satellite system designed specifically for vegetation mapping. With four operating satellites, SPOT can provide pan-sharpened image down to resolution of about 2.5 meters. Spot is also panchromatic, acquiring a single spectral band covering portions of the visible and near-IR, with a spatial resolution of 10 meters. SPOT has a 60 km by 60 km footprint (Spot Image 2003). For large area coverage, the price of the imagery can be considered moderate. Though having a smaller coverage area than Landsat, the satellite is targetable and, depending upon the latitude of the area of analysis, it can conduct repeat coverage of the same area every 6 to 10 days.

Continuous Coverage (High Spatial Resolution)

QuickBird. This is a 2.8-meter multispectral satellite remote sensor, with blue, green, red, and near-IR bands. A 0.6-meter panchromatic (black and white) band allows for the production of a 0.6-meter image sharpening, multi-band (color) product. It has a 16 km by 16 km footprint. QuickBird data has been studied in the Black Hills of South Dakota to detect ponderosa pine mortality over a small project area. Multi-spectral sensor parameters are: 2.5 meter (ground sampling distance—GSD—at nadir), 32x32 km area, and visible and near infrared ranges (b=450-520 nm, g=520-600 nm, r=630-690 nm, near-IR=760-890 nm). Average revisit period is 2-11 days, based on latitude and allowable off-nadir acquisition.

Ikonos. This is a multispectral, 4-meter resolution satellite scanner with the same four bands as QuickBird: blue, green, red and near-IR satellite system. Its footprint is 11 km by 11 km. A 1-meter panchromatic band allows for the production of a 1-meter pan-sharpened multi-band product (color). Like QuickBird, it is fairly good at detecting faded conifers primarily in patch size and larger. But, though counting individual dead trees is possible with the 1-meter pan-sharpening image, the images are somewhat blurry (Thomas 2004). It works well with "Feature Analyst," an extension available in the ArcView image application corporate ESRI software: this approximates doing photointerpretation (PI) work, but with ArcGIS software.

Ikonos imagery has been used to investigate detection and assessment of spruce beetle-caused mortality on the Kenai Peninsula (see Figure 3). The interpreters were able to extract larger areas of mortality using visual interpretation: however, due to the inherent difficulties in identifying visible signs of spruce beetle mortality (fickle signature), they were unable to extract information on single faders or small pockets of mortality from the Ikonos imagery (Space Imaging 2003, Johnson et al. 2002). Counting precise numbers of dead trees may not be possible for spruce beetle-caused mortality. This tool shows merit and additional work should continue in the forest health application arena.


Figure 3. Ikonos 4-meter multi-spectral imagery, Kenai, AK (Jan Johnson).

Hyperspectral Imagery

Also examined were the characteristics of hyperspectral scanners mounted in or on aircraft and flown at altitudes appropriate for the systems. These types of sensors are considered high spatial-resolution scanners.

AVIRIS (Airborne Visible/Infrared Imaging Spectrometer). This is a "whiskbroom" system operated by NASA/Jet Propulsion Laboratory (JPL). It collects hyperspectral remote sensing data from 224 channels covering the 0.4 to 2.5 µm spectral range at approximately 10 nm spectral resolution (Green et al. 1999). AVIRIS acquires data flying on the high-altitude NASA ER-2 aircraft at an elevation of 20 km, and has a 10.5 km swath width, which produces a 20-m pixel spatial resolution on the ground. The sensor can also collect data when mounted on a lowaltitude aircraft, resulting in a 2- to 4-m pixel on the ground. The 20-m pixel data was used as the base of comparison because cost information for the 4-m pixel was not available at this time.

Probe-1. Probe-1 is a "whiskbroom" sensor that acquires 128 bands covering the visible to the mid-infrared spectrum (400 to 2500 nm) (see Figure 4). Earth Search Sciences Incorporated (ESSI) in Missoula, Montana operates this airborne sensor. Spectral band resolution ranges from 10 to16 nm, common spatial resolution, a nominal five-meter pixel on the ground, and radiometric resolution of 12 bits. One data set covers approximately 17 km^2.

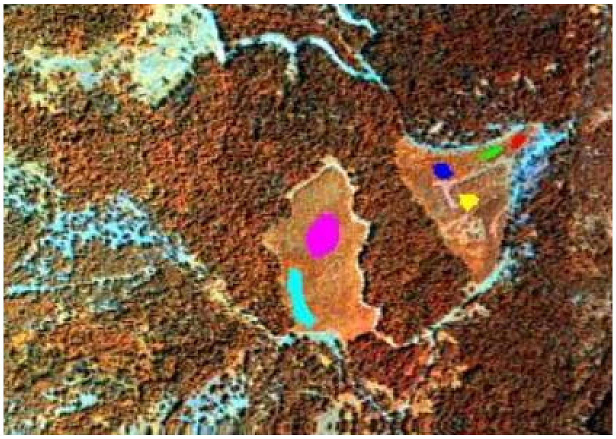

Figure 4. Probe-1 hyperspectral airborne scanner (Roberto Avila). Near Moscow, ID.

Aerial Photography

Aerial photography is generally classified into panchromatic black-and-white (B&W) or color, and depending on the film by their spectral ranges. Panchromatic film goes from 0.4 to 0.9 um; color film from 0.4 to 0.7 um; and color-infrared (CIR) films from 0.4 to 0.9 um. For vegetation discrimination and tree damage analysis, color-infrared (CIR) films are widely used (National Academy of Sciences 1970).

For any photogrammetric project, the larger the scale (closer to 1:1), the higher the resolution of the image. To plan a project, the selection of method is guided by the simplest and least expensive product to meet the photogrammetric objectives (Eliel et al. 1966). Large-scale images (1:100 to 1:2,000) can identify individual trees features—for example, color and CIR film can detect the degree of tree damage at a relatively high scale of 1:1,584. Medium-scale images (1:10,000 to 1:20,000) are used to define accurately stand boundaries, forest and non-forest land boundaries, and areas of tree disease. Small-scale images (greater than 1:20,000) identify large vegetation changes (see Figure 5).

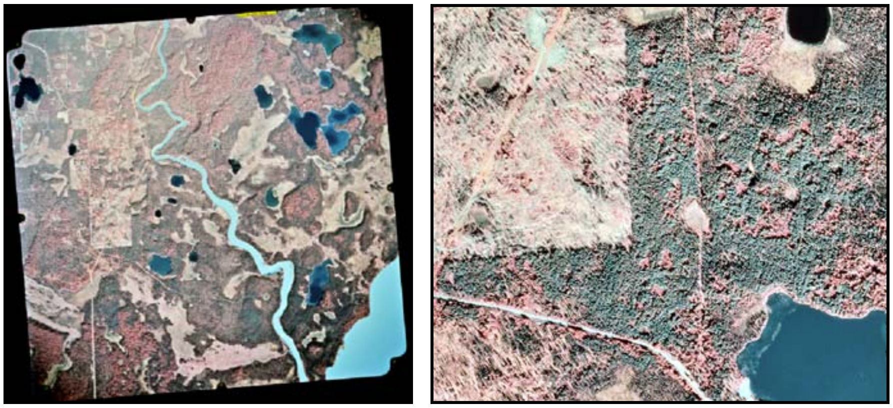

Figure 5. Medium resolution aerial photography, Kenai, AK (Jan Johnson). Left: scanned, registered image at 1:30,000. Right: full screen image at 1:7,000.

Aerial photography is also used to monitor nationwide extents of forested lands. The aim of the National Aerial Photography Program (NAPP) is to acquire and store imagery at 1:40,000 scale of the conterminous United States every five years using black-and-white or CIR film photography (Jensen, 1996). At this scale, a total of 10 stereoscopic photos and two flight lines are needed to cover a 7.5' quadrangle area or four photos per quad.

Conventional (Film-based) Aerial Photography. Film-based aerial photography continues to deliver high-resolution images of forestlands, so its use is critical to monitoring forest ecosystem changes. According to Aldrich (1979), aerial photography can be seen as the major source of remote sensing data within the Forest Service. In fact, the still-frame Zeiss single-lens mapping camera scale 1:15,840 with a 9 x 9-in (229 x 229-mm) format has been used widely in several National Forests to analyze and plan forest management options. Color photography is limited only by the type (quality) of the camera and the analysis employed to do photointerpretation (Sewell et al. 1966). Nowadays, color-infrared (CIR) aerial photographs are being used to quantify recognizable signs of tree defoliation caused either by insect outbreaks or disease.

However, detecting all diseases using aerial photography is not possible, so other sensors can complement the strengths of this method of detection. For example, studies using hyperspectral imagery have correlated foliage analysis with spectral band discrimination (Kokaly and Clark 1998, Yoder et al. 1995), and new sharpening techniques can be a means to combine aerial photography and hyperspectral imagery.

Digital Aerial Photography. Digital cameras are becoming popular within Forest Service. Several systems have been evaluated, and two models have been selected for color infrared digital imagery: the Kodak DCS 42 CIR (1.5 million pixels) and the new Kodak DCS Pro Back 645C CIR camera (16 million pixels). Both cameras produce natural color and CIR imagery useful for quantification of forest pest detection and other uses at various ground resolutions. The area covered by the DCS Pro Back is 11 times more than that of the DCS 420, resulting in a larger coverage area (Ishikawa 2003) (see Figure 6). Studies conducted by RSAC and others have compared data from CIR digital photography and what is on the ground: Finco et al. (1999) conducted a study regarding various forest fuel models (slash, shrub, timber, and other), and concluded that fuel field plots can be accurately tracked using CIR photography when crown closure was less than 60 percent.

Figure 6. CIR and true-color photography, pinyon pine mortality, Grand Junction, CO (Paul Ishikawa). Airborne sensor: Proback digital camera, 35 mm.

<u>Digital Aerial Videography</u>. Digital video camera imagery has been used for the detection of forest insect and disease problems. Videography arose within Forest Pest Management (FPM) as a method to enhance aerial sketchmapping, and to fill aerial photography data gaps (Myhre 1992). Everitt and Escobar (1992) and Forest Health Protection specialists have implemented different video systems for natural resources mapping. Because of ongoing technology innovation, various commercial video camera models are available. FHTET uses the Sony DCR-VX2000 video camera, with an image resolution of 720 x 480 lines (Russell 2003). This system is integrated with a GPS and 2-axis gyroscope to compensate for aircraft tilt and roll. Through a post-processing software package, the Airborne Video Toolkit (AVT), imagery can be automatically georeferenced (Linden et al. 1996). While widely useful, the resolution and area coverage is not always ideal for forest survey applications. Some success has been found in projects (10,000 acres) size application documenting southern pine beetle caused mortality.

Aerial Sketchmapping

Aircraft-based sketchmapping surveys have been the most widely used method of collecting and monitoring forest ecosystem changes over the past 50 years (McConnell et al. 2000). Because the interpretive element of data analysis takes place at the same time as data recording, aerial sketchmapping is more an art form than science, making the method highly subjective. The sketchmapper makes rapid decisions about damage, cause, location, intensity, surrounding conditions, size, and shape of affected areas, and must immediately capture these factors in shapes on a map or computer screen, while traveling between 80 and 130 miles per hour, at approximately 1,000 to 3,000 feet above the landscape. On test areas, the same area covered by the same person, often yields varying results, plus these surveys are not repeatable. But due to the quick acquisition time and low cost, this has been the most widely utilized tool in forest health detection and monitoring (see Figure 7).

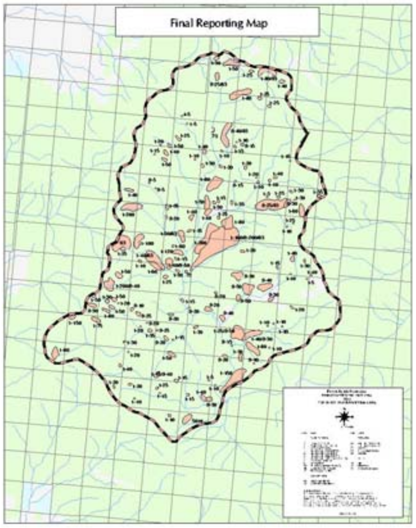

Figure 7. Sketchmapping output: digitized final map (aerial overview survey, scale 1:100,000, north Idaho: Kevin McCann).

RELATIVE COST COMPARISON

Costs for each type of sensor were estimated, except for aerial survey, which was actual costs. This is the most complicated type of comparison because data is collected at such widely different scales: it can be captured in a few small frames through QuickBird and Ikonos; a few photos or few flight lines of video; or in large coverage areas, as is the case of MODIS, Landsat (7.8 million acres per image), or one day's worth of AVIRIS data (6.2 million acres). Based on the type of data and area coverage, estimated costs were based on an approximate 1 million acres as the scenario for comparison. To compare costs, estimated costs for imagery purchased or acquired in small frames were extrapolated upward, while estimated costs for small-scale imagery covering large areas was extrapolated downward. A certain amount of distortion of costs was therefore unavoidable.

For instance, one scene of MODIS or Landsat covers more than 1 million acres. QuickBird and Ikonos sell data for a minimum area of 100 square kilometers, so cost was interpolated up. Likewise, SPOT coverage was below the acreage set, and Probe-1 imagery for one day's worth of data is around 444,000 acres, which must both be multiplied to reach 1 million acres. One day of AVIRIS data covers around 6.2 million acres, but its costs were estimated based on 2.8 million acres' worth of data used to survey the Black Hills National Forest. Likewise, FHTET-Fort Collins was contracted for aerial photography image acquisition for the Black Hills National Forest, and that project became the basis for estimated costs because of its extensiveness over the same area as was the aerial sketchmapping.

Because of the variables described above, costs derived are only relative and approximate. Real cost data for hyperspectral sensors, for instance, are still unknown because of its relative newness to the market and the limited number of vendors. Some of the price of imagery was acquired on the Internet. Additional price information was also acquired by talking to marketing personnel of remote sensing data vendors (e.g., Probe-1 data). FHTET specialists provided useful cost information for aerial photography and videography.

In summary, cost estimates were organized by type of data, quality of data (pixel size), scope, and final product rectification. Generally, the higher the spatial and spectral resolutions, the higher the price of imagery over the study area. Because higher resolutions necessitate smaller footprints, more data per square kilometer, and more processing time (labor), was required. Overall, image processing and analysis are the most expensive component of any remote sensing project, and must be a separate area of study for forest health applications.

In the case of the aerial survey example costs were actual, coming from the 2003 Rocky Mountain Region overview survey of the Black Hills National Forest, with two observers using two digital sketchmap systems using a three miles flight line spacing (Johnson 2003).

Comparison Assumptions

It is important to point out that, in developing the cost estimates, all information is based on in-house estimates where facilities, equipment, and expertise exist. Forest Service personnel have the skills to interpret these remote sensing data, except possibly hyperspectral, which would be outsourced. Major assumptions include:

1. Hardware and software (remote sensing, GIS, and others) have already been purchased.
2. The remote sensing analyst has a medium to advanced degree of knowledge and skills to conduct image analysis and processing.
3. All imagery is georectified—if not done, georectification costs are based on remote sensing lab charges.
4. Overhead costs such as office space, lighting, etc. are not included in the estimates.
5. The measuring ends with a final ARC shape file with final attributes.
6. Reporting, distribution, and publication costs are not included in the analysis.

Cost Factors

The total cost of a project regardless of the type of remote sensing method used can be broken down into three major components: materials and/or data acquisition, labor, and operating expenses.

Materials/data. Materials and/or data acquisition costs include acquisition of remote sensing data and, if necessary, any other peripherals needed for data acquisition during flight time. It also includes expenses for rolls of film and hardcopy maps used to complement the image acquisition. Depending on the type of remote sensing method, it may include very inexpensive materials like hardcopy maps, digital GIS-based data, or very expensive data, such as QuickBird, Ikonos, Probe-1, and others. (One-time major equipment costs have not been included here—current digital mapping cameras can cost $1.5 million; the DCS Pro Back 645C CIR camera costs about $25,000—so these costs are not included in the estimates.)

Labor. Labor costs for a survey include all expenses necessary to generate final maps based on image analysis and classification. Flight preparation generally takes two to three days to verify project area coordinates. Film processing, film to title, film to print, and scan pertains to conventional aerial photography. Map processing costs are grouped to include aerial sketchmapping expenses, such as costs for pilot time, lead sketchmapper time, and post-processing and planning tasks time. Analysis and processing costs refer to those remote sensing expenses related to image pre-processing, analysis, processing, classification, and post-processing (GIS based), as well as georectification when necessary—as is the case of aerial photography and videography (this task is influenced by time and skill of the analyst). In general, airborne hyperspectral data can be georectified or there are utilities to do so, but data takes longer to analyze than multi-spectra data. Ground-truthing is considered part of any remote sensing project, as the resulting data are used for system validation. This includes the acquisition of ground data in the form of polygons, points, or lines of major features of interest (vegetation) using a Global Positional System (GPS).

Operating Expenses. Operating expenses include tasks related to aircraft use time, per diem costs for personnel, and fixed operation tasks for aerial photography, videography, and sketchmapping. These costs can be applied to any pest-specific project, though it is possible that less time will be needed to detect and recognize dead trees caused by beetle infestations, for instance, than trying to identify needle cast of defoliation at early stages of pest development. There can be many factors to take into consideration to detecting a specific forest pest, but aerial sketchmapping guidelines have been given specifically to detect and recognize pine beetle infestations in southern conifers (Billings and Ward 1984).

Table 2 is a cost estimate summary of remote sensing methods and aerial survey selected for comparison.

Table 2. Estimated costs of aerial detection survey systems including remote sensing sensors and aerial sketchmapping.

Description	Remote Sensing Methods										
	Landsat			Commercial		Hyperspectral		Aerial Photography		Video	Visual
	MODIS	*Landsat	SPOT	QuickBird	Ikonos	**AVIRIS	***Probe-1	Film 9"x9"	Digital 645C	Digital	Sketchmap
MATERIAL/DATA											
Image purchase		$600	$4,275	$244,836	$222,585	$36,000	$50,000				
Film								$11,128			
Hard copy maps											$100
TOTAL MATERIAL	**$0**	**$600**	**$4,275**	**$244,836**	**$222,585**	**$36,000**	**$50,000**	**$11,128**	**$0**	**$0**	**$100**
LABOR											
Fly preparation	$200	$200	$200	$200	$200	$300	$300	$300	$300	$300	$300
Ground truething	$5,000	$5,000	$5,000	$5,000	$5,000	$6,500	$6,500				
Film processing								$5,980			
Frames to title								$1,800			
Frames to print								$9,600			
Scan								$30,000			
Map processing											$3,678
Geo-rectification								$250,000	$250,000	$14,000	
Analysis & process	$6,000	$18,000	$24,000	$42,000	$42,000	$80,000	$80,000	$384,000	$384,000	$384,000	
TOTAL LABOR	**$11,200**	**$23,200**	**$29,200**	**$47,200**	**$47,200**	**$86,800**	**$86,800**	**$681,680**	**$634,300**	**$398,300**	**$3,978**
OPERATING EXPENSES											
Aircraft								$8,000	$8,000	$14,000	$3,376
Per diem and other								$1,442	$1,442	$2,884	$1,845
Fixed operation								$4,550	$4,550	$9,100	
TOTAL OPERATING EX.	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$13,992**	**$13,992**	**$25,984**	**$5,221**
TOTALS	**$11,200**	**$23,800**	**$33,475**	**$292,036**	**$269,785**	**$122,800**	**$136,800**	**$706,800**	**$648,292**	**$424,284**	**$9,299**
Start to Finish Product	**2 weeks**	**4 weeks**	**2 months**	**8 months**	**8 months**	**1 year**	**1year**	**1 year**	**1year**	**1 year**	**3 weeks**
COVERAGE AREA											
Square mile	8996	12,190	1,369	1,563	1,563	9,692	694	4,375	4,375	4,375	4,375
Acres	5,757,440	7,801,600	876,160	1,000,000	1,000,000	2,800,000	444,160	2,800,000	2,800,000	2,800,000	2,800,000
COSTS											
Per square mile	$0.97	$1.75	$22.63	$186.90	$172.66	$12.67	$197.12	$161.55	$148.18	$96.98	$2.13
Per acre	$0.002	$0.003	$0.04	$0.29	$0.27	$0.02	$0.31	$0.25	$0.23	$0.15	$.003
Per million acres	**$2,000**	**$3,000**	**$35,000**	**$292,000**	**$270,000**	**$44,000**	**$308,000**	**$252,000**	**$232,000**	**$152,000**	**$3,000**
CHARACTERISTICS											
Spectral coverage (nm)	459-2155	450-2350	500-1750	450-900	450-850	380-2500	400-2450	400-900	400-900	400-900	NA
Spectral resolution	Discrete	Discrete	Discrete	Discrete	Discrete	10 nm	Discrete	Discrete	Discrete	Discrete	NA
Spatial resolution (m)	250/500	15/30	2.5/10-20	0.6/2.4	1/4	20	5	0.5	1	1	Discrete
Spectral bands	5	7	3	4	4	224	128	3	3	3	NA
Swath width (km)	2,300	185	60	16.5	13.8	10.5	1-6	3.6 km	4 km		NA
Temporal (days)	1-2	16	6-10	2-11	3	Variable	Variable	Variable	Variable	Variable	Variable

*FS has cooperative agreement, much imagery is free. **Assumes 1-day of flying (clear weather). ***Assumes 2.5-day of flying (clear weather).

Sources: cost estimates were derived from various sources including literature review, FHTET personnel from the Remote Sensing and Image Analysis Program Area, and authors' personal experiences.

COST AND EFFECTIVENESS

The determination of alternative or complementary remote sensing methods to complete aerial detection overview surveys must be focused on simplicity, cost, and effectiveness as it applies to forest health detection and monitoring for the Forest Service. The question is: what method will provide acceptable quality outputs for forest pest detection at a reasonable price tag? An attempt was made to make a fair comparison among the different sensors in the study. However, as Aldrich (1979) and Ciesla and Eav (1987) found, it is very difficult to make a completely objective comparison due to differences in project scales, timing, and expertise. We can, however, summarize some of the capabilities of different remote sensing systems, focusing on their strengths and weakness, as well as their cost per acre. The following additional information is to help clarify Table 2.

MODIS data is best used to detect forest changes when such changes occur over large areas of analysis, but is too coarse for forest pest detection. Landsat is considered spatially “intermediate,” and it is relatively inexpensive (less than $600 per scene). Image analysis and processing are fairly straightforward because, generally, the data is geometrically and radiometrically calibrated. The image analyst deals with few spectral bands for analysis. Landsat imagery is still too coarse for detection of small clumps of tree mortality less than five acres patch size, in areas of less than 20 percent tree mortality. Detection of very large patches of heavy mortality where there is primarily only one tree species, such as the mountain pine beetle outbreak in ponderosa pine in the Beaver Park area, Black Hills National Forest of South Dakota, have been analyzed. Using the 2001 to 2002 change detection classifications, Landsat detected large wildfire areas, but could not detect tree mortality due to bark beetle activity with any certainty where mortality affected 3-10 trees per acre or less (Johnson and Inman 2003). Detecting individual red (dead) trees is still a challenge for Landsat. In dense-canopied forests, stand replacement disturbances such as clear-cuts can be accurately monitored with Landsat data (Cohen et al. 2002). Also, in consistent nadir imagery, multi-temporal change detection can be achieved.

QuickBird and Ikonos, the two commercial multi-spectral scanners, offer high spatial resolution, but still low spectral resolution. Though individual and small clumps of dead trees might be detected, their cost is high—$292,000 and $270,000 per million acres, respectively. Comparison between these data sets has not been experienced, and it might be useful to test spectral sharpening in combining QuickBird and CIR data, for example. Environment for Visualizing Images (ENVI) software has spectral sharpening algorithm to do so, and it can be promising to improve classification. For example, a study done by Capolsini et al. (2003) on which they compared ETM+, SPOT, Ikonos, and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) remotely sensed data to map coral reef habitat in South Pacific islands. They demonstrated that ETM+ and Ikonos agreed in classifying coral reef components when few training classes (three to seven) were used for coral reef habitat mapping. This type comparison could be used for QuickBird and aerial photography to see if they might produce the same results to classify forest pest problems.

QuickBird and Ikonos might offer an alternative to photography where 0.6-meter imagery is suitable. Aerial photography offers a higher spatial resolution at a slightly lower price ($252,000 and $232,000, respectively), but at the loss of radiometric resolution. Due to the limited sensitivity of the film to record a wide range of light, film has a lower radiometric resolution compared to digital systems, which are often recorded in a 12-bit resolution. This allows for user control or contrast, which is helpful in identifying forest health problems. Ikonos can detect small groups of dead trees, but each scene covers such a small area (footprint) and the cost per scene is expensive, making large area coverage very expensive. Data from these sensors have been used in land urban planning for environmental analysis and monitoring—much smaller areas of interest.

Airborne and spaceborne hyperspectral sensors can be a viable alternative for forest pest detection and identification. They offer high spatial and spectral resolution at a higher cost ($308,000 per million acres for Probe-1 data, for instance). A great advantage in using hyperspectral imagery is that, due to its high spectral resolution, fine spectral differences can be studied to track vegetation changes for planning for future management alternatives (Avila 2003) and potentially, the spread of a forest health concern. Forest pest signature analysis using hyperspectral imagery is being studied and comparative studies are starting to emerge; however, the technology requires a steep learning curve. Examples of forest pest studies using hyperspectral remote sensed data have been done at university settings, and in special government and industry settings (such as by Kodak). To yield hyperspectral forest pest and disease discrimination analysis comparisons, more work needs to be done. From this analysis, AVIRIS ($44,000 per million acres) and Probe-1 ($308,000 per million acres) costs were estimated. AVIRIS can derive low-flight data at 4 meters pixel size, but the imagery is more expensive. Probe-1 at 5-meter spatial resolution makes an attractive choice for vegetation discrimination (Avila 1999), but it is also an expensive option.

In summary, hyperspectral systems are relatively new to the forest health remote sensing community, and show potential to analyze forest health conditions. High spatial and spectral resolutions make these scanners the right choice when biophysical information is extracted in order to study phenological changes and quantify temporal reflectance spectra. However, this technology, too, has an expensive, small footprint, and the analysis expertise lags behind at the National Forest expertise level.

Aerial photography has been used extensively in the Forest Service for individual projects. The cost of collecting the images, if photointerpretation is done on a large area, can become relatively expensive. In addition, spectral resolution determines the level of spectral analysis. For example, 9x9 aerial photo and 645C cameras' cost per million acres is around $252,000 and $232,000, respectively. Current use of digital cameras has been limited to very small project areas (plots or transects): it can be expensive when covering large project areas like the Black Hills National

Forest due to data acquisition time requirements (see Table 3). Resolutions can be quite high: film resolution of a 9x9 camera can be as high as 500 megapixels; current digital mapping cameras produce an image of 128 megapixels; the DCS Pro Back 645C is a 16 megapixel CIR camera. The smaller footprint takes more flight paces to cover the same area at the same resolution; however, due to the advantages of a digital system (radiometric resolution) with on-the-fly contrast change, a lower spatial resolution image can potentially support more accurate interpretation.

Exact photointerpretation of photo images is generally unrepeatable because of the human factor of making a “call” on what is observed subjectively and much the same as in aerial sketchmapping. However, a call can be changed easily because the image is permanent and not moving even though it was taken from a moving aircraft. However, new methods under development at RSAC involving a computer-generated stereo mode can offer even greater capabilities to review final photointerpretation work (Caylor et al. 2002).

In comparison to other techniques, aerial photography is valuable for quantifying events that have already taken place, such as defoliation, tree mortality, and other events (Aldrich 1979), but may not necessarily capture all changes occurring at the landscape. Hyperspectral sensors, on the other hand, because of spectral resolution, may track fine details that, once measured, will help to support silvicultural treatments in time to avoid severe spread of a damage agent into the forest.

Airborne videography, can be expensive and yield only low-resolution images. It offers some advantages, as recorded images can be viewed in the aircraft to verify coverage, be available for analysis immediately after flights, and an audio track can be added to record related event occurring during flights. However, georectification, image processing, viewing discrete images, and mosaicking can be difficult (Lillesand and Kiefer 1979). (The Airborne Video Toolkit was developed to provide a quick-and-dirty rectification). To collect video imagery at finer scales, flight line swath width must be narrow, making for many more flight lines than is normally done in aerial photography missions (3 to 4 flight lines per mile). Thus, in all cases, there is more flight time required with videographic sensors than for photography or for sketchmapping (Russell 2004, Thomas 2004). Videography may better be used as a sampling tool for strip sampling than for complete block coverage.

Sketchmapping offers a simple and quick alternative to record forest pest infestation on a map: that is why it has been widely used in the Forest Service. Aerial sketchmapping can cover large areas in only a few days; it is a matter of processing priority that determines turn-around time for the final product, and not in processing paper maps into digital data. It is very inexpensive ($3,000 per million acres), but it does not provide any spectral capabilities for analysis. The goal of sketchmapping is to detect and document visible mortality, defoliation, and other visible forest change events; meeting the minimum Forest Health Aerial Survey Standard of 1:100,000 scale basically states that high resolution (accuracy) is not critical to the data collection process of overview surveys. However, it has been long known that a land manager should never plan a timber sale solely from information on an aerial survey map: if greater information is desired, forest health specialists or land managers must include another method in a multi-tiered sampling scheme.

This comparison was aided by adapting the comparison standards for camera systems by Lillesand and Kiefer (1979) that assesses qualitatively differences among such systems. We caution that this comparison does not take into consideration the problem of image degradation due to atmospheric conditions, sensors reflections, and inherent motion during flights. We were interested only in the ability of remote sensing systems to detect, recognize, and identify individual dead trees or defoliation damage. Table 3 is a summary of the remote sensing methods studied, the features used for comparison, and a qualitative description of sensors' capabilities.

Table 3. A cost, quality, and scope features comparison of remote sensing methods and their ability to detect, recognize, and identify forest pest damage.

Remote sensing methods	Features to be compared			Sensor Capabilities to: *Detection (D), Recognition (R) and Identification (I) of forest pests
	Costs based on a Million acre	Quality imagery pixel size (in meters)	Scope	
MODIS	$2,000	Low spatial 250/500	Large area analysis	Detect and recognize objects if they happen over very large areas, no identification
LANDSAT	$3,000	Low-Med spatial 10/30	Large area analysis	Detect and recognize objects if they happen over large areas, no identification
SPOT	$35,000	Medium spatial 2.5/10 or 20	Med-Large area analysis	Detect and recognize objects if large areas, but no identification of individual dead trees
QuickBird	$292,000	High spatial 0.6/2.4	Small-Med area analysis	Detect, recognize, and identify individual dead trees, but low spectral resolution
Ikonos	$270,000	High spatial 1/4	Small-Med area analysis	Detect, recognize, and identify individual dead trees (10 meters tree crown diameter)
AVIRIS	$44,000	High spatial 20	Small-Med area analysis	Detect, recognize, and identify individual dead trees, and high spectral resolution
Probe-1	$308,000	High spatial 5	Small-Med area analysis	Detect, recognize, and identify individual dead trees, and high spectral resolution
9x9 camera	$252,000	High spatial 0.15-2	Small-Med area analysis	Detect, recognize, and identify individual dead trees, but low spectral resolution
645C camera	$232,000	High spatial 0.15-2	Small-Med area analysis	Detect, recognize, and identify individual dead trees, but low spectral resolution
Video Camera	$152,000	High spatial 0.5-2	Small area analysis	Detect, recognize, and identify individual dead trees, but low spectral resolution
Sketchmapping	$3,000	Depend on map scale	Small-Large area analysis	Detect, recognize, and identify individual dead trees, but no spectral resolution

*Detection discerns separate objects discretely; Recognition determines kinds of objects, e.g., grass from trees; and Identification identifies specific objects, e.g., live from dead trees.

Forest Health User Acceptance

User acceptance of remote sensing technologies has been and will continue to be mixed. The Forest Service users' community will not likely accept global coverage methods, specially those large footprints, because of the disparity between project area and data coverage. Aerial photography and aerial sketchmapping surveys are methods widely accepted in the Forest Service because of their history and proven uses: they will continue to provide valuable forest health information at small to large scales. Acceptance of new technologies will probably take time and occur on a pest-by-pest basis.

Aerial sketchmapping surveys have been recognized for over 50 years as an efficient and economical method of detecting and monitoring forest change events over a large forested area. Because it is a relatively low-cost method—requiring little technology for processing and analysis—aerial sketchmapping is often relied upon to provide coarse, landscape-level overviews of forest health conditions, but not repetitive or spectral analysis capabilities. For this next level of analysis, photography can be used as a complement in a multi-tiered process of detection, monitoring, and evaluation, using ground sampling techniques to verify and augment it. Eventually, the capabilities of other sensors might be accepted as complementary techniques, and then, upon familiarity, as primary techniques to data acquisition.

Even though, in theory, other remote sensing methods could be accepted and used now, the technology is not familiar the Forest Service primarily because of a lack of trained remote sensing image analysts. For interpretation of hyperspectral data, for example, little expertise exists within the Forest Service. QuickBird and Ikonos might not be economic feasible for large forest pest areas of analysis, so they might never might be taken into consideration in an operational basis, though such data will work for small areas of analysis. This represents a conundrum: acceptance of new technologies may be dependent upon training, which will be justified by acceptance of those technologies.

<u>From a remote sensor's point of view</u>: remote sensing methods are undoubtedly effective aerial detection overview surveys to assess forest pest conditions. Remote sensing can, not only identify resource features, but also provide the supporting detail to help analyze and interpret biophysical concerns, thereby helping to reduce analysis time and improve overall planning productivity. Attention should be taken to the resultant spatial precision, since precision allows for the analysis with other resources concerns (e.g., critical habitat for endangered species). A combination of methods should be an optimal choice to analyze and define forest pest management options. With respect to remote sensing skills, it is necessary to train a work force to provide the skills necessary to effectively utilize these tools.

<u>From an operational forester's point of view</u>: aerial sketchmap overview surveys are currently the staple for forest health information nationally, and should continue with an emphasis on training, quality assurance, and safety. Aerial survey coverage of forested areas continues to increase, as does flight time and commitment to a useful product. Support for the digital sketchmap system has improved "turn-around time" for aerial survey data, and in places revitalized the sketchmapping chore—although pre-flight preparation and post-flight processing remain a grueling part of aerial sketchmapping, whether it is on paper maps or digital. This support should continue as technological improvements are applied to this system. Because of their short turn-around time, sketchmapping and digital aerial photography have their advantages over some Landsat or commercial satellites. However, more choices for data acquisition can deliver data at a particular period of time. The window of opportunities for data collection can always be available for sketchmappers to do the job, as flying is not often affected by cloud cover. In the case of QuickBird and Ikonos, they can deliver the imagery relatively quickly, but it will cost much more. But, because of whether conditions, it might be very possible for satellite systems not to get a clear view of the area of analysis. With respect to hyperspectral imagery, it will require a trained workforce before it becomes an practical option (and this may take years).

From a forest health specialist's point of view: depending on scale, aerial sketchmap or multispectral systems can be used to survey when the damage is visible, but does not convey information on fine spectral differences useful to study biophysical changes (e.g., tree stress from disease). Hyperspectral data can provide more information because of its higher spectral resolving power. Spectral signatures can differentiate spectral profiles of healthy and unhealthy vegetation in some cases (e.g., fertilized or unfertilized forest stands) (Avila 1999).

With respect to the question: Do we (FHP) have the skills to interpret other types of data? Expertise within the Forest Service exists for most types of data except hyperspectral, and it is generally centralized at the Regional Office level with some field offices also having the skill level.

From a decision-making manager's point of view: to be cost-effective, it is necessary to assess a remote sensing method's cost against desired data quality. Wright et al. (1992) conducted conventional aerial photography and IR video imagery to study not only data quality, but also to derive cost estimates. Cost-effectiveness drives technology, and current data collection methods have focused on aerial photography and sketchmapping for cost-effectiveness at typical project scales. But with a growing emphasis on landscape-scale analysis there will be greater demand for high multi-spectral data and for site-specific hyperspectral data, even though these are high-volume, costly, and more complicated to analyze. Appendix B, is a matrix representation of project area scope, cost per acre, and forest pest considerations that offers a basis for selecting a remote sensing method (notice: this matrix is a work in progress).

The whole process of identifying appropriate sensor technology for each study case could be automated in a user-friendly computer-based (Web-based) development environment in which prices of imagery for remote sensing methods can be updated and the user can generate realistic project cost projections. This system can support the decision-making process for technology selection. Thomas (2003), for instance, has been working in a computer application using ArcView software that helps to do flight planning and derive cost estimates for aerial photography. It is the opinion of the authors that this decision making matrix for remote sensing applications should be further developed.

Availability to FHP Users

Remote sensing data are or can be available to resource analysts specifically for vegetation classification. Archive imagery is available from the Aerial Photography

Field Office for photography, from the USDA Foreign Agriculture Service for satellite imagery archive, and from the USDA Forest Service RSAC for satellite data MODIS (no cost). The principal complication lies in the timing of new image acquisition: it must be collected during the period that the conditions of interest are most visible—the biological window in which damage signatures are most visible for the species of interest (McConnell et al. 2000; Ciesla and Eav 1987)—to support project definition and planning. For example, to plan an AVIRIS flight requires at least a year of preparation due to airplane deployment and availability, and six months for image delivery. QuickBird and Ikonos can be acquired at a short notice, but at a price. Sketchmapping offers a quick turn around time for data acquisition that makes them suitable for quick forest pest assessment. In short, we can say that remote sensing data is not available every day; it will depend on type of data needed and time available to get it.

The Forest Service maintains facilities to provide end-users with hardware and software for image processing and spatial analysis. Even though hyperspectral remote sensing data creates large data sets, new algorithms in some image processing packages can assist in manipulating them: for example, principal component Minimum Noise Fraction (MNF), a data redundancy technique, reduces data file sizes, and might be applicable for enhancing acquired data.

Current Status

As it stands right now, forest health management practices do not incorporate the latest remote sensing technology, but rely on aerial surveys to provide general forest health condition information. Some static and derived forest pest models, such as the Forest Vegetation Simulator (FVS) pest extensions, are being used across forest stands in the landscape; however, there are issues with respect to data gaps that are not resolved yet. Remote sensing could complement FVS output to provide up-to-date information for decision-making.

Current technology trends promote a rapid deployment of remote sensing scanners for more powerful applications (e.g., QuickBird-type and hyperspectral sensors). Aerial photography and sketchmapping are two historical areas of expertise well-developed in the Forest Service; however, except at national centers, the Forest Service has few qualified personnel working in remote sensing technology at the operational level. It seems there is a lack of expertise to be addressed if other remote sensing methods are to be effectively employed. Until more remote sensing methods are accepted, it will difficult to conduct technology transfer. However, General Dynamics Corporation, under a contract with the Forest Service, will provide spatial services (GIS) to the Remote Sensing Laboratory in Sacramento (Pacific Southwest Region) and the Regional Office (Geospatial Solutions 2004).

There is a likelihood that the industry will move away from conventional film-based camera systems and toward digital frame camera systems: RSAC is pursuing the use of the DCS Pro Back camera to collect imagery (Ishikawa 2003). Cameras of 128 magapixels are commercially unavailable; however, costs are currently quite prohibitive. New high-resolution satellites are available for data collection, and as prices structure becomes more competitive, more interest will develop in this option. Sketchmapping continues to be widely used, though training and experience are ongoing concerns. Sketchmapping takes aptitude, practice, and many hours of experience to do well, and must be built on familiarity with aviation management.

CONCLUSIONS

This report attempts to answer the Forest Health Protection (FHP) Aerial Detection Overview Surveys Futuring Committee questions by examining aerial detection survey sensors and methods and their relative costs, quality, and scope in detecting and identifying forest pest problems. There are no simple answers to the Directors' questions, as there is no single best method to yield the most cost effective, timely, and appropriate quality data for the task at hand. Following is a discussion on the Directors' questions based on the finding of this report.

How much more expensive are other remote sensing tools?

> The analysis showed marked cost differences among the remote sensing methods analyzed. Relatively low-cost methods include MODIS, Landsat, and sketchmapping. MODIS, at approximately $2,000 per million acres, is an inexpensive alternative, but its footprint cannot resolve forest pest damage, at least over very large areas of analysis. Landsat, at approximately $3,000 per million acres, offers an alternative for forest pest detection when the damage covers few acres, but cannot detect individual dead trees. Sketchmapping overview surveys, at approximately $3,000 per million acres, provides a shape of the damage on a paper map; its footprint is based upon the map scale in use, but produces only approximate locations and general damage descriptions. SPOT, at approximately $35,000 per million acres, has a small footprint, but still cannot detect individual tree mortality. QuickBird and Ikonos, $292,000 and $270,000 per million acres, respectively, can detect individual tree mortality; however, it is expensive data if used for large areas of analysis. AVIRIS and Probe-1 price of imagery is also expensive, and at 20 m and 5 m spatial resolution, respectively, cannot detect individual tree mortality; they are better used to conduct spectral profile analysis to keep track of temporal changes at the canopy level. Aerial photography, even though is expensive, offer the best spatial resolution for individual tree mortality.
>
> Table 3, above, summarizes the cost involved in conducting a forest health detection project for an area of analysis.

Note: This list of sensors is not comprehensive, as other options continue to surface. One sensor that was not included in this analysis is OrbView-3, the first commercial satellite to provide one-meter panchromatic and four-meter multispectral (8 km swath width) data (Geospatial Solutions 2004). The OrbView-3 satellite orbits the earth around 15 times, i.e., approximately every 94 minutes, and could become a source for quick and large-scale data acquisition.

What are the costs and risks of aerial survey compared to other remote sensing tools?

> The purchasing of commercial or government-supplied imagery, either airborne or satellite, does not require any risk from the client point of view, since remote sensing data providers supply the final product (i.e., the digital data). However, relative costs and risks associated with in-house aerial survey techniques can be compared among those systems that require airplane maintenance and operation: aerial photography, videography, and sketchmapping. All three bear the costs and risks of aircraft use; beyond these, videography consumes the most flight time of the three when collecting data for a large area; it is best suited for use over a small area of analysis—in the neighborhood of 10,000 acres (Spriggs 2004). As with any aerial survey method, a project might require so many flight lines that the cost of acquired imagery is more expensive than data purchased from another source. A cost-benefit analysis could be developed to find out if it is worth to acquire such imagery. With respect to other remote sensing methods, image analysis and processing represents the highest cost from the start to finish product, though most satellite or airborne imagery is provided with georeferenced data, saving the cost of that step in data preparation generally associated with aerial photography and sketchmapping.

Do we (FHP) have the skills to interpret other types of remote sensing data?

> Forest Service remote sensing analysis skills exist, but some expertise—especially for hyperspectral data analysis—is lacking within the FHP staff. Multi-spectral image analysis and processing has been well-defined, but while the same image analysis principles for multi-spectral data processing also apply to hyperspectral data, the latter requires advanced expertise, ground-truthing, and specific interpretative user's skills. Much of the interpretation work can be outsourced.

In conclusion, no single or ideal method exists when dealing with specific scales, change signatures, spectral differences, and other data needs. Ultimately, a combination of remote sensing methods can contribute to a multi-tiered sampling approach if more information is needed beyond the typical aerial detection overview survey. If additional or greater information is not needed a strong aerial survey program, that includes aviation management (which includes risk management), observer training in both safety and quality assurance for timely data reporting can continue to be the first step of forest health detection and monitoring.

GLOSSARY

Ancillary data is any type of spatial or non-spatial information that can be utilized to provide support for classification work: for example soils, geology, watershed boundaries, vegetation maps, slope, or aspect (Jensen 1996). The term can be used interchangeable with the term "auxiliary data."

CCD charge-coupled device is a micro-electronic silicon chip—solid-state sensor that produces electronic charges when electromagnetic energy is captured (Lillesand and Kiefer 1979), as a result of taking a photography.

Hyperspectral imagery is a term used to describe the imagery derived by subdividing the electromagnetic spectrum into very narrow bandwidths. These narrow bandwidths may be combined with or subtracted from each other in various ways to form images useful in precise terrain or target analysis. Improved software and image analyst skill are now required to process the new hyperspectral imagery within the USDA Forest Service.

Nadir is the point or line traced on an object (ground) straight beneath the aircraft when the picture is taken.

NAPP National Aerial Photography Program – Black and White/Infrared, 1:40,000 scale imagery, completed once every 5-7 years covering most of the United States.

nm nanometers, a measure of wavelength used to describe spectral bands for digital sensors. Common units of wavelength (λ) equal to 10^{-9} m

A pixel is defined as a two-dimensional array of discrete picture elements in an image (Lillesand & Kiefer 1979). An example of digital scale is one pixel represents 30 meters on the ground, or .22 acres (Landsat 7).

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand & Kiefer 1979).

Resolution is the character of data or an image that limits the ability of a user to detect and identify an object or feature of interest on an image or within data. The most common resolution discussed for this report is spatial resolution.

Scale refers to the relation between a measure on the image and a comparable measure on the ground. It is usually expressed as a phrase such as "one inch equals one mile" or by a representative fraction 1:100,000 in the same units, e.g., inches, feet, centimeters, meters, etc. (National Academic of Sciences 1970).

Spatial resolution is a measure of sharpness of fineness of spatial detail, and determines the smallest object that can be identified in the data. For digital imagery, spatial resolution is controlled by the pixel size of the sensor. It is roughly analogous to "grain" in photography. In vegetation mapping, the minimum mapping unit determines the minimum spatial resolution that a user needs (Bobbe et al. 2001).

Spectral coverage is the range of sensing that a scanner possesses. For example, aerial camera systems spectral range extends from 0.3 to 0.9 micrometers (µm), and has wider wavelength bands than hyperspectral systems, which have very narrow and contiguous spectral bands (see “hyperspectral imagery”).

Spectral reflectance is the amount of incident energy that is reflected, measured in wavelengths (Lillesand and Kiefer 1994, Jensen 1996).

Spectral resolution is the broadness of the wavelength band for a given detector, in reference to the signal-to-noise-ratio image generation. Spectral resolution is the ability to differentiate fine spectral differences (Lillesand & Kiefer 1979).

µm micrometers, a measure of wavelength used to describe spectral bands for digital sensors. Common units of wavelength (λ) equal to 10^{-6} m

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APPENDIX A: CHAPTER OF THE FOREST HEALTH PROTECTION AERIAL DETECTION OVERVIEW SURVEYS FUTURING COMMITTEE

Charter
of the
Forest Health Protection
Aerial Detection Overview Surveys
Futuring Committee

Background: Forest Health Protection (FHP) and its State cooperating partners have been conducting aerial detection surveys for, in some areas, over 50 years. These cost-effective, overview surveys have provided essential information on insect and disease occurrence and other forest disturbance agents to our many customers for timely reporting and response to forest health conditions and trends. Users that rely on aerial detection survey information include federal, state, and tribal land managers, the public, and government officials.

To conduct these aerial detection overview surveys, FHP sketch mappers fly over 2,000 hours annually covering millions of forested acres. While all possible safety precautions are routinely exercised, there are inherent risks in using aircraft to collect data. Recent advances in remote sensing technologies and image analysis techniques suggest there may be alternatives to aerial detection overview surveys that should be considered.

Overall Goal: We will conduct future (5 to 10 years) forest health surveys safely and cost effectively.

Desired Outcomes From This Effort: The FHP Directors will: 1) Understand the costs and benefits of alternative ways to provide information from forest health overview surveys including aerial sketch mapping, airborne sensors and satellite imagery; and 2) Be able to determine the preferred option(s) for providing forest health overview information in the future that address pest-specific, local, regional, and national needs.

Committee Scope: National with regional and pest specific considerations where appropriate. This review is focused on the technical ways to conduct detection monitoring through aerial surveys and using other remote sensing technologies/methods. It is not a management review of the Aerial Survey or Forest Health Monitoring Programs.

Committee Deliverables, and Due Dates: By February 1, 2003, complete a report (maximum of 20 pages, including appendices, with 1-2 page executive summary) that addresses the Overall Goal and Desired Outcomes 1 and 2. Report should identify the relative advantages and disadvantages of alternative ways to conduct synoptic overview forest health surveys. Key points to be presented at FHP Directors meeting in early 2003.

Committee Guidance: Andy Mason (Director, Forest Health Technology Enterprise Team-Fort Collins) and Borys Tkacz (National Program Manager, Forest Health Monitoring).

Proposed Committee Members:

Tim McConnell (Lead, FHP National Aviation Safety Manager)

FHP Remote Sensing Specialist (Lisa Fischer, R5)

FHTET Remote Sensing Mgr (Jim Ellenwood)

FHTET Aerial Survey Database Mgr (Ross Pywell)

RSAC Rep (Paul Greenfield)

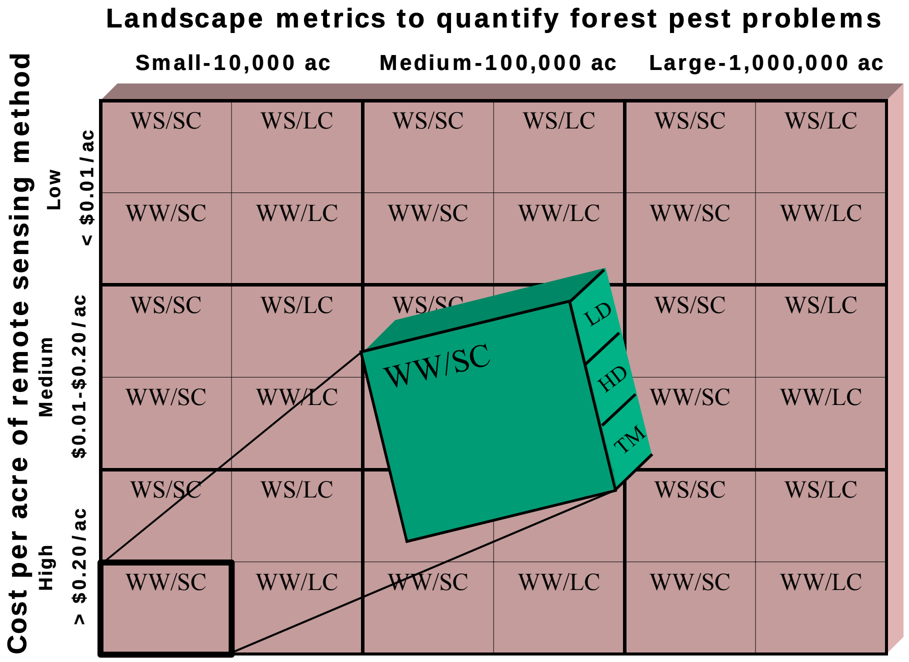
FHP Aerial Survey Program Mgr (Erik Johnson, R2)

NFS Remote Sensing Specialist (Ken Brewer, R1)

FHM Coordinator from Regional/Field Office (Jim Brown, R8)

APPENDIX B: SELECTING A SENSOR FOR THE PROJECT

A three-Dimensional Matrix



Adapted from Thomas, 2003 and modified to suit our remote sensing forest pest considerations

WS = widely scattered; SC = small clumps; LC = large clumps; WW = wall-to-wall.

Each cell must also be further subdivided according to type of damage: low defoliation (LD), high defoliation (HD), and total mortality (TM).

Figure 1. Cost-effectiveness evaluation matrix, showing landscape metrics and cost per acre of remote sensing systems as related to forest pest considerations.

Costs have been described of some sensor systems and discussed their capability to detect, recognize, and identify forest pest problems from a qualitative viewpoint. Now, with the help of the cost-effectiveness evaluation matrix in Figure 1, it is possible to depict a theoretical process to decide on the alternative or alternatives for conducting a forest pest detection project. Each cell is a multi-dimensional representation of three major project considerations: financial resources, scope, and forest pest damage level. (This matrix should be seen as a guide, rather than a final remote sensing method recommendation). It can be used to organize the decision-making process when implementing an aerial survey forest pest project:

1. First, define the problem of data requirement. Table 1 helps to identify type of pest, damage, and pattern.

2. Define the project scope and most appropriate unit of measurement (e.g., stand, compartment, etc). Identify existing or new ancillary data needs.

3. Organize and study the information and knowledge. Conceptualize goals and constraints. Tables 2 and 3 will be very useful for gathering baseline

information to formulate system goals. Also, literature sources, experts' knowledge, and other practical information will help. For example, a mix of factors to be considered in a beetle infestation project should include sensor capabilities, cost, scale, and other considerations. Factors such as time of data acquisition will determine the type of sensor to use. In a hardwood defoliation study, Ciesla and Eav (1987) found the window of opportunity to acquire imagery was shorter for satellite based systems than for low-level aerial surveys such as photograph or sketchmapping during peak defoliation seasons.

4. Define and implement the goals. For example: management has available $300,000 to conduct a remote sensing project over 600,000 acres; the target is to detect, recognize and identify widely scattered/small clumps (WS/SC) of mountain pine beetle mortality (TM). In Table 2 (remote sensing methods cost estimates), management can pinpoint the options for remote sensing systems to achieve the desired goal.

5. Evaluate the results and make any changes as necessary.

An automated system would help to define alternatives out a number of technologies that may be considered. To reach to a conclusion “by hand” using different remote sensing choices and forest pest is a daunting task. Indeed, a remote sensing information management system could be flexible enough to adapt to new changes in technology and forest pest management problems. So, for example, aerial photography and sketchmapping can complement each other, especially when specific pockets of tree damage are to be analyzed. Combination of sensors can be used: for example, hyperspectral and multi-spectral scanners like QuickBird or Ikonos to track temporal changes and develop data fusion for analysis purposes.