Forest Monitoring and Remote Sensing

A Survey of Accomplishments and Opportunities for the Future

DJ Peterson, Susan Resetar, Jennifer Brower, Ronald Diver

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PREFACE

This report surveys the types of forest monitoring currently conducted in the United States and the role of satellite-based remote sensing in these data collection efforts. Of specific note, the report examines how remote sensing is being used in an operational manner in forest monitoring for economic uses and values, ecosystem management, sustainable forestry, and management of climate change in the US. The report also analyzes the extent to which the mix of existing monitoring technologies provide the information about the forest environment called for by federal policy and needed by managers in the field. The project also surveyed the use of remote sensing in forest monitoring by the private sector as well as its use in other countries that may have significance for policy in the US.

This report is intended to aid the federal government in identifying opportunities to improve the efficiency and effectiveness of existing forest monitoring capabilities; to integrate satellite imagery in forest monitoring; to improve coordination among government agencies providing or using forest data; and to negotiate enhanced cooperation with other countries. This report will also be of interest to forest specialists interested in exploring the use of remote sensing in forest monitoring.

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Inquiries regarding the Institute or this document may be directed to:
Bruce Don, Director
RAND Science and Technology Policy Institute
1333 H Street, NW
Washington, DC 20005
Phone: (202) 296-5000
Email: stpi@rand.org
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SUMMARY

Forests in the United States are managed for an evolving constellation of objectives: timber and other commodities production; recreation; maintenance of wildlife habitat; water quality protection; wilderness and open space preservation; and, in the coming years, as a buffer against climatic change. Effective management of these resources, both public and private, requires reliable and timely information about their status and trends. To this end, the federal government, states, and the private sector spend hundreds of millions of dollars on forest monitoring activities.

Yet, questions about the state of America’s forests have led to a widespread perception that existing monitoring efforts and capabilities—characterized by a decentralized set of programs that rely on ground and aerial observations—are failing to meet increasingly complex and large-scale forest management needs. Can existing monitoring efforts be upgraded or better integrated to meet managers’ and policy makers’ forest information needs in terms of timeliness, scope, and rigor?

New technologies may be able to satisfy the nation’s forest information needs. An important development over the past quarter-century has been the deployment of Earth-observing satellites and rapid improvements in computing power and algorithms to interpret space-based imagery. Now that these technologies have been available for a significant period of time, how have they been integrated into forest monitoring practice and, importantly, exploited by decision makers?

STUDY OBJECTIVES

The RAND Science and Technology Policy Institute set out to provide US policy makers with an overview of forest monitoring and remote sensing programs and capabilities in the United States and selected comparisons with other countries. Two areas of special concern addressed in this report are capabilities of forest monitoring to meet US Government objectives for ecosystem management and carbon flux accounting. To this end, this report addresses several questions:

- What forest measurement capabilities are in place?
- How is satellite-based remote sensing being applied in these forest monitoring efforts?
- How is forest measurement information being used?
- What insights from monitoring efforts abroad may be used to improve US programs?
Answers to these questions are analyzed to address policy issues of interest to federal decision makers seeking to improve the nation’s measurement efforts:

- Given current and prospective policy and management needs, what gaps exist in forest monitoring programs?
- Can the US enhance the effectiveness of forest measurement by better integrating monitoring programs and technologies?

FINDINGS

Broadly speaking, the forest monitoring capabilities in the United States fall well short of the federal government’s management commitments and policy objectives.

- **The US lacks a national and timely forest data base.** The US has nation-wide forest monitoring programs but they do not generate uniform national forest resources data bases. Rather, decentralized forest monitoring efforts greatly complicate the data delivery process. This “bottom-up” system limits the ability of decision makers to draw timely conclusions about forest conditions at the national and even regional levels. The lack of a national forest database, for example, hampers efforts to conduct timely and accurate carbon accounting and to report on sustainable forestry status and trends.

- **Non-vegetation monitoring remains limited.** By law, forest measurement and analysis continue to emphasize earlier timber sale objectives and do not yet produce information of sufficient breadth to meet White House and Forest Service objectives in the areas of ecosystem management, the Environmental Report Card, sustainable forestry, and climate change. The limited biomass and soils data for forest lands, for example, impedes efforts to estimate carbon flux.

- **The nation’s forest management structure impedes efforts to produce more comprehensive and uniform forest information.** Efforts have been made by the US Forest Service headquarters to improve the timeliness and comprehensiveness of monitoring. These efforts largely have focused on developing uniform monitoring standards, yet the agency’s decentralized structure, inconsistent funding by local entities, and the absence of a federal funding commitment to sustained, comprehensive ground monitoring thwarts effective implementation of a truly nationwide system.

- **Despite these shortcomings, US monitoring practices are, on average, equivalent if not more advanced than most other countries with significant forest resources.**

Despite its great promise, satellite imagery has not been widely integrated into public or private forest monitoring efforts on an operational basis in the US or abroad.

- **Remote sensing is not a panacea for existing shortcomings in forest measurement and often has shown little utility to operational management needs on its own.**

- **Integrating remote sensing is perceived as difficult and costly by potential data users in the field.** While satellite imagery may be a low-cost source of information, indirect costs associated with image processing and analysis, as well as the
initial investment required to develop this capacity, is perceived by most forest managers as too high.

- **Exploitation of the benefits of space-based remote sensing in forestry is slowed by institutional barriers.** The integration of remote sensing has been impeded by organizational and professional divides between technology providers in the aerospace and information technology sectors and its users in the forestry and ecosystem management communities. The utilization of satellite data also depends on significant changes in skill sets, technologies, and practices within the forest management community.

- **Growing experience suggests that the technology does hold promise in several types of applications.** Opportunities for greater integration include: preliminary resource assessment, especially where aerial and ground information is limited; basic classification of forest cover and type; intensive study of high-value forest resources; and public education.

- **Where remote sensing has been used, Landsat Thematic Mapper is the dominant data source—**given its relative image quality, lengthy database, and direct and indirect costs. With the significant time required to develop new data bases and to develop and disseminate data analysis capabilities, Thematic Mapper is likely to remain dominant for the foreseeable future despite the coming availability of new high-resolution space imagery.

- **The operational application of remotely sensed imagery in other countries with significant forest resources, in general, is not more advanced.** In contrast with the US, Finland is using Landsat imagery as the primary source of information for its national forest industry. Many countries use US imagery, often in cooperation with US agencies, in a research and development mode.

**RECOMMENDATIONS**

Based on these findings, we make several recommendations for federal policy makers:

- **Set clear national forest management priorities.** The crafting and implementation of a national forest monitoring system useful to decision makers first requires specification of the management objectives that monitoring is to guide. These objectives ideally should be based on a consensus among the general public as well as top-level decision makers on the broad direction of forest policy and on agreement among specialists on the science of forest ecosystem dynamics.

- **Implement mandatory forest monitoring standards across all Forest Service divisions.** Uniform standards have been proposed for Forest Inventory Analysis and Forest Health Monitoring and they should be extended to the National Forest System. This measure would entail abandoning the traditional “bottom-up” monitoring approach in favor of a more centralized “top-down” system.

- **Augment federal funding dedicated to in situ forest monitoring on a national scale.** A “top-down” national forest monitoring effort that meets federal policy and management objectives requires the continuous support and long-term commitment to a uniform, nationwide system of ground measurement. Significant efficiencies may also be gained though better management and
integration of existing programs, such as Forest Inventory Analysis, Forest Health Monitoring, Gap Analysis Program, National Resources Inventory, and Multi-Resolution Land Classification.

- **Explore nationwide utilization of Thematic Mapper imagery to speed up the forest inventory stratification process.** If a nationwide, consistent program of ground measurement is implemented, then the use of TM data for area measurement on a national scale may be more efficient than conventional aerial photography in terms of data cost, timeliness, and uniformity. The experiences of Minnesota, Utah, Illinois, and Indiana suggest opportunities for coordination, integration, and cost-sharing with other programs, such as GAP. The initial use of TM imagery for forest inventory stratification is likely to stimulate diffusion of remote sensing to other forest monitoring efforts.

- **Develop a strategic vision for remote sensing in forestry.** With a substantial fleet of sensors now in space, efforts to develop remote sensing should return to Earth and focus on meeting the operational management needs of foresters in the field. With strategic market and technology assessments, national resources can be allocated to develop and diffuse the most promising and needed data processing and interpretation capabilities, thus lowering the costs of remote sensing associated with the current localized, ad hoc development scenario.
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All errors of fact and judgment are those of the authors. Views and recommendations expressed here are not necessarily those of RAND or any of its sponsors.
# LIST OF ABBREVIATIONS

<table>
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<tr>
<th>Abbreviation</th>
<th>Expansion</th>
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<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer</td>
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<td>BOREAS</td>
<td>Boreal Ecosystem-Atmosphere Study</td>
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<td>CBERS</td>
<td>China-Brazil Earth Resources Satellite</td>
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<td>CCFM</td>
<td>Canadian Council of Forest Ministers</td>
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<td>CCRS</td>
<td>Canadian Center for Remote Sensing</td>
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<tr>
<td>DNR</td>
<td>Minnesota Department of Natural Resources</td>
</tr>
<tr>
<td>EOSD</td>
<td>Earth Observation for Sustainable Development of Forests</td>
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<tr>
<td>EOS</td>
<td>Earth Observation Satellite</td>
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<tr>
<td>ERS</td>
<td>European Resources Satellite</td>
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<td>FEMAT</td>
<td>Forest Ecosystem Management Assessment Team</td>
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<td>FIERR</td>
<td>Forest Inventory, Economics, and Recreation Research</td>
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<td>FLPMA</td>
<td>Federal Land Policy and Management Act</td>
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<td>FHM</td>
<td>Forest Health Monitoring</td>
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<td>FHP</td>
<td>Forest Health Protection</td>
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<td>FIA</td>
<td>Forest Inventory Analysis</td>
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<td>GAP</td>
<td>Gap Analysis Program</td>
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<tr>
<td>GIS</td>
<td>Geographical Information Systems</td>
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<td>GOES</td>
<td>Geostationary Operational Environment Satellite</td>
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<td>GOFC</td>
<td>Global Observations of Forest Cover</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>GTOSS</td>
<td>Global Terrestrial Observing System</td>
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<tr>
<td>IGBP</td>
<td>International Geosphere-Biosphere Program</td>
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<tr>
<td>INPE</td>
<td>Instituto Nacional de Pesquisas Espaciais</td>
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<tr>
<td>IRS</td>
<td>Indian Remote-Sensing Satellite</td>
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<tr>
<td>IUCN</td>
<td>International Union for the Conservation of Nature</td>
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<tr>
<td>JERS</td>
<td>Japan Earth Resources Satellite</td>
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<tr>
<td>LBA</td>
<td>Large Scale Biosphere-Atmosphere Experiment in Amazonia</td>
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<tr>
<td>LTER</td>
<td>Long-Term Ecological Research Program</td>
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<tr>
<td>LU/LCC</td>
<td>Land-Use and Land-Cover Change Project</td>
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<tr>
<td>MRLC</td>
<td>Multi-Resolution Land Classification</td>
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<td>MSS</td>
<td>Landsat Multispectral Scanner</td>
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<td>NFMA</td>
<td>National Forest Management Act</td>
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<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<td>NRI</td>
<td>National Resources Inventory</td>
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<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>OFIC</td>
<td>Oregon Forest Industries Council</td>
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<tr>
<td>RPA</td>
<td>Forest and Rangeland Renewable Resources Planning Act</td>
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<tr>
<td>SAR</td>
<td>Synthetic Aperture Radar</td>
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<td>SPOT</td>
<td>Système Probatoire d’Observation de la Terre</td>
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<tr>
<td>TM</td>
<td>Landsat Thematic Mapper</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
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<td>USGS</td>
<td>United States Geological Survey</td>
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CHAPTER 1
INTRODUCTION

STATEMENT OF ISSUE

Forests have played a central role in the economic, social, and cultural development of the United States. For over 300 years, US forests were used primarily to produce commodity goods, such as fur, game, and timber, which helped to drive American expansion and economic growth. Over the last 30 years, and particularly over the past decade, however, public attitudes towards forest resources and their uses have shifted dramatically. Whereas forests were once seen solely as a frontier from which resources could be extracted, they now are viewed by many as precious islands that serve as refuges for nature and recreation and act as buffers against environmental degradation. This shift in values has been most noticeable in terms of the country’s public forests.

As the valuation of forest resources has evolved, the management tasks for forest managers and policy makers have grown increasingly complex. Today, the nation’s forests, both public and private, are managed for a host of uses: timber and other commodity production, recreation, maintenance of wildlife habitat, water quality protection, and wilderness and open space preservation. In the coming years, US forests also are likely to be managed as a sink for atmospheric carbon and a buffer against climatic change.

Effective management of forest resources requires reliable and timely information about the status and trends of forest resources. Historically, all levels of the government, the private sector, and research institutions have conducted a wide range of forest inventory and monitoring efforts in the US. New forest management priorities, however, have raised the question of whether these efforts—characterized by the use of ground and aerial observations and by a focus on vegetation measures—are evolving sufficiently to meet the nation’s future information demands in terms of depth, breadth, and timeliness. There are many new measurement challenges:

- To successfully pursue an ecosystem management approach policy makers and land managers will require a much greater volume of information, covering larger spatial and temporal scales, than traditionally has been gathered
- As a major player in the Montreal Process, the US has committed itself to reporting on its progress towards sustainable forest management which requires measuring a comprehensive set of ecosystem as well as socioeconomic measures
- As a central actor in the global climate change negotiations, the United States must develop methods and capabilities for monitoring carbon flux as well as implementation of potential treaty obligations.
Despite the increased demands for improved forest monitoring, there exists the widespread perception that US monitoring programs and capabilities are failing to meet these needs.

New technical capabilities for forest measurement may be able to meet some of the nation’s burgeoning forest information needs. An important development over the past quarter-century has been the deployment of a range of Earth-observing satellites, along with rapid improvements in computing power to support the analysis of space-based imagery. In theory, such advances offer the potential to enhance the timeliness, scope, and rigor of the forest measurement information available to decision makers and many policy initiatives have called for the greater integration of this technology in forest inventory and monitoring programs. Now that these technologies have been in place for a significant period of time, we may review how they have been integrated into forest monitoring practice and, importantly, exploited by decision makers. From this, we may draw insights into the remote sensing technology diffusion process and the future of forest monitoring practice as new capabilities emerge.

**APPRAOCH**

For this policy study, we carried out a comprehensive review of the theory, methods, and practice of existing forest monitoring and inventory methods across a range of policy and management objectives in order to assess the current state of the field with a view towards better integrating measurement capabilities. Two areas of special concern addressed in this report are capabilities of forest monitoring to meet White House objectives for ecosystem management and carbon flux accounting. To these points, this research had several objectives:

- to provide federal decision makers with a road map of forest monitoring programs and technologies currently in use in the US and to assess the extent to which they provide the types of information about forest resources that decision makers need
- to examine to what degree remote sensing technologies are being exploited and assess whether they can enhance the timeliness, scope, and rigor of the forest measurement information available
- to delineate opportunities for better integrating programs and measurement approaches, drawing on lessons from domestic and international efforts.

To address these objectives, we first performed a review of the scientific and technical literature on forest and ecosystem management and monitoring, as well as on remote sensing technologies and their forestry applications, both in the US and abroad. We also surveyed a wide range of documents and reports from forest management, monitoring, and remote sensing programs. Next, we conducted over forty-five telephone and in-person interviews with officials from US federal and state agencies, staff members of government agencies in Canada and Finland, and representatives from academia and non-governmental organizations. Finally, we interviewed ten representatives from the private forestry sector, including resource managers from several of the largest forest management firms in the United States.
Forest monitoring and remote sensing are broad subjects that have received much attention in the scientific and technical literature over the past several decades. This study of forest monitoring and remote sensing is not intended to be exhaustive; rather, our objective is to provide a brief overview of monitoring principles and practice and to highlight opportunities for federal decision makers to enhance and better integrate programs in order to meet broad national policy objectives.

DEFINITIONS

Unless otherwise stated, in this report the use of the term “remote sensing” refers to space-based satellite systems. We note that this definition differs from conventional usage by the principle federal forest land managers (the US Department of Agriculture’s Forest Service and the US Department of the Interior’s Bureau of Land Management), in which remote sensing typically connotes aerial technologies (that is, cameras flown on low-altitude aircraft). Aerial technologies were not included within the scope of this research project and will be discussed in only a limited capacity.

This exclusion, however, should not be interpreted as an implicit downplaying of the role of aerial remote sensing. To the contrary, aerial technologies have been the dominant form of remote sensing (broadly defined) in the United States for the past 50 years. Moreover, important advances in aerial technologies (such as the advent of digital photography, infrared radiography, and videography), as well as digital manipulation of film-based images, are extending the utility of aerial remote sensing. As this study suggests, aerial remote sensing technologies will continue to have a prominent role in forest monitoring for the foreseeable future, and, indeed, may forestall the integration of space-based imagery.

In addition, our definition of remote sensing covers only civilian technologies. It is important to note, though, that exploratory efforts to apply reconnaissance imagery to the forestry sector do show promise for application to civilian management questions (Pace et al., 1997; Richelson, 1998). The high resolution and extended data sets offered by reconnaissance imagery, for example, may yield significant benefits to forest measurement efforts in countries and regions with limited measurement capabilities.1

OVERVIEW OF REPORT

Chapter 2 reviews the context in which forest monitoring currently is carried out in the US. This chapter includes the following: key data on the status and trends of US forests; an overview of the range of objectives for which these forests are managed and the information needed to manage them; and a review of recent critiques of forest monitoring efforts in the US.

Chapter 3 reviews existing forest monitoring programs and techniques used by government, industry, and research institutions in the United States. All of these

1 Except for a few exceptions, US reconnaissance missions were excluded from imaging US territory. Therefore, US imagery would apply to other nations, while Soviet and Russian imagery may prove useful for research on US forests.
monitoring programs use ground (in situ) measurement methods and some use aerial (airplane) observations. The discussion also draws out numerous shortcomings that stem in large part from the way monitoring efforts are organized.

Chapter 4 discusses the application of remote sensing to forest monitoring in both the public and private sectors. To identify feasible applications for remote sensing in the future, the chapter closes with several brief reviews of cases in the US in which remote sensing has had a readily discernible impact on the understanding of forest status and trends, and on management and policy decisions.

Chapter 5 integrates the results of this research and presents recommendations for federal policy makers. We orient this discussion around three decision issues presently of importance to federal policy makers:

- upgrading of forest inventory and monitoring;
- implementation of criteria and indicators for sustainable forest management; and
- inventory, verification, and certification of carbon flux and carbon sequestration efforts.

The chapter then explores broader federal policy issues regarding the development of forest monitoring and remote sensing integration.

For reference, Appendix A presents an extensive summary in tabular form of major US and international civilian satellite and sensor capabilities, with their potential and operational applications to forest resources management. The chart includes data on systems that are expected to be operational in the next 5–10 years.

Finally, Appendices B and C provide brief case studies of Brazil and Canada, two countries with forest monitoring and remote sensing experiences that may inform US policy. These sections outline the countries’ forest resources, national and regional monitoring programs, and the role of remote sensing.
CHAPTER 2

THE FOREST MONITORING POLICY ENVIRONMENT

America’s forests constitute an economic, cultural, and ecological resource of national and even global importance. As such, they are the focus of a wide range of public and private policies and programs that govern their management. Forest monitoring activities, thus, play an important role in informing forest management and policy decisions.

This chapter briefly describes the various forest management objectives as well as forest laws and policies that guide the monitoring of public and private forest resources in the United States. US forest management objectives are both ambitious and in flux, and, not surprisingly, forest measurement practice has come under criticism. In this chapter we review the principle critiques. To establish the management context, we first begin with an overview of the state of the nation’s forest resources.

FOREST RESOURCES OF THE UNITED STATES

Forests occupy an important place in the landscape of the United States. At the start of European settlement, forests covered an estimated one-half of the future nation’s land. Since 1600, though, about 30 percent of original US forest land has been converted to other uses—mainly agriculture. However, the area of total forest land has remained relatively steady since the 1920s, as a result of the reversion of agricultural land to forest, fire suppression, and other land management changes, and as of 1992, one-third of the nation’s land—737 million acres—was forested. These forests are of global significance: The United States is the world’s fourth most forested nation and contains 6.2 percent of global forest cover (see Figure 2.1). ²

² Data cited in this chapter are taken from most recent US forest resource planning assessment (Powell et al., 1993).
US forests have many different owners. Federal holdings account for about 35 percent (249 million acres) of US forest land, of which 56 percent (140 million acres) is administered by the Forest Service. Other major federal forest administrators include the US Department of Interior Bureau of Land Management, the National Park Service, the Fish and Wildlife Service, and the US Department of Defense (Figure 2.2). Ten million private owners control over sixty percent of US forests. In the East, most forested land is under state and private ownership, while in the West, the federal government is the dominant owner (Figure 2.3).
Figure 2.2
Ownership and Administration of US Forests, 1992


Figure 2.3
Geographic Distribution of Forest Ownership, 1992

In 1992, two-thirds of US forest land (490 million acres) was classified as timberland. The nation’s inventory of timber (commodity) resources in the US differs greatly between the East and the West: The East accounts for 70 percent (343 million acres) of US timberland, while the West accounts for 30 percent (147 million acres). Public lands account for 27 percent (132 million acres) of total US timberland, and 18 percent of the total harvest. Conversely, the private industrial forests account for 15 percent (70 million acres) of timberland and 33 percent of the total harvest. Between 1952 and 1992, the extent of timberland decreased by about 4 percent, while improved silvicultural practices boosted the volume of growing stock on these lands by an average of 33 percent.

After declining in the first half of the century, average timber harvest levels in the US resumed their climb, and, since the mid-1970s, have been at record levels, and domestic timber demand is expected to continue to be strong in the coming decades. The Forest Service has observed that, despite increasing growing stock volume, “For the first time in history, the US does not have a large reserve of high quality softwood sawtimber available for harvest” (Powell et al., 1993, p. 20).

MANAGEMENT OBJECTIVES OF FOREST MONITORING

The nation’s forests are managed for a complex and evolving constellation of objectives: timber production, non-timber uses and values, environmental protection, biodiversity preservation, wilderness and open space, and mitigation of climate change. As the nation’s forest management objectives change, forest measurement practices must also evolve to provide decision makers with information relevant to these objectives.

Timber production

The forest products industry plays an important role in the US economy, and forest inventories have been the dominant form of forest monitoring in the US for the past century. Inventories help foresters at the stand, forest unit, regional, and national level plan harvests, monitor changes in standing stocks, and predict future supplies.

Forest health assessments are another important monitoring activity. Timberlands and other valuable forests are currently threatened by many stresses, such as insects, disease, fire, and weather – a consequence, in part, of past fire suppression, harvesting, and stocking practices. In eastern Oregon, for example, forests have been in a state of decline

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3 The Forest Service defines timberland as “forests capable of producing 20 cubic feet per acre of industrial wood annually and not reserved from timber harvest” (Powell et al., 1993, p. 4).

4 Industrial forests are defined as an ownership class of private lands where the owner also owns wood-using plants (Powell et al., 1993).

5 Timber volumes increased in the North (95 percent), South (104 percent), and Rocky Mountains (27 percent); they dropped by 4 percent in the Pacific Coast region.

6 In 1991, production volume for all types of forest products (lumber, plywood and veneer, fuelwood, pulp, and others) totaled almost 18 billion cubic feet.
since the 1960s, due to infestations of bark beetles and other insects; each year, disease and insects reported destroy timber equivalent to one-third the state’s harvest (Kline, 1997). A resulting build-up of dead wood resulting from the suppression of seasonal fire has raised the risk of catastrophic wildfires in many regions, such as Yellowstone National Park. These threats have generated greater need for more forward-looking preventive approaches to forest health protection, such as advanced measurement methods that enable foresters to predict and prevent pest and catastrophic fire outbreaks (Joint Fire Service Drafting Committee, 1998).

Non-timber uses

In addition to timber production, monitoring activities have increasingly measured non-tree forest values. These include recreational activities such as fishing, hunting, hiking, as well as cultural and aesthetic appreciation of old growth forests, wilderness, and open space. To help meet these interests, Congress passed the Multiple-Use/Sustained-Yield Act in 1960 which marked the inception of planning and management of national forests for “multiple-uses”: recreation, rangeland, timberland, watershed, and wildlife and fish habitat. As a result of this act, by the mid-1990s over one-quarter (50 million acres) of national forest land had been reserved from commercial timber harvest in wilderness, scenic areas, and other conservation areas. The challenge for monitoring has been to measure uses, such as wilderness and scenic areas, in a technically rigorous manner that is useful to decision makers.

Environmental protection, biodiversity preservation

With increasing attention to environmental protection in the 1960s and 1970s, greater effort was focused on monitoring the impacts of timber and recreation activities on stream water quality from pollution discharges, runoff, and sedimentation, and on forest and riparian habitats.

Despite the growing demand for sawtimber, public pressure to regulate and reduce timber cuts (and ancillary activities such as road building and chip mill construction) has increased in recent years, particularly on federal lands in the West. This trend has been driven in part the federal listing of endangered species, such as the spotted owl and salmon in the Pacific Northwest and the red-cockaded woodpecker in the Southeast. Growing population and development pressures are likely to exacerbate these debates in the future, as federal forests play an increasingly central role in wilderness and biodiversity preservation.

---

7 Between 1950 and 1995 the recreational use of national forests (as measured by visitor days) increased 14-fold.

8 Whereas Forest Service timber sales averaged 12 billion board feet annually in the 1970s and 1980s, sales in the 1990s have fallen to an average of 4 billion board feet.
Ecosystem management

As the uses of forests have intensified and diversified, the scientific understanding of forests as ecosystems (especially old-growth forest ecosystems) has evolved. Growing numbers of endangered species, exotic species invasions, and catastrophic wildfires, such as in Alaska and Yellowstone National Park, have led to a realization that managing forests for individual environmental objectives may not be sufficient. As the empirical valuation of intact forest ecosystems has grown, the Forest Service, other federal land managers, and many industrial forestry firms have moved towards the principle of ecosystem management. To successfully pursue an ecosystem management approach, data are needed to establish baseline conditions of the ecosystem, monitor implementation of management tools, and make adaptive management corrections. Thus, policy makers and land managers will require a much greater volume of information, covering larger spatial and temporal scales, than traditionally has been gathered. An important prerequisite of these endeavors is greater cooperation between landowners in data collection, integration, and analysis (Kohm and Franklin, 1997; Aplet et al., 1993).

Climate change

Forests also are being valued to a higher degree for the environmental services they provide: improving air quality and water quality, maintaining watersheds, and supporting fisheries. The growing concern about global climate change has also intensified attention on US forests because of their role in sequestration of atmospheric carbon. These trends have led to heightened interest in the inventory and monitoring of forest resources, especially measures of vegetation and soil carbon, both in the US and abroad.

Given their vast extent and productivity, US forests play a particularly important role in the nation’s carbon balance through their capacity to sequester and offset the nation’s anthropogenic carbon emissions. The United States recently signed the Kyoto Protocol and, assuming ratification or voluntary compliance, needs to undertake several carbon accounting tasks:

- Monitoring to establish a 1990 baseline carbon inventory
- Annual reporting of the carbon inventory to measure performance against the baseline
- Monitoring to evaluate projects to sequester carbon under the clean development mechanism and joint implementation
- Monitoring to support carbon markets and trading.

These tasks imply expanding our nation’s monitoring capability to more accurately measure carbon flux in different locations and across many scales, as well as applying forest monitoring to qualitatively different management tasks: verification and certification.

Sustainable forestry

All of the management issues above, as well as the socioeconomic status of the communities in which forests are found, are addressed jointly by the concept of sustainable
forestry. The need for sustainable forestry, loosely defined as managing forests to preserve their values for future generations, was raised most pointedly at the United Nations Conference on Environment and Development in Rio de Janeiro and incorporated in Chapter 11 (“Combating Deforestation”) of Agenda 21 and the Statement of Forest Principles (1992). Among the actions called for in the latter was “provision of timely, reliable and accurate information on forests and forest ecosystems” to promote “public understanding and informed decision-making.”

This call has been answered in several intergovernmental forums to develop criteria and indicators to define and measure progress towards sustainable forestry. The US has joined twelve other temperate and boreal forest nations in the Montreal Process and has endorsed the Santiago Declaration (1995), which defines seven national-scale criteria and 67 indicators to guide high-level decision makers and educate the public on the conservation and sustainable management of forest resources. As a “major player” in this process, the US has committed itself to reporting on a comprehensive set of forest and socioeconomic measures by 2003 (Buchanan, 1998).

**LEGISLATIVE AND POLICY DRIVERS OF FOREST MONITORING**

Many federal statutes address the inventory and monitoring of forest resources in the United States, and their development has followed the evolution in forest management objectives described above. The most notable statutes are catalogued in Table 2.1.

Given the importance of the forest products sector, in 1928 Congress created the Forest Survey, now known as the Forest Inventory and Analysis, to provide periodic information on the supply and condition of the nation’s timber resources. The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 expanded forest monitoring beyond the scope of tree vegetation inventory and was the basis for Forest Service’s current mandate to

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9 Promoting sustainable forestry and related monitoring frameworks has also been supported by the United Nations (UN) Intergovernmental Panel on Forests through its forest policy dialogue; the UN Food and Agriculture Association through its development of decennial Forest Resources Assessments (see, for example, Food and Agriculture Association, 1997); and through activities around the convening of the XI World Forestry Congress in 1997. The US has played a visible role in these forums as well.

10 The Montreal Process countries are Argentina, Canada, Chile, China, Japan, Mexico, New Zealand, Republic of Korea, Russia, Uruguay, the United States. Separate Criteria and Indicators development efforts have been undertaken by temperate and boreal forest nations (the Montreal Process); the European Union (the Helsinki Process); nations in the Amazon basin (Amazonian Process); the International Tropical Timber Organization; Dry-Zone African nations; and other. For a brief comparison of these, see International Institute for Sustainable Development (1996), and UN Food and Agriculture Organization (1997).

11 The Parties to the Montreal Process are intending to establish an initial reporting deadline. The date—2000 (corresponding to the new millennium) or 2003 (coinciding with the next World Forestry Congress)—has not yet been set.
conduct “broad-scale resource inventories” (FIERR, 1992). In addition, the National Forest Management Act (NFMA) and the Federal Land Policy and Management Act (FLPMA) require the Forest Service and the Bureau of Land Management to develop long-range, land-use plans based on comprehensive inventory monitoring.

In addition to forest-specific laws outlined in Table 2.1, forest monitoring comes under the purview of numerous broad-based environmental laws, such as the National Environmental Policy Act of 1969, which requires federal agencies to assess the environmental impact of major management decisions. In the case of forest management, this requirement is most commonly applied to timber sale decisions by the Forest Service and Bureau of Land Management. The Endangered Species Act also exerts a strong influence on forest monitoring, by requiring land managers to monitor and protect the habitats of species identified as threatened or endangered.

Table 2.1
Major Federal Laws Guiding Forest Monitoring

<table>
<thead>
<tr>
<th>Law</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Administration Act of 1897</td>
<td>Established national forests to improve and protect forest lands; secure favorable water flow conditions; and provide a continuous supply of timber to the nation. The law marked the official inception of the sustained-yield management principle by the Forest Service.</td>
</tr>
<tr>
<td>Forest Research Act of 1928</td>
<td>Established the national Forest Survey (now Forest Inventory Analysis) to gather information on the supply and condition of timber resources.</td>
</tr>
<tr>
<td>Multiple-Use/Sustained-Yield Act of 1960</td>
<td>Marked beginning of the multiple-use objective for national forest management. The law identified six uses: “Outdoor recreation, range, timber, watershed, and wildlife and fish purposes.” The law also reaffirmed the sustained-yield principle: The Forest Service is to manage its lands to provide high levels of all of these uses to current users while sustaining undiminished the lands’ ability to produce these uses for future generations.</td>
</tr>
<tr>
<td>Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA)</td>
<td>Directed the Forest Service to periodically assess the “present and anticipated uses, demand for, and supply of the renewable resources, with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationships trends,” and to submit to Congress recommendations for long-range programs essential to meet future resource needs.</td>
</tr>
</tbody>
</table>
Table 2.1 (continued)

<table>
<thead>
<tr>
<th>Act</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Federal Land Policy and Management Act of 1976 (FLPMA)</strong></td>
<td>Analogous to NFMA, this law required the Bureau of Land Management to adhere to and plan for the sustained-yield and multiple-use principles: recreation, range, timber, minerals, watershed, fish and wildlife, and natural scenic, scientific, and historic values.</td>
</tr>
<tr>
<td><strong>Forest Ecosystems and Atmospheric Pollution Act of 1988</strong></td>
<td>Amended the RPA to direct the Forest Service to establish a ten-year program to increase the frequency of monitoring to evaluate the effects of atmospheric pollutants on the health and productivity of forest ecosystems. It provided a legislative basis for the Forest Health Monitoring Program.</td>
</tr>
<tr>
<td><strong>Food, Agriculture, Conservation, and Trade Act of 1990</strong></td>
<td>Directed the Forest Service to develop and implement methods to monitor, inventory, and analyze the status of urban forests to improve the management of the urban-forest land interface.</td>
</tr>
<tr>
<td><strong>Global Climate Change Prevention Act of 1990</strong></td>
<td>Instructed the Forest Service to study the effects of global climate change on forestry, including temperature and carbon dioxide increase, severe weather events, and changes in hydrologic regimes. It required study of methane, nitrous oxide, and hydrocarbon emissions from tropical and temperate forests; how such emissions may affect climate change and vice versa; and how such emissions may be mitigated through management practices.</td>
</tr>
<tr>
<td><strong>Agricultural Research, Extension, and Education Reform Act of 1998</strong></td>
<td>Amended RPA to require the Forest Service to measure 20 percent of all sample plots in each state annually, and to provide a complete analysis every 5 years. The Forest Service is requested to develop “national standards and definitions” for forest and forest resources inventory and analysis, including a core set of variables. The law called for the development of a plan to implement “remote sensing, global positioning systems, and other advanced technologies.”</td>
</tr>
</tbody>
</table>

Forest monitoring has been addressed in several federal policy initiatives, such as the White House’s Environmental Report Card effort, which seeks to assess, in a straightforward manner, the nation’s progress in improving environmental quality, including the management of forest resources. Under the auspices of the White House Office of Science and Technology Policy, the Environmental Monitoring Initiative has sought to better integrate the US Government’s diverse environmental measurement efforts and to more effectively apply their outputs to informing policy and management decision making. As a result of these efforts, on July 14, 1998, federal agencies managing
forest lands initialed an agreement recognizing the Santiago Criteria and Indicators as the basis for understanding the United States’ progress towards sustainable forestry and pledged to cooperate on their implementation.

It is important to note that while these federal legislative and policy initiatives have sought to improve the management of the nation’s forests by increasing the range of management objectives, they have not provided explicit guidance on national-scale monitoring of non-timber uses and values, or on measures for ecosystem management, biodiversity, preservation, sustainable forestry, or carbon accounting.

CRITICISMS OF US FOREST MONITORING EFFORTS

As we have seen, the range of forest management objectives has significantly changed in recent years. This has been accompanied by demands for improved forest monitoring and the integration of this information in management decision making. As monitoring is an “issue-driven” concern, monitoring capabilities need to be flexible. However, US forest monitoring programs and capabilities have come under criticism in recent years for not meeting current or expected forest management needs.

The First Blue Ribbon Panel on Forest Inventory and Analysis (American Forest Council, 1992) noted that the Forest Service program needed to improve and expand monitoring of forest ecosystem and non-commodity values, including ecosystem sustainability, fragmentation, and biological diversity, and that it needed to use new technologies, approaches, and analytical tools.

Six years later, a second Blue Ribbon Panel (American Forest and Paper Association, 1998, p. 6) sharpened its critique, asserting that FIA was “in a state of crisis, its usefulness threatened by increasing cycle length, its credibility endangered by failure to develop an accountable, responsive organization, and its viability crippled by a lack of funding.” This condition led to “the loss of important ecological and economic benefits to society by hindering our ability to monitor forest health and sustainability.” The Panel added that, while FIA offices collect “considerable information” pertinent to understanding ecosystem sustainability and biodiversity, “these data have received little analysis [and] even less reporting.” The Panel called for more timely inventory and reporting, and “a core set of ecological data” to be collected in addition to conventional tree vegetation measures.

The Office of Technology Assessment (1992) concluded that the Forest Service does not have adequate data to meet the objectives of ecosystem management, and the data the agency does collect often are inaccurate, updated infrequently, and classified in terms of commodity production.

In a study of Forest Service decision making, the US General Accounting Office (1997, p. 7) found that the agency

- “has historically given a low priority to monitoring during the annual competition for scarce resources”
- “continues to approve projects without an adequate monitoring component”
- “generally does not monitor implementation of its plans as its regulations require”
is “not adequately monitoring the effects of past management decisions to more accurately estimate the effects of similar future decisions.”

The General Accounting Office also observed that the agency’s monitoring activities are largely driven by timber sale issues, as opposed to other objectives such as ecosystem management, and that the agency unduly relied on timber production models for its forest projections. Yet, the Forest Service’s failure to comply with the planning and monitoring mandates of the National Environmental Policy Act and the Endangered Species Act has resulted in numerous lawsuits by environmental organizations and other parties, as well as large monetary damage claims for suspended and canceled logging contracts. Such violations have led to rising costs for timber sales preparations and increasing delays in sales implementation.

Shortcomings in US monitoring practice were highlighted in the Montreal Process progress report to the World Forestry Congress on implementation of sustainable forestry criteria and indicators:

A vast amount of data is available in the USA, including a relatively comprehensive national inventory of wood production values. However, much of the non-wood data has been collected by different entities, at different times for different purposes using different approaches. Therefore much of the existing data on biodiversity, forest health, soil and water conservation, and public use lacks consistency and is inadequate for national level assessments, especially as little data is available for private lands. Virtually no data exist for non-timber products (Buchanan, 1997, p. 35).

A survey by the Forest Service (1996) of experts in government agencies, academia, industry, and environmental organizations determined that of the 67 indicators of sustainable forest management agreed to at Santiago, the US is able to measure and report on only nine. A new monitoring strategy developed by the Forest Service (1998) recommends that another 20 to 25 indicators could be tracked if funding for federal monitoring programs were increased by over 400 percent. These findings are summarized in Table 2.2 below.

Although questions have been raised about the salience of individual Montreal Process indicators, the usefulness of the measures across a range of critical forest issues is widely acknowledged. Thus, the data collection and reporting gaps identified in Table 2.2 indicate that notable shortcomings exist in the United States’ current and planned forest monitoring efforts.

The following two chapters explore this argument in more detail by surveying the current in situ and remote sensing monitoring capabilities and efforts in the US.
### Table 2.2
US Implementation of Santiago Agreement Criteria & Indicators

<table>
<thead>
<tr>
<th>Criterion and Indicator</th>
<th>Current Capability</th>
<th>Planned Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Biodiversity Conservation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area of forest by type</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Area of forest by type &amp; age</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Area of forest by type &amp; IUCN category</td>
<td>yes*</td>
<td></td>
</tr>
<tr>
<td>Area of forest by type, age, &amp; IUCN</td>
<td>yes*</td>
<td></td>
</tr>
<tr>
<td>Fragmentation by forest type</td>
<td>yes*</td>
<td></td>
</tr>
<tr>
<td>No. forest-dependent species</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Status of forest-dependent species</td>
<td>yes</td>
<td>yes*</td>
</tr>
<tr>
<td>No. forest-dependent species in restricted range</td>
<td>yes*</td>
<td></td>
</tr>
<tr>
<td>Population levels of representative species</td>
<td>yes*</td>
<td></td>
</tr>
<tr>
<td><strong>2. Productive Capacity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area of forest land &amp; timber land</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>All live &amp; growing stock volume</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Area &amp; growing stock in plantations</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Annual removals for products as percent of sustainable volume</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Removals of non-timber products as percent of sustainable levels</td>
<td>no</td>
<td>yes*</td>
</tr>
<tr>
<td><strong>3. Ecosystem Health</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent forest damaged by insects, disease, fire, flood, etc.</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Percent forest affected by air pollution</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Percent forest with diminished biological components</td>
<td>no</td>
<td>yes*</td>
</tr>
<tr>
<td><strong>4. Soil &amp; Water Conservation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent forest with significant soil erosion</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Percent forest managed for protective functions</td>
<td>yes</td>
<td>yes*</td>
</tr>
<tr>
<td>Percent stream length in forested areas with altered flows</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Percent forest with significantly diminished soil organic matter</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Percent forest with significant soil compaction</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Percent water bodies in forested areas with significant change in biodiversity</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Percent water bodies in forested areas with significant change in hydrologic character</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Percent of forest experiencing significant accumulation of toxic substances</td>
<td>no</td>
<td>yes*</td>
</tr>
</tbody>
</table>
### Table 2.2 continued

<table>
<thead>
<tr>
<th>5. Carbon Cycle</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total forest biomass &amp; carbon pool by type &amp; age</td>
<td>no</td>
</tr>
<tr>
<td>Contribution of forests to carbon budget</td>
<td>maybe</td>
</tr>
<tr>
<td>Contribution of forest products to carbon budget</td>
<td>no</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6. Long-Term Socioeconomic Benefits</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Value &amp; volume of wood products</td>
<td>yes</td>
</tr>
<tr>
<td>Value &amp; quantity of non-wood forest products</td>
<td>no</td>
</tr>
<tr>
<td>Per capita supply &amp; consumption of wood &amp; wood products</td>
<td>yes</td>
</tr>
<tr>
<td>Value of wood &amp; non-wood forest products as percent of Gross Domestic Product</td>
<td>maybe</td>
</tr>
<tr>
<td>Degree of recycling of forest products</td>
<td>maybe</td>
</tr>
<tr>
<td>Supply &amp; consumption of non-wood products</td>
<td>maybe</td>
</tr>
<tr>
<td>Percent forest managed for recreation</td>
<td>maybe</td>
</tr>
<tr>
<td>Number &amp; type of recreation facilities per forest area &amp; population</td>
<td>maybe</td>
</tr>
<tr>
<td>Number of recreation visitor days per forest area &amp; population</td>
<td>no</td>
</tr>
<tr>
<td>Value of investment in forest growth, health, management, and recreation</td>
<td>yes</td>
</tr>
<tr>
<td>Spending on forest research &amp; education</td>
<td>no</td>
</tr>
<tr>
<td>Extension &amp; use of new &amp; improved technology</td>
<td>no</td>
</tr>
<tr>
<td>Rate of return on investment</td>
<td>no</td>
</tr>
<tr>
<td>Percent forest managed to protect cultural needs</td>
<td>no</td>
</tr>
<tr>
<td>Non-consumptive forest use values</td>
<td>no</td>
</tr>
<tr>
<td>Direct &amp; indirect employment in forest sector</td>
<td>maybe</td>
</tr>
<tr>
<td>Average wage &amp; injury rates in forest sector</td>
<td>maybe</td>
</tr>
<tr>
<td>Viability &amp; adaptability of forest-dependent communities</td>
<td>no</td>
</tr>
<tr>
<td>Percent of forest used for subsistence</td>
<td>no</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7. Institutional Capacity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent legal framework supports conservation and sustainability</td>
<td>no</td>
</tr>
<tr>
<td>Extent institutional framework supports conservation and sustainability</td>
<td>no</td>
</tr>
<tr>
<td>Extent economic framework supports conservation and sustainability</td>
<td>no</td>
</tr>
<tr>
<td>Capacity to monitor change in conservation and sustainability</td>
<td>no</td>
</tr>
<tr>
<td>Capacity to conduct and apply research for improved forest management, goods, and services</td>
<td>no</td>
</tr>
</tbody>
</table>

* Requires integration of Forest Service and other agency data.

CHAPTER 3

CURRENT MONITORING PROGRAMS AND PRACTICE

The US Government, together with state governments, industry, and academia sponsor a wide and evolving array of programs that monitor the nation’s forest resources. In the early part of this century, these activities focused on trees with the objective of ascertaining the location, volume, and quality of timber available for extraction. With the rise of the sustained-yield/multiple-use principle in mid-century, monitoring was broadened to track timber removals and regeneration; an array of vegetation measures; pest and disease activity; and measures of recreation use and wildlife. In the 1970s, environmental regulations brought about new efforts to monitor air and water quality as well as endangered species in forests. With growing concerns today about forest health, biodiversity preservation, and climate change, monitoring efforts have shifted towards more integrated measures such as fire risk, habitat fragmentation, and carbon flux. In sum, forest monitoring evolved from a focus on wood to a concern about forests as complex systems.

This evolving focus has been associated with a multiplication of monitoring programs—mostly federal—with different institutional and scientific bases, levels of effort, scopes, methods, and objectives. The development of such a diverse array of monitoring initiatives, has raised questions about their collective ability to monitor forests with a systems approach. Indeed, as we have noted in Chapter 2, the US Forest Service has concluded that the nation presently has the ability to report on only 9 of 67 Santiago Agreement indicators of sustainable forest management, with the most capability still focused on timber production and vegetation measures.

This chapter presents a broad overview of the different forest monitoring efforts currently underway in the US—with an emphasis on federal programs—and includes information about information who sponsors them, what data they collect, where these activities are located, and program objectives. In addition, the chapter expands on the critiques raised in Chapter 2 and details how current measurement services are failing to meet the nation’s policy and management needs, and it identifies opportunities for improvement and integration across programs.

MONITORING PROGRAMS

The federal government, together with states, industry, and academia sponsor an array of long-term forest inventory and monitoring activities—with a level of effort on the scale of several hundred million dollars.12

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12 A figure for total federal funding of forest monitoring is difficult to ascertain. The Forest Service does not have accounting systems in place to track forest monitoring activities. Monitoring often is
Ground (in situ) monitoring is the most important means of forest measurement. All of these monitoring programs make use of in situ methods where a forester visits a sampling site (typically a standardized plot) to gather detailed data (e.g., tree size, age, biomass, changes over time, land use) on the resources of that plot. A few programs also rely on aerial photography, sketch mapping, and satellite-based remote sensing for preliminary resource assessments; to target ground investigations (for example, concerning fire, pests) and for area estimation (i.e., to estimate the extent of forest characteristics identified on the ground).

The US Department of Agriculture (USDA) Forest Service is main collector and reporter of forest data in the United States. Additional monitoring efforts are carried out by the USDA Natural Resources Conservation Service and by several agencies within the Department of Interior: the Bureau of Land Management, the US Geological Survey, Natural Resources Conservation Service, and US Fish and Wildlife Service. A summary of the most significant federal monitoring programs are outlined in Table 3.1, and a more detailed characterization of the different types of forest monitoring, their levels of effort, and the uses of their data outputs follows.

**Nation-wide Forest Measurement**

The Forest Service manages three programs that survey different attributes of forests across the United States. *Forest Inventory Analysis (FIA)* is a state-by-state inventory of forest area and type, volume of timber, growth and depletion, and other measures. FIA is the nation’s most ambitious forest monitoring program with funding at $22 million in 1998. FIA is carried out in a two-phase process: first with forest area and type classified typically using aerial photographs, and second with Forest Service field crews conducting site visits to ground plots to gather detailed data for each forest class. These area and unit data are then combined to provide estimates of the total types of forest resources of the state and, ultimately, nation. FIA outputs are widely used for strategic analysis and planning by federal and state officials, and universities. The forest industry also uses the information to guide capital investment, operations, land acquisition, and timber sale decisions.

Undertaken cooperatively across agencies and in conjunction with states which makes tracking expenses difficult. Finally, many programs outside of the forestry sector monitor important components of forest ecosystems, but are not accounted for under forest monitoring.
## Table 3.1

Major Federal Forest Monitoring Programs

<table>
<thead>
<tr>
<th>Program</th>
<th>Primary Monitoring Mission</th>
<th>Sponsoring Agency</th>
<th>Geographic Coverage</th>
<th>Frequency of Data Collection</th>
<th>Principle Guiding Laws</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest Health Monitoring</td>
<td>Forest health status &amp; trends; air pollution and climate change</td>
<td>Forest Service in cooperation w/states</td>
<td>2000 sites (4000 planned) in 22 states, all ownerships</td>
<td>4 year average</td>
<td>Forest Ecosystems, Atmospheric Pollution Act</td>
</tr>
<tr>
<td>(Plot System)</td>
<td>impact detection</td>
<td></td>
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<tr>
<td>Forest Health Protection</td>
<td>Forest pest and disease detection and monitoring</td>
<td>Forest Service in cooperation w/states</td>
<td>nationwide</td>
<td>Annual</td>
<td></td>
</tr>
<tr>
<td>Forest Inventory and Analysis</td>
<td>Forest and timber inventory, with some non-tree value monitoring</td>
<td>Forest Service</td>
<td>135,000 sites on 609 million acres mostly in East; doesn’t include most National Forests</td>
<td>10 year average</td>
<td>Forest Research Act</td>
</tr>
<tr>
<td>National Forest System</td>
<td>Facility planning, timber sales, regulatory compliance</td>
<td>Forest Service</td>
<td>156 National Forests; 140 million forest acres with a majority in West</td>
<td>As needed or required by law</td>
<td>National Forest Management Act; ESA, NEPA, etc.</td>
</tr>
<tr>
<td>BLM Unit Monitoring</td>
<td>Facility planning, timber sales, regulatory compliance</td>
<td>Bureau of Land Management</td>
<td>36 million acres in the West and Alaska</td>
<td>As needed or required by law</td>
<td>Federal Land Policy and Management Act; ESA, NEPA, etc.</td>
</tr>
<tr>
<td>Wildland Fire Assessment</td>
<td>Assess and warn of forest fire risks</td>
<td>Forest Service</td>
<td>1500 weather stations nationwide</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>Joint Fire Service Program</td>
<td>Fuel and fire risk assessment; fire management and response</td>
<td>Forest Service/Bureau of Land Management</td>
<td></td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>Experimental Forests</td>
<td>Research on vegetation, soils &amp; water pollution, wildlife</td>
<td>Forest Service</td>
<td>Hundreds of sites</td>
<td>Varies</td>
<td>Renewable Resources Act</td>
</tr>
</tbody>
</table>
Under the *Forest Health Protection* (FHP) program, state agencies, in collaboration with the Forest Service, conduct summertime aerial and ground surveys of forest insect, disease, and other change agents. The highly descriptive and anecdotal data are used by state officials and Forest Service regional representatives to evaluate trends and to target management responses.

In 1990, the *Forest Health Monitoring* (FHM) program was created in response to growing concern about air pollution, global climate change, urban forests, and sustainable forestry. FHM collects data on tree condition, air quality indicators (e.g. lichens), and vegetation diversity. Because at present only part of its ground sampling plots and no area classification component is funded at present, FHM only reports average estimates, not totals like FIA. Nevertheless, the program has generated some preliminary conclusions about forest trends in the eastern US.

**Federal Facility Monitoring**

Managers of National Forests, and Bureau of Land Management (BLM), Department of Defense, and other federal facilities with significant forest resources are responsible by law for periodically measuring the status of forest resources, compliance with environmental regulations, conservation activities, and facility uses. At National Forests and BLM units, this information is used by facility managers to design and monitor implementation of decennial plans according to the multiple-use and sustained-yield principles. Historically, many facilities concentrated on monitoring to plan timber cuts and assess their environmental impact, but in recent years increasing attention is being devoted to ecological criteria to guide habitat restoration, controlled burns, and variable density thinning.

**Other Resource-Based Monitoring**

Many different agencies monitor environmental conditions on forested lands in the US. For instance, the US Fish and Wildlife Service monitors the numbers and location of threatened and endangered species, such as the Mexican spotted owl and red-cockaded woodpecker. Under the US Geological Survey *Gap Analysis Program*, states have sought to identify critical habitats (many of them forested lands) and to assess land management activities and biodiversity preservation efforts in order to avoid declines in threatened species.

13 FHM originally was designed to utilize the landscape component of EPA’s Environmental Monitoring and Assessment Program (EMAP) for area classifications, however, the latter program was never fully implemented.

14 FHM monitoring found, for instance, that in 1991–1994 mean crown dieback was “consistently higher” in New England than in the mid-Atlantic and South (Forest Health Monitoring, 1996, p. 23).

15 For example, the Allegheny National Forest (1997) reported on developed recreation, dispersed recreation, and wilderness uses; stream and soil improvements; trail and road management; hunting and fishing; habitat improvement; minerals and wood production; and tree health and silvicultural treatments.
species. The US Environmental Protection Agency is concerned with stream water and air quality, particularly during and after major forest fires. The National Atmospheric and Oceanographic Administration (NOAA) monitors weather conditions and its data are integrated with Forest Service and BLM fuel load measurement data to model and predict fire hazards and treatment alternatives. The USDA Natural Resources Conservation Service National Resources Inventory (NRI) monitors land use and natural resource conditions and trends, particularly soil resources, on non-federal agricultural lands, many of which are forested. As such, NRI carries out an important forest monitoring function, especially in the South (Czaplewski, 1999). NRI, like FIA, uses aerial photointerpretation for area classifications to estimate total resources. Another important forest monitoring activity at the national level is the Multi-Resolution Land Classification (MRLC) data base, which is being developed jointly by the US Environmental Protection Agency, US Geologic Survey, NOAA, and National Biological Service, specifies 33 land cover and land use classifications for the continental US, including three forest classes. The US Geological Survey Biological Status and Trends program monitors diverse biological resources to identify critical gaps in knowledge and to predict and determine changes in the status or distribution of biota or ecological conditions in order to promote better resource management and conservation.

Private Facility Monitoring

Forest monitoring activities in the private sector commonly focus on the management of forest stands. In general, larger firms emphasize the management of forests for sustained yields and dedicate greater monitoring efforts to this end. Proprietary monitoring by larger firms typically includes ground and aerial surveys of forest acreage and distribution by age class and species type. This information is used in decisions regarding timber cuts, replanting, and stand treatments. One of the largest forest owners in North America, for example, takes forest inventory and stand growth data on about ten percent of its holdings with a site return interval of five years. Another firm that advocates sustainable forest management uses GIS to track and integrate information about soils, terrain, waterways, and other forest characteristics. In contrast, owners of smaller holdings, many of whom are farmers, conduct little or no monitoring, and their timber cuts are often dictated by financial imperatives (to defray inheritance taxes, for example), rather than ecological or silvicultural principles. All private owners must comply with regulatory (e.g. water, species) monitoring requirements.

Ecoregional Assessments

One outcome of heated land-use debates has been efforts in recent years to better understand forest ecosystem and community status and trends by conducting ecoregional assessments that integrate a larger set of measurement data over larger spatial scales and across diverse ownerships. Many of these interagency data integration efforts have concentrated on forest resources, and include the Interior Columbia River Basin Ecosystem Management Plan (ICRB), the Sierra Nevada Ecosystem Plan (SNEP), and the Forest Ecosystem Management Assessment (FEMAT) in the Pacific Northwest. The ecoregional assessments have sought to improve forest monitoring through the better coordination of
existing data collection efforts and enhanced data analysis. In some cases, such as the Southern Appalachian Assessment (SAA), regional forest monitoring efforts have been expanded to meet new information needs stipulated by the program.16

**Research**

Research-driven monitoring is conducted under the auspices of a large number of programs at hundreds of sites. The Forest Service maintains 83 Experimental Forests that support agency and cooperative research on a range of topics including vegetation, wildlife, soils, and hydrologic cycles. In 1995, funding for research under this program totaled $200 million. Other site-specific research programs include Forest Service Wilderness Areas (sites used primarily for local-level research and monitoring that are particularly important in air quality monitoring) and the Long-Term Ecological Research (LTER) program, started in 1980, which includes five forests. The Ameriflux program currently is establishing an infrastructure for collecting, synthesizing, and disseminating long-term measurements of carbon dioxide, water, and energy exchange from a variety of ecosystems, including old-growth forests. Ameriflux ground monitoring will be used to calibrate data collected by the Earth Observation Satellite (EOS) system.

**SHORTCOMINGS IN EXISTING MONITORING CAPABILITIES**

As we noted in Chapter 2, many studies have led to the conclusion that, even with the large number of federal, state, and private monitoring services in place, US forest monitoring practices are unable to satisfy current or expected policy and management information needs. These shortcomings include a continued focus on vegetation, the lack of national-scale measurement and reporting, problems with timeliness, and a lack of salience to contemporary decision making needs—points we explore in more detail below.

**Non-Vegetation Monitoring Remains Limited**

Forest monitoring remains focused on tree vegetation data despite the multiplication of programs over past years which monitor forest resources. Forest Inventory and Analysis, a program geared towards measuring the nation’s timber supply, is considered the only broad-scale source of information on forest resources status and trends in the US (FIERR, 1992). Not surprisingly, forest officials investigating the United States’ ability to report on Santiago Agreement sustainable forestry indicators (Forest Service, 1996) have determined that significant data gaps remain for non-vegetation criteria, such as biodiversity preservation, soils and water conservation, ecosystem health, carbon cycles, socio-economic progress, and institutional capacity (see Table 2.2). The limited availability of biomass measures and the paucity of soils data for forest lands, for example, impedes foresters’ ability to estimate carbon flux from forest systems—a measure necessary for compliance with the Kyoto Protocol.

16 Under the auspices of the Southern Appalachian Assessment, FHM monitoring by the Forest Service and cooperating states tracked additional measures, such as forest floor thickness, soil carbon content and pH, and forest scenic beauty (Forest Health Monitoring, 1996).
The information gathered and reported in the National Forest System also has been limited. For example, the plan for California’s Stanislaus National Forest includes ninety-three data items across twenty-two categories ranging from air quality, soils, and water to economic status, transportation, and recreation. In 1997, actual monitoring addressed 29 of these items as well as nine measures not in the plan (Stanislaus National Forest, 1998). So-called monitoring efforts may also entail the compilation of already existing information with no new data collection (Raines, 1998). In consequence, many National Forests have been sued for noncompliance with Endangered Species Act and National Environmental Policy Act monitoring requirements.

Expanding the nation’s capabilities to monitor a wider and more complex suite of forest measures will take time, perhaps decades. Already, the development of new programs such as Forest Health Monitoring, FHM’s integration with Forest Health Protection, and a planned merging of FIA and FHM represent important steps in this direction. Some National Forests and FIA regions (e.g. Pacific Northwest) and have expanded the range of information they gather beyond traditional inventory criteria (see Table 3.3). Nevertheless, the Forest Service as well as the Bureau of Land Management have not truly reoriented their organizational priorities towards monitoring for ecosystem management and sustainable forestry. This situation ultimately stems from the agencies’ legislative and budget mandates which continue to emphasize timber production and which call for multiple-uses that often conflict.

**The US Lacks a National Forest Data Base**

Both FIA and FHM, while national forest monitoring programs in intent, do not generate national forest resources data bases. The lack of a national-scale data is illustrated by the gaps noted in Table 3.3 above. When national reporting is required—as for the 5-year Resource Planning Act assessments mandated by law—information from divergent sources such as FIA, the National Forest System, and state agencies must be aggregated and harmonized. This complex process is a result of the decentralized structure and highly autonomous components of the Forest Service—most significantly the National Forests in the West—which rely on their own data collection and interpretation protocols.

In addition, the FIA program is administered regionally through five Forest Service Experiment Stations (see Figure 3.1), and each regional FIA Director maintains authority to determine the data definitions, sampling and reporting protocols, and analysis techniques to be used in their region. This organization, in the opinion of the Forest Service (1998, p. 4) has resulted in “a collection of regional inventory systems with limited consistency for drawing conclusions at the national level and for making comparisons among regions.” Accordingly, a lack of a national forest database will hamper the nation’s efforts to achieve timely and accurate carbon accounting to meet its international climate change obligations in the future.
<table>
<thead>
<tr>
<th>Data</th>
<th>Pacific NW</th>
<th>Inter-Mountain</th>
<th>North Central</th>
<th>South</th>
<th>North-east</th>
<th>South-east</th>
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<tbody>
<tr>
<td><strong>Non-Tree Vegetation</strong></td>
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<td>Species Abundance</td>
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<td>Vegetation Profile</td>
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<td>Biomass</td>
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<td><strong>Wildlife Habitat</strong></td>
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<td>Edge</td>
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<td>Animal use, browsing</td>
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<td>Snags</td>
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<td>Down, woody material</td>
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<td>Cover, shelter</td>
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<td>Suitability</td>
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<td><strong>Recreation</strong></td>
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<td>Opportunity assessment</td>
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<td>Use</td>
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<td><strong>Soils</strong></td>
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<td>Landscape context</td>
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<td>Physical characteristics</td>
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<td><strong>Water</strong></td>
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<td>Type</td>
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<td>Proximity to plot</td>
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<tr>
<td><strong>Other</strong></td>
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<tr>
<td>Forested range for grazing</td>
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<td>Logging operability</td>
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<tr>
<td>Spatial coordinates</td>
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<tr>
<td>Residential fuelwood</td>
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<tr>
<td>Fire fuel quantities</td>
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<tr>
<td>Woodland assessment</td>
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<tr>
<td>Rescue zone</td>
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</table>

Similarly, management of the National Forests is highly decentralized. Each of the nine National Forest System regional offices establishes its own measurement, reporting, and analysis protocols, with levels of effort at each National Forest varying greatly. In consequence, the degree to which data from the National Forests can be integrated varies among, and even within, regions (FIERR, 1992). Thirty-five National Forests are located within the Interior Columbia River Basin ecosystem, and each has a unique monitoring program and data base. The General Accounting Office (1997) noted that such independent efforts on the wrong scale result in unnecessarily duplicative and time-consuming analyses and reduce the effectiveness of federal management decision making.

Efforts have been underway to remedy these compatibility problems. The Forest Inventory, Economics, and Recreation Research (FIERR) staff working out of the Forest Service Washington Office have been working on the development of a national manual to ensure that the measurement and processing of ground plot data are standardized and that the plots are located in a statistically valid sample (Hansen, 1999). FIA officials have

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17 Forest monitoring by National Forests in California, Oregon, and Washington differ significantly from other Forest Service monitoring efforts (Gillespie, 1998).
developed a list of core variables to be collected by all regions (Forest Service, 1998), and they have called for the extension of the FIA program to include National Forest lands, beyond those already being inventoried in the East. Should these measures be implemented over the next 5 years as planned, they would significantly improve the quality and scope of data available at the national scale.

**Forest Data is Not Timely**

While FIA data are regarded as valuable by the forest industry, the existing inventory cycle time (typically 8–15 years) is considered to be too long. Many in industry would like to see the interval reduced to five years, and they are working to sue the Forest Service for violation of the Resources Protection Act in order to accomplish this goal. The timeliness issue also has been raised in the two industry-sponsored Blue Ribbon Panels on FIA (American Forest Council, 1992; American Forest and Paper Association, 1998), and in the Agricultural Research, Extension, and Education Reform Act of 1998.

Improvements in FIA have been made. In the FIA Southern Region, the Southern Annual Forest Inventory System (SAFIS) has achieved a five year inventory cycle time with one-fifth of FIA in situ forests monitoring plots in a state being visited every year, as prescribed in the legislation mentioned above. This pace has been achieved in part through the use of local crews—an approach that also has reduced expenses, rather than the traditional itinerant crews that move from state to state—an arrangement that is subject to bottlenecks. The Forest Service (1998) has developed a strategy to speed up the FIA process nationwide, using SAFIS as a model, but the plan still relies on the use of itinerant crews and has been criticized as being too costly.\(^{18}\)

Another source of the timeliness problem is resource allocation. In many states, FIA must resort to borrowing aerial photos from other sources, such as the Natural Resources Conservation Service, and officials may have to wait for years for the necessary coverage to become available (Hansen, 1998a). The FIA strategy does not address the aerial data acquisition problem.

The nation’s decentralized forest monitoring and management structure slows down the data delivery process. Extra time must be allocated to data acquisition, aggregation, and interpolation to smooth out differences in data collection methods between regions and organizations. This structure also has slowed the integration of monitoring efforts themselves. For example, the development and implementation of measurement protocols and data collection and reporting standards for a set of FIA measures at lower scales, resulting in the Eastwide Data Base, took 20 years to complete (Schreuder, 1998).

**Research is not Integrated with Decision Making**

While the Forest Service (as well as other federal agencies) supports significant research on forest resources, questions have been raised about its applicability to pressing decisions

\(^{18}\) The quality of existing in situ forest inventory capabilities relies in part on the loyalty of Forest Service field crews to their institution. If in situ forest inventories were moved out of the Forest Service structure, the quality of effort may decline (Czaplewski, 1999).
regarding climate change, biodiversity, and other issues. In an analysis of forestry research, the National Research Council (1990) concluded:

The existing level of knowledge about forests is inadequate to develop sound forest management policies. Current knowledge and patterns of research will not result in sufficiently accurate predictions of the consequences of potentially harmful influences....

One issue is that Forest Service-sponsored research often has been site-specific and short-term, making extrapolation to larger regions difficult, as the Forest Service (1993) noted:

In the past, Forest Service researchers have worked somewhat independently of one another, each pursuing individual and often unrelated goals within a single discipline. In addition, much research has been conducted as case studies applicable only to local situations; as a result, the findings cannot be expanded to broader regional applications. When making regional resource evaluations, another problem is that individual disciplines or specialties tend to develop their own terminology, standards, and methodology, often inconsistent with other disciplines. This lack of comparability makes it very difficult, if not impossible, to relate results to a common resource situation or common land base.

As a result of such problems, information generated by forest research projects typically is not aggregated or organized by researchers for use by managers or decision makers.

Adaptive management is one way that ecosystem measurement and research outputs can be more fully integrated into operational forest management decisions. For example, at Eglin Air Force Base, Florida, The Nature Conservancy has worked closely with base managers to design and implement a comprehensive program to restore the long-leaf pine ecosystem (Hardesty et al., 1997; McWhite et al., 1993). This program was based on years of research by both organizations, and ongoing monitoring and research will be used to monitor progress and inform decisions on corrective actions.

OBSERVATIONS

This survey of forest measurement practices and programs in the US raises many issues about integrating and enhancing monitoring and inventory practices in order to improve forest management. In the discussion below, we address several organizational factors that have impaired forest monitoring in the United States.

Forest Service Structure Impedes Data Integration

The Forest Service is working towards integrating the FIA and FHM programs, and FIA has been working intermittently to collaborate more closely with the National Forest System with the goal of producing more comprehensive and uniform forest information. However, the existing structure of the Forest Service makes accomplishing these goals difficult. FHM is run out of nine regional offices of the State and Private Forestry deputy division, while FIA is run out of five experiment stations under the Forest Research deputy division. The monitoring of Forest Service lands is conducted by National Forest System deputy division (except when eastern National Forests contract with FIA), and
measurement practice varies significantly between National Forest System units and regions. FIA managers (Forest Service, 1998) have addressed this issue by calling for the integration of FIA and FHM field monitoring, as well as the addition of National Forest System monitoring under the auspices of the five experiment stations.

This reorganization, if fully implemented, will only solve part of the problem. As aforementioned, specialists on the FIERR staff have attempted to remedy the problem of standardization by establishing a standard minimum data set to be collected on similar plots across all programs and forest lands and by developing consistent sampling methodology and data reporting protocols. But, as can be seen in Figure 3.2, these staff no direct authority to implement these efforts so progress in developing uniform national measurement standards has been slow. Reducing regional and local disparities, may require a reorganization that allocates more direct authority for measurement standards and protocols to Washington-based officials placed above the deputy chief level.

Limited Funding Renders FHM's Value

The creation of Forest Health Monitoring was intended to broaden the scope of forest monitoring to address the concerns of ecosystem management and sustainable forestry and include measures such as plant species diversity, soils, wildlife habitat, scenic beauty. The program is also intended to serve as the United States’ principle program for detecting and evaluating stresses such as air pollution, acid precipitation, and climate change (Sommers, 1998). FHM is designed to provide policy-relevant information for national, state, and local decision-makers.

However, a shortage of funding prevents FHM from monitoring the wide range of variables needed to meet the program’s ambitious policy objectives. Because FHM does not have an area estimation component, the program currently only provides estimates of average forest conditions for the variables it covers (for example, average biomass by forest type and species) and does not report any estimates of totals (Hansen, 1999). In consequence, FHM reports highly descriptive and anecdotal information; this allows officials to respond quickly with additional investigations, but the program cannot yet produce quantitatively meaningful information with any consistency over time or space. Only about half of FHM plots currently are monitored, thereby leaving large gaps in parts of many ecoregions. This renders the data collected virtually irrelevant except in regions, such as New England and other portions of the eastern US, where more neighboring states participate.19 Because the program is implemented and largely funded on a state-by-state basis, the level of effort and range of variables monitored and analyzed varies by state. Yet, as the program currently stands, states have little incentive to support FHM because the data are not relevant at their scale.

19 As an illustration of the type of results FHM has generated, its monitoring found that, in 1991–1994, mean crown dieback was “consistently higher” in New England than the mid-Atlantic and South (Forest Health Monitoring, 1996, p. 23).
Funding for FHM repeatedly has fallen short of expectations as the Forest Service’s budget has been cut in recent years. While the Forest Service (1998) has called for a quadrupling of...
funding for a merged FIA/FHM program (to be called Forest Inventory Monitoring), the agency’s strategic plan focuses on increasing the rate of data collection, but it does not explain how monitoring will be conducted and how resources will be allocated to make the FHM component meaningful. Even within an expanded FIM, future funding for ecosystem monitoring is likely to fall short of needs without explicit legislative and budgetary mandates.

Integration of Monitoring across Agencies Needed

One important outcome from the numerous ecosystem assessments undertaken in recent years is the recognition that monitoring remains highly fragmented, even in regions with critical forest ecosystems. Pacific Northwest Forest Ecosystem Management Assessment Team (FEMAT, 1993) found that the collection, tabulation, and analysis of ecosystem data by different organizations including the Forest Service, Bureau of Land Management, state agencies, and the Nature Conservancy was inconsistent and difficult to compare.

As a result of the ecoregional assessments and other White House policy efforts, the Forest Service and other federal forest managers have moved in recent years to build partnerships. For instance, the Joint Fire Service, a new Forest Service/Bureau of Land Management program is starting to coordinate fire prediction, monitoring, and response activities at the local to national level (Joint Fire Service Drafting Committee, 1998). The FHM program which was based on the EPA’s Environmental Monitoring and Assessment Program, involves close partnerships with the states, and has established a reputation for interagency and federal-state collaboration that may serve as a model.

Many more opportunities for integration exist. For example, the National Resources Inventory monitors land use and natural resource conditions and trends on non-federal agricultural lands. In contrast to FIA, NRI generates a truly national land resources database and NRI data are statistically valid at the national, regional, state, and sub-state levels of analysis. Because NRI monitors land use and land cover, including forest type, there may be opportunities to integrate this information with Forest Service inventories using the National Vegetation Classification Standard as a starting point. The NRI maintains extensive soils databases and expertise; their integration with forest monitoring programs could contribute to a better scientific understanding of forest ecosystems and carbon flux. Similarly the USGS Biological Status and Trends program could measure a common set of indicators in coordination with FIA, FHM, and the National Forest System. A recent pilot project in Oregon to integrate NRI and FIA as well as Bureau of Land Management and USGS monitoring efforts generated positive results (Goebel, et al., 1998).

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20 The Forest Service is obligated to coordinate activities with respect to the National Vegetation Classification Standard, with oversight from the Federal Geographic Data Committee. The Standard is used to increase accuracy, consistency, and clarity in a systematic vegetation taxonomy so that resource managers and others can make efficient decisions and develop and report statistically correct national vegetation figures (Vegetation Subcommittee, 1997). Programs such as the Gap Analysis Program, the National Park Service Inventory and Monitoring Program, and the Forest Service’s Eastern and Southern ecoregional assessments use or have used the National Vegetation Classification Standard (Vegetation Subcommittee, 1997).
Further collaborations of this type also would serve the goal of ecosystem-based monitoring.

As we have seen in this chapter, the federal government sponsors a diverse array of forest monitoring services. Yet, the nation’s goal to implement ecosystem management and sustainable forestry principles would be extremely difficult to attain using the current data collection efforts. As we have noted, many initiatives to upgrade and modernize the nation’s forest measurement capabilities are under consideration or are already underway. These create a rich opportunity to try distinctly new approaches and technologies. All of the monitoring programs mentioned above rely on in situ, and to a lesser extent, aerial monitoring methods. In the next chapter, we will examine the potential for another approach—satellite-based remote sensing—to enhance the cost-effectiveness, timeliness, and versatility of the nation’s forest monitoring efforts.
CHAPTER 4

USE OF REMOTE SENSING IN FOREST MONITORING

While the nation’s existing ability to monitor critical forest measures across a range of values using in situ and aerial methods is limited, the advent of improved measurement technologies and capabilities—in particular, space-based remote sensing—has the potential to dramatically improve our forest monitoring efforts.

Satellite imagery offers numerous advantages over traditional aerial photography or in situ methods:

- In comparison to in situ and even aerial monitoring, medium and low resolution satellite imagery provides a synoptic perspective over large areas and offers frequent revisits.

- Satellite imagery overcomes jurisdictional and physical impediments to large-area monitoring on the ground.

- Several satellite sensors sample mid- and thermal infrared wavelengths that cannot be detected with film. This multi-layered data archive that can be manipulated according to the user’s information needs.

- The digital format facilitates ready manipulation in a spatial database and sending of data over computer networks.

Remote sensing capabilities have evolved rapidly over the past quarter century with the development of new satellites and sensors, information management technologies, and image interpretation techniques. Most importantly, the spatial and spectral resolution of imagery has been enhanced, enabling interpreters to discern more attributes of a forest from a given scene. As more satellites are placed in orbit, the revisit cycle is falling, thereby allowing a more real-time measurement capability.

In recognition of these developments, many policy initiatives have called for the greater integration of this technology in forest inventory and monitoring programs. The Second Blue Ribbon Panel on FIA (American Forest & Paper Association, 1998) stated that satellite imagery should replace traditional aerial photos “wherever this will lead to improved efficiency” and that the FIA program should enhance data collection through cooperation with other agencies with greater remote sensing expertise. The Agricultural Research, Extension, and Education Reform Act of 1998 requested development of a plan to implement “remote sensing, global positioning systems, and other advanced technologies” in the FIA program. In the international arena, the Committee on Earth Observing Satellites (1995) has called for greater international cooperation on remote sensing.

This chapter describes the different remote sensing technologies and platforms commonly used in forestry, and reviews the kinds of applications to which they have been applied. In
addition, this chapter discusses the limitations that have prevented the wider use of the technology in forestry, and outlines opportunities for greater integration in the future.

REMOTE SENSING TECHNOLOGIES FOR FOREST MONITORING

Remote sensing satellites are capable of collecting and transmitting data on different measures and at varying degrees of detail. The way in which data is collected by a sensor and the processing of that data on the ground have much to do with whether or not that information is applicable to the needs of foresters. Satellite sensors with potential applications to forestry can be grouped into two types: electro-optical and synthetic aperture radar.

Electro-optical systems

Electro-optical (EO) systems are passive sensors which use an electronic sensor to detect optical signals but operate only when there is sufficient light reflected from the target for them to form an image. EO systems typically monitor blue, green, and red portions (or bands) of the visible spectrum, as well as near-infrared, and long-wave, or thermal, infrared bands. The near-IR bands have a wide variety of applications, including the ability to detect certain indicators of the health of vegetation. Most EO systems operate in two different regimes: panchromatic (Pan), in which imagery from all portions of the spectrum are recorded as shades of gray (i.e. producing a “black-and-white” image); and multispectral (MS), in which the discrete bands of light are recorded individually to be analyzed either individually or in composite, producing a “color” image.

Synthetic aperture radar

Synthetic aperture radar (SAR) is an active sensor, that is, it provides its own illumination and can therefore operate at night. SAR collects information by measuring reflected microwaves which generally have very good atmospheric penetration capability, so the satellite can collect data through clouds and light rain—an important capability in many forest regions such as the Pacific Northwest and British Columbia. A notable disadvantage of SAR is that the imagery shows only those objects that reflect the microwave signal energy back to the imaging platform; organic targets, such as vegetation, are much less visible than physical structures.

REMOTE SENSING PLATFORMS

Over the past 25 years, many satellites have been placed in service which carry sensors with capabilities salient to forest monitoring. And, in the next five years several more satellites will be placed in service which will expand potential forest measurement capabilities. (Specifications of these systems are presented in tabular form in Appendix A.) Of the large number of satellite platforms currently in operation, six have demonstrated greater potential to gather data is that useful to forest monitoring based on their type of sensor, spectral and spatial resolutions, length of data sets, and ground coverage. The basic characteristics of these platforms are summarized in Table 4.1.
Table 4.1
Specifications of Remote Sensing Satellites and Sensors with Potentially Significant Forestry Applications

<table>
<thead>
<tr>
<th>Platform</th>
<th>Principal Owner</th>
<th>Initial Service Date</th>
<th>Sensor Type</th>
<th>Spectral Bands</th>
<th>Spatial Resolution (meters)</th>
<th>Swath Width (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERS 1, 2</td>
<td>EU</td>
<td>1991</td>
<td>SAR</td>
<td>30</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>IRS 1C</td>
<td>India</td>
<td>1995</td>
<td>MS Pan</td>
<td>23</td>
<td>6</td>
<td>142</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Landsat 4, 5</td>
<td>USA</td>
<td>1982</td>
<td>MS</td>
<td>7</td>
<td>30</td>
<td>185</td>
</tr>
<tr>
<td>NOAA POES 6-12, 14</td>
<td>USA</td>
<td>1979</td>
<td>MS 4/5</td>
<td>1100</td>
<td></td>
<td>2399</td>
</tr>
<tr>
<td>Radarsat 1, 2</td>
<td>Canada</td>
<td>1995</td>
<td>SAR</td>
<td>10-100</td>
<td></td>
<td>50-100</td>
</tr>
<tr>
<td>SPOT 1-4</td>
<td>France</td>
<td>1986</td>
<td>MS Pan</td>
<td>20</td>
<td>10</td>
<td>60</td>
</tr>
</tbody>
</table>

Of the six platforms listed in the table above, data from three, using electro-optical sensors, have been utilized to a greater extent on an operational or production basis in forestry: the National Aeronautic and Space Administration’s (NASA) Landsat series; the National Atmospheric and Oceanographic Administration’s Polar Orbiting Earth Satellite (typically referred to as NOAA), and the French Système Probatoire d’Observation de la Terre (SPOT). These platforms are described below.

**Landsat**

Five Landsat satellites have been placed in service since 1972, thus generating the longest data base of remotely-sensed Earth imagery. Landsats have carried two medium resolution multispectral sensors: the Multi-Spectral Scanner (MSS), operational from 1972 to 1994 provided 80 meter resolution, and Thematic Mapper (TM), operational since 1982 provides 30 meter resolution. In mid-1999, Landsat 7 is due to be launched with an improved sensor—the Enhanced Thematic Mapper Plus (ETM+)—with an added 5 meter resolution panchromatic sensor to boost overall resolving power. Several features make the Landsat series well suited for forest monitoring:

- TM sensors scan 7 spectral bands, including portions of the infrared spectrum, selected to optimize vegetation monitoring.
- The sensors’ wide ground scan swath width reduces the need to mosaic images and is most efficient for large-area monitoring.
- The system has been modernized in manner to maximize data set consistency between platforms and sensors.
To date, Landsat TM imagery has been the most widely used space imagery in applied forestry, both in the US and abroad. The Forest Service has a standing commitment to acquire TM imagery and is said to be the federal government’s biggest user of Landsat imagery (Dull, 1998). Thematic Mapper imagery was selected for the development of the Multi-Resolution Land Classification (MRLC) data base. Internationally, Thematic Mapper data has been used in Brazil and Canada for mapping forest cover and other purposes (see Appendices B and C). TM imagery is the primary remotely-sensed data used by Finland for its national forest inventory—the only large-scale operational forestry use of remote sensing in Europe (Tomppo, 1998).

**NOAA**

Since 1979, eight NOAA meteorological satellites have been placed in service with a multispectral sensor, the Advanced Very High Resolution Radiometer (AVHRR). Several features make AVHRR well-suited for forest monitoring:

- Its polar orbit affords global coverage and is especially useful for mapping boreal forests in northern latitudes.
- A very wide (2399 kilometer) swath provides a synoptic view with near-global coverage twice daily.
- Imagery is available at nominal cost: a digital, geometrically-registered data set costs $190.

NOAA’s low spatial resolution (1100 meters) and more limited spectral resolution are sufficient to monitor only basic forest attributes. The technology is unable to detect forests with crown cover of less than 20 percent, for instance (Czaplewski, 1989b). AVHRR imagery is considered suitable for land cover mapping at continental scale, for generating very broad forest classifications, and for detecting fire outbreaks. For instance, the Forest Service used AVHRR imagery to produce the first national map showing forest cover grouped by 25 forest types (Zhu, et al., 1993). In the Interior Western States, this forest type group map has been used for stratification of forest inventory plots. The sharp spectral signal generated by forest vegetation in this region offsets the technology’s lower resolution (Moisen, 1999). Finally, AVHRR has been used in a demonstration mode in many countries, such as Russia, to gain a basic understanding of forest trends, such as wildfire occurrence and extent.

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21 A survey of satellite data use by state agencies revealed that forestry and land cover/land use were the most prevalent applications (Warnecke, 1997).

22 The previous national map, compiled in 1967, was produced by interpolation of field data and other maps and rendered only a generalized representation of forest type distribution (Powell et al., 1993).
Figure 4.1
Example of AVHRR Scan Swath

SPOT
In 1986 France launched its first of four SPOT satellites carrying multispectral and panchromatic sensors with these features:

- SPOT provides higher spatial resolution than Landsat
- A near-polar orbit affords coverage of high latitudes not accessible by Landsat.
- SPOT has a data storage capability on-board, which allows coverage over entire range, even when the satellite is out of contact with its ground receiving stations.

Given these features, SPOT imagery has been focus of cooperative agreements between the US and France (Wagner, 1998).

In general, the use of SPOT imagery has been more selective. SPOT has a smaller swath (60 kilometers) than Landsat which increases the complexity of larger-area applications that require multiple images to be co-registered and mosaicked. Moreover, the first generation SPOT sensors (1986-1998) scanned only three spectral bands and thus offered less spectral data than Thematic Mapper. In Finland and Minnesota, forest inventory programs have turned to SPOT when timely Landsat imagery is not available due to cloud cover (Tomppo, 1998; Heinzen, 1998). In California, SPOT imagery has been used to verify the interpretation of ground cover in TM imagery (Fire and Resource Assessment Program, 1998b).

EXAMPLES OF THE INTEGRATION OF REMOTE SENSING IN FORESTRY

The most common operational remote sensing applications in forestry entail vegetation mapping as a preliminary step in a forest inventory and for identifying the boundaries of habitats and ecosystems. Fire prediction, detection, response, and burned area assessment is another area in which remote sensing has been used to a greater extent (Dull, 1998; Sommers, 1998).

To illustrate the various uses of remote sensing in forestry, we present a small sample of operational applications involving federal and state authorities, non-governmental organizations, and the private sector.

TM Imagery for Forest Stratification in Minnesota

The Minnesota Department of Natural Resources (DNR) is one of the first state agencies to use Landsat TM imagery for FIA forest stratification (Phase I) on a production basis. As with conventional aerial photo interpretation, Minnesota officials use satellite imagery to determine where in situ monitoring should occur. DNR officials have found that purchasing Landsat imagery is more cost-effective on a per acre basis: Whereas the state would have to pay about $2 million to commission an up-to-date aerial photography campaign, Minnesota DNR initially acquired TM imagery for about $100,000. On the other hand, the state has allocated significant resources to developing its Landsat image production interpretation capability, and it currently employs 5 full-time remote sensing analysts. The Minnesota forest inventory database is now being used by DNR as the basis for the state’s Gap Analysis—an integration opportunity that is expected to cut processing time in half (Heinzen, 1998; Befort, 1998).

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23 Each state’s inventory is performed in two-phases. During Phase I, aerial photography is interpreted to classify a state’s lands according to uses, forest cover, and predominant tree species and size. Using a standardized grid, one-acre sampling plots (typically with one plot per 5,000 acres) are located and then a subset is selected for field visits.

24 Minnesota DNR’s satellite images and forest inventory information are available at http://www.ra.dnr.state.mn.us/.
Existing Maps for Forest Stratification in the Intermountain West, Illinois, and Indiana

Satellite-based vegetation maps, such as the TM-based Utah Gap Analysis and Intermountain land cover maps (Homer et al., 1997), or the AVHRR-based RPA forest type group map (Zhu et al., 1993), are used for stratification of forest inventory plots in the Interior Western States. These maps replace the traditional photo-interpretation for Phase I, saving an average of $300,000 per state by not having to purchase aerial photography and by eliminating the traditionally lengthy photo processing and interpretation phases (Edwards, 1998; Moisen, 1999). The switch was shown to result in less than 3 percent loss in precision on estimates in northern Utah (Moisen et. al., in press). Additional work is underway to consider the impact under an annualized inventory system.

Gap data also will be used by the FIA North Central office in the coming forest inventories for Illinois and Indiana. Whereas Phase I stratification using aerial photography would take an average of 2 to 3 person years per state, this task can be accomplished in 2 months using Gap TM imagery. Moreover, FIA will avoid the cost of commissioning an aerial campaign or waiting for photographs to become available from another program. While fewer forest strata in these states can be identified by remote sensing, FIA officials have concluded that the loss in precision will be more than offset by the more current data, uniform georeferencing, and simplified image registering process afforded by TM imagery (Hansen, 1998a, 1998b).

Cascades Checkerboard Project

The Wilderness Society Center for Landscape Analysis in Seattle is using borrowed and donated Landsat TM imagery to inform activists, decision makers, and the public about the condition and management status of forest lands in the Cascade Mountain Range. The central subject of study is the “checkerboard” land ownership pattern that has resulted in the fragmentation of mountain habitats from development and clear cutting. The checkerboard pattern is clearly evident in the satellite images, and thus readily show an observer the impact of complex land ownership patterns without the need for costly assessment or verification. This information has been used to identify parcels for purchase, exchange, and other mechanisms to bring them under protection. From this experience, Wilderness Society officials have concluded that the synoptic view obtained by remote sensing is seen by as “the most effective way” to convey land cover and land use patterns in the Cascades region (Thompson, 1998).

Puget Sound Ecosystem Analysis

Landsat imagery has also been used by another non-governmental organization to educate the public about urban sprawl in the Puget Sound region (American Forests, 1998). Multispectral Scanner and Thematic Mapper images were used to show that high vegetation and tree canopy coverage decreased by 37 percent between 1972 and 1996. The satellite images drew much attention to and discussion of the role of urban forests. On the

25 Information in the Checkerboard Project may be found at http://www.wilderness.org/standbylands/ten_snoqualmie.htm.
other hand, American Forests’ use of images with different spectral and spatial resolutions (the MSS images for 1972 were more coarse) also raised questions about the reliability of the study’s findings (McOmber, 1998).26

Westvaco Corporation

The Westvaco Corporation Forest Resources Division, based in Summerville, South Carolina, manages 1.4 million acres of forest located mostly in the southeastern US. Most forest management decisions occur at the stand level (30–50 acres), for which the company relies on aerial photography and in situ measurement methods. Remote sensing imagery does not provide the spatial resolution the firm requires, yet management sees this changing with higher resolution imagery becoming available from private providers and cheaper imagery from Landsat 7 at the lower resolutions. Westvaco also manages 150,000 acres of forest in Brazil, where it has used Landsat TM imagery for large-scale measurement. TM was utilized to overcome the challenges gaining access on the ground to the forest and because of the scarcity of in situ and aerial data (Prisley, 1998, 1999).

Western Oregon Mapping Project

In 1996, the Oregon Forest Industries Council (OFIC), an association of industrial forest owners, together with the Oregon Department of Forestry, engaged a private contractor to develop a forest condition data base for Western Oregon. The GIS data base was developed using TM imagery and includes data layers on crown closure, vegetation species, size/structure, and owl habitat (Pacific Meridian Resources, 1998). The one million-dollar project was organized to independently evaluate and verify the US Fish & Wildlife Service’s monitoring efforts to support the designation of “special emphasis areas” to protect spotted owl habitat. The OFIC project brought together foresters from private forestry firms and the state to develop and agree on standard ground measurement protocols to be used on their companies’ lands. The use of remote sensing was selected because it was perceived as the most feasible way for a non-governmental entity composed of competing firms to undertake ecosystem monitoring across public and private ownerships (Cannon, 1998).

California Land Cover and Vegetation Change Detection

The Forest Service together with the California Department of Forestry and Fire Protection is in the fourth year of a statewide effort to identify and quantify land cover changes (Levien, 1998a; Fire and Resource Assessment Program, 1998a). The five-year project entails the integration of a large volume of ground and aerial data with land-cover maps derived from TM imagery. Changes that have been mapped include increases and decreases in vegetation cover, which, when used in combination with vegetation data can give information on changes such as basic vegetation lifeform, tree size, and crown closure. The information is intended for watershed disturbance analysis; timber inventories and sales planning; monitoring harvests on private lands; land-use and habitat management

26 The images and analysis can be found at http://www.americanforests.org/ufc/uea/report.html.
planning; and pest-induced tree mortality and fuel modeling. For this large-scale project, using remote sensing has cut the data processing time in half, while requiring a significantly smaller staff. Outputs are being used to update state vegetation maps, and this related effort has achieved costs averaging $0.15 per acre, as opposed to $1.00-1.50 per acre using conventional aerial photo analysis of smaller areas (Warbington, 1998).

INTEGRATION OF SATELLITE IMAGERY IS LIMITED

Even with its many perceived advantages, remote sensing has not been used by foresters to support management or policy decision making on an operational or production basis to a significant extent.

Within the Forest Service, Bureau of Land Management, and other federal agencies, aerial photography and sketch mapping remain the dominant means to monitor forests over large scales. Similarly, a study sponsored by NASA of the use of satellite imagery by state governments concluded “some states have realized benefits from satellite data use,” but most had only experimental or very limited use or knowledge of satellite data (Warnecke, 1997, p. 47). A survey of international experience also revealed the limited use remote sensing. In Australia, a country with active remote sensing applications development programs, the integration of satellite imagery and GIS has been described as “sluggish,” and operational applications as “not terribly sophisticated” (Skidmore and Turner, 1998, p. 44).

Although the forest products industry is a major proponent of greater remote sensing integration within the Forest Service, interviews with several monitoring experts at industrial forestry firms suggested that while many were familiar with remote sensing capabilities, satellite imagery has been used only in a limited capacity, for example, to define boundaries between forest and other ecosystems, to observe forests outside company boundaries, and to track changes in land use. Rather, respondents suggested that the use of in situ monitoring, aerial photography, GIS, and GPS was more cost-effective.

To summarize a viewpoint expressed by several people interviewed for this study, the merits of remote sensing have been “oversold.”

BARRIERS TO REMOTE SENSING INTEGRATION

Remote sensing has not been used widely in forestry for a number of reasons: the technology’s capabilities are viewed as insufficient; the cost to acquire and interpret satellite data are perceived as too high relative to alternative approaches; and the scale of the information is seen as inappropriate for answering most operational management questions. For illustration, an extensive review of the scientific and professional literature on applications of multispectral imagery in forest management over the past quarter-century concluded:

Current satellite sensors are not in general suitable for forestry planning since (a) they contain little relevant information, and (b) for forest management planning purposes there are often more efficient ways of collecting the information required (Holmgren and Thuresson, 1998, p. 90).
A Relatively Young Technology

While numerous forestry applications of satellite imagery have been documented in the literature over the past 25 years (see, for example, Holmgren and Thuresson, 1998), most of these efforts have involved work still in the research, development, and demonstration phases. The lack of production-grade experience is significant: Private forestry firms tend to wait until a new technology is well-proven before adopting it (Sader, 1998).

Many of these test cases have limited practical relevance because the imagery or reference locations were chosen to test the limits of data interpretation or favored ideal conditions (i.e. the images had to be cloud-free and have sharp spectral differentiation) and do not have relevance to the most pressing decision maker information needs and the decision making environment (Befort, 1998).

As importantly, most remote sensing R&D projects are still young or have not been funded at a very high level of effort over time. Thus, most forest mapping efforts using remote sensing have been though only one iteration to date, and, thus, cannot yet be used to detect and explain forest trends—a critical information need for decision makers.

Resolution

The limited technical capabilities of spaceborne sensors often is cited as a barrier to their integration in forest management, as noted in recent survey:

Despite much hype and promise, satellite remote sensing is rarely used in day-to-day forest resource management, largely because of the coarse resolution of the last generation of spaceborne sensors (Wynne and Carter, 1998, p. 23).

While satellite imagery is sufficient for monitoring broad land cover classifications and abrupt or significant changes, limited spatial and spectral resolution still limits the ability of foresters to track subtle, yet important differences in land use such as suburbanization and forest fragmentation (Befort, 1998). This constraint is particularly significant for discerning species types in complex forests, such as those of New England and the mid-Atlantic states.

Similarly, many entomologists and pathologists have concluded that existing space imagery is not sharp enough to detect most forest stresses (Bartuska, 1998). Although Forest Service representatives cited the danger and rising cost of aerial monitoring, this is still the preferred surveillance method, as suggested by officials in the Pacific Northwest: “Aerial sketchmapping surveys are a cost-effective way to rapidly estimate tree damage (especially caused by insects) across large areas” (Campbell et al., 1997, p. 44). Finally, as we have seen in Chapter 3, a lot of forest monitoring is conducted to answer stand- or facility-level management questions, yet existing remote sensing capabilities do not offer the needed resolution to support most smaller-scale decisions.

Insufficient temporal resolution has also been cited as a shortcoming in some regions. Although Landsat has a revisit cycle of 16–18 days, the availability of imagery for a specific location can be greatly limited by cloud cover, especially in forested areas of the north central states, the Pacific Northwest, and Alaska. Sixty percent of the Landsat images of Minnesota have cloud cover (Befort, 1998). A consistent sun angle and vegetation season
also are necessary for year-on-year comparisons. Due to these limitations, a clear, reliable Landsat image of the central Cascades has not been available since 1993 (Raines, 1998).

**Costs**

As we have seen with the case of Minnesota noted above, satellite imagery can be cost-competitive with aerial photography on a per acre basis in many applications, especially when coverage of large areas is purchased. On the other hand, significant indirect costs associated with image processing must also be appreciated.

First, forest managers must invest considerable resources up front to build their capability to process and interpret satellite imagery. Requisite information technologies, such as GIS software and processing hardware, must be acquired. While the cost of information technology has fallen sharply over the past decade, this can represent a significant new expenditure to a field office. Forest Service remote sensing analysts in California had been mapping vegetation and developing image interpretation algorithms for many years before they embarked on the statewide mapping project in 1995. Yet, because remote sensing expertise within the federal and state forestry agencies was still limited, they have had to rely on universities and private contractors (Levien, 1998).

Second, image processing and interpretation to make use of satellite data is a critical, yet time consuming step. Taking the California vegetation change mapping project as an example, this involves building the data base for the state by co-registering images to each other and correcting for atmospheric differences between image dates using regression analysis (see Figure 4.1). The registered images are then run through a change detection process and identified changes are then labeled. This entire process for the state will take five years (Fire and Resource Assessment Program, 1998b).

Third, ground verification must be included as a significant cost—at least in the initial stages of development. Satellite imagery cannot fully substitute for in situ methods for most information needs: Remote sensing provides data about the spectral landscape, so labor-intensive ground sampling must be used to relate the spectral data into information that can be used by decision makers. As a simple indication of such an effort, the integration of remote sensing into the FIA program will initially require GIS logging of over 100,000 plot locations using GPS. Where a ground monitoring campaign is not already in place, the use of remotely sensed imagery could impose significant ground verification costs up front. On the other hand in places were ground or aerial monitoring is not feasible, such as in Alaska or many developing countries (see the study of Brazil in Appendix B), remote sensing may be the only means to collect timely forest data.

27 Data cost can be a factor for non-federal users of Landsat imagery who must pay a higher commercial rate—a fact NASA research suggests has depressed demand by state authorities (Warnecke, 1997).
The issue of cost is particularly salient within the context of the Forest Service: Spending on forest measurement has been declining in real terms since the 1970s, due to significant cutbacks in agency funding and Congressional mandates that place a primacy on timber production on public lands and monitoring towards this end (General Accounting Office, 1997). The Forest Service struggled for years over the choice of technology for a Service-wide GIS system, and current acquisition plans are falling behind schedule due to a lack of funding.

Reliability of Interpretation

Ultimately, the integration of remotely-sensed forest information is constrained by concerns over reliability.

Significant effort has been devoted to developing rigorous remote sensing processing algorithms and data verification techniques. In many cases, the precision of maps and other data products based on satellite imagery is comparable to that of aerial photography and is sufficient for various applications (Oregon Forest Industries Council, 1998; Moisen, 1998).
Nevertheless, private contractors, non-governmental organizations, and the Forest Service alike have been criticized for their handling of satellite imagery. For instance, some mapping efforts have not included sufficient reliability assessments using ground or aerial data, and this has undermined the credibility of forest monitoring efforts based on remote sensing (Raines, 1998; Cannon, 1998). One of the most visible and contentious cases involved the mapping of old-growth forests in the Pacific Northwest by the Forest Service (which engaged a private contractor to interpret TM imagery) and the Wilderness Society, which relied on MSS imagery and aerial photographs. In an investigation of the conflict, Robert Norheim (1996) concluded:

The short timeline for both projects, the nature of the remote sensing devices employed, the differing geographic scope of the projects, the application of the old growth definition, the respective budgets, and the institutional pressures on the projects, all had important impacts on the ways that the projects were conducted and thus on their results.

Many forest management issues in the United States, especially those concerning public lands, are highly contested (e.g. Thomas et al., 1990; Thomas et al., 1993; FEMAT, 1993). Disputes like this in the Pacific Northwest suggest that the addition of remotely-sensed forest information, regardless of its technical precision, will not be sufficient by itself to allay such heated disputes.

OBSERVATIONS

Despite the many perceived benefits of remote sensing, its integration has been inhibited by several characteristics of the technology as well as the institutional environment in which it would be applied that undermine its perceived cost-effectiveness and, hence, its attractiveness to forest managers.

While remote sensing has yet to be integrated widely into forest monitoring on an operational basis, we have shown that there are notable instances in the US where the technology has been used in a more discrete capacity and has influenced management and policy decisions. Generalizing from these and experiences, we identify instances where remote sensing is most likely to be successfully integrated into forest management and policy decision making:

- **First approximation resource assessments.** Remote sensing can provide important information about basic features of forest resources where attaining high levels of precision are not necessary or feasible. In such cases, satellite imagery (particularly new high resolution imagery) may not need to be interpreted using complex digital methods, but could be analyzed using basic photointerpretive methods similar to the current practice with aerial imagery.

- **Large-area forest cover and type classification.** Existing resolution capabilities make remote sensing more useful and cost affective for large-area (i.e. millions of acres) forest classifications, where economies of scale in image acquisition and processing can be realized and detailed forest data are not required. Large area assessments also offer greater opportunities to share resources between programs.
• **Base mapping.** Where more detailed monitoring and assessment is required, remote sensing can provide cost-effective data to develop base maps, with which aerial and in situ data are integrated. Remote sensing is increasingly being used for vegetation classification in Gap Analysis and other regional assessments, offering more opportunities to integrate data sets with forest inventory and classification efforts.

• **Study of high-value resources.** The utilization of remote sensing of high-value and contested resources, such as critical ecosystems, habitats, old-growth stands, where the added information may contribute to a common understanding and be supported by greater investments in ground verification. Conversely, remote sensing is likely to be less cost-effective in areas with limited forest cover or low-value forest resources.

• **Public education and outreach.** Satellite imagery, when used like photographs to convey synoptic, large-area views, can be effective in conveying basic information about forests to the public and policy makers.

To conclude, these areas of opportunity illustrate that remote sensing is not a panacea and often has little utility on its own. Rather, the technology offers greatest value when it is strategically integrated with in situ and, to a lesser extent, aerial data collection and analysis efforts. Greater benefits from remote sensing may also be derived when the technology is exploited in larger-scale programs in order to take advantage of particular economies and data of scale available with satellite imagery. Increasing opportunities to integrate remote sensing and in situ forest monitoring in nationwide programs is the subject of the next chapter.
CHAPTER 5

OPPORTUNITIES FOR INTEGRATION

US forest policy is evolving and this requires a concomitant change in the types of forest information available. Examining the policy goals of the US Government, we see three key forest monitoring decision points facing top-level policy makers in the next decade:

1. Reforming the Forest Inventory Analysis Program;
2. Adjusting US monitoring capabilities to support ecosystem management goals and to measure progress towards the principles of sustainable forestry; and
3. Developing the nation’s carbon accounting capabilities to meet its climate change commitments.

In the past, little effort has been devoted to developing a nationwide plan to strategically integrate remote sensing in forest monitoring. Now that a truly nationwide, consistent in situ monitoring policy is being contemplated with the mandated reform of the FIA program, it makes sense to also reassess the traditional, piecemeal use of aerial monitoring. Moreover, the current transitional policy environment offers a rich opportunity for reconsidering the role of satellite imagery to meet sustainable forestry and climate change goals.

In this concluding chapter we address how remote sensing may be used to support these three forest objectives. Our conclusions are based on the findings presented in the previous chapters as well as findings from our survey of the use of remote sensing abroad, most importantly, in Brazil and Canada as outlined in Appendices B and C, respectively.

Identifying opportunities to integrate remote sensing, we assert, is not sufficient to accomplish the aforementioned tasks. Rather, significant institutional changes must be made to overcome the obstacles to program and technology integration that have minimized the ability of in situ and remote sensing forest measurement campaigns to work together. Therefore, we conclude with several findings pointing to the need for top-level decision makers to reappraise the nation’s general approach to forest monitoring and remote sensing.


The Agricultural Research, Extension, and Education Reform Act of 1998 called on the Forest Service to develop and implement a strategy to improve the performance of the Forest Inventory Analysis. To comply with the law, the Forest Service (1998) developed a strategic plan that provides for annual monitoring with a five-year cycle and establishes a core set of forest measures. To accomplish this, it recommended merging FIA and with the field measurement components of FHM, and called for a four-fold increase in funding for 1999. Notably, the integration of remote sensing and other technologies to increase monitoring efficiency was not addressed. In contrast, we assert that the integration of
satellite imagery should be considered at the state level as well as an integral part of the redevelopment of a national FIA system.

If most of the proposed changes to FIA are implemented (including the integration with FHM), the United States will achieve a truly national, broad-scale system of ground plot forest measurement. Along with this system of enhanced in situ monitoring, a nationwide system of area classification is also needed to generate statistically valid estimates of total resources.

If a nationwide, consistent program of ground measurement is implemented, then moving to use of remote sensing data for area measurement on a national scale is likely to offer the greatest value—in terms of data cost, timeliness, and uniformity. Given this eventuality, we conclude that Landsat TM imagery appears to be the more practical and timely means to obtain such information on a national scale. Several states already have adopted space imagery for area classifications. Accordingly, Minnesota DNR can be used as a model showing both the benefits and challenges of scaling up to national-scale production of Thematic Mapper imagery for Stage I stratification.

While an investment in information technology and human resources would raise the costs of using TM imagery initially (example in establishing an national GPS grid and image processing capability), they likely would drop over several years to a point closer to current levels as learning and economies of scale offer opportunities to increase production efficiency (Heinzen, 1998). Similar cost estimates have been produced by experts at the Forest Service’s Rocky Mountain Science Center (Czaplewski, 1998a) and elsewhere (Remote Sensing Band, 1998).

In many states, FIA need not start with raw TM imagery. The cases of Utah, Illinois, and Indiana, where USGS Gap Analysis vegetation cover maps are being used by FIA to speed up the stratification process and save resources, suggest that there are many opportunities for coordination, integration, and cost-sharing with other programs in the use of satellite imagery. Currently, 22 states have completed or nearly completed their Gap Analysis projects. Moreover, the MRLC program is using TM data to characterize three categories of forest land across the continental US. Should funding permit regular updates, this database could also be used as a starting point for FIA forest stratification.

Finally, the United States may look abroad for insights on the use of satellite imagery for forest inventories.

- **Finland** Since 1990, Finland has pursued a more ambitious approach that relies on Thematic Mapper imagery as the principle data source for its National Forest Inventory. Finland uses statistical analysis of TM imagery to estimate the extent of its holdings by species, volume, and timber class. The goal of Finnish officials in using remote sensing has not been to lower the cost of the inventory process, but to improve accuracy while relying on less ground data (Tomppo, 1998). Thus, the Finnish case can offer insights on how US programs can use remote sensing for more than a Phase I forest classification process.

- **Brazil** Brazil has used AVHRR, Thematic Mapper, and other satellite data to quickly build its capacity for forest inventories (see Appendix B). Because it has lacked an aerial and in situ monitoring infrastructure, Brazil’s foresters have “leapfrogged” to space technologies. Thus, Brazil’s experience offers insights on a “top-down” monitoring approach and the technology transition process.
• **Canada**  Forest officials in British Columbia have investigated the utility of remote sensing for forest inventories and have concluded that 19 of the 25 Canadian national forest inventory measures could be monitored substantially or partially using remote sensing (see Table C.2).

The Brazilian and Canadian cases may be especially salient for enhancing forest monitoring in Alaska, where in situ and aerial capabilities are more limited and public holdings are more extensive.

**MEDIUM TERM (2000-2003): MONITORING FOR ECOSYSTEM MANAGEMENT AND SUSTAINABLE FORESTRY**

Meeting the goals of sustainable forestry and ecosystem management requires the nation to increase its monitoring efforts to measure more variables across larger spatial and temporal scales than have been measured in the past. In 1992, the Forest Service and Bureau of Land Management announced their intent to manage their lands according to ecosystem principles. As major player in the Montreal Process, the US has committed to reporting on its progress towards sustainable forest management by 2003. This will require measuring a comprehensive set of socioeconomic as well as ecosystem measures.

Many sustainable forestry and ecosystem management measures address smaller scale, more diffuse or hidden, and less tangible subjects (e.g. stream flow, incidence of endangered species, viability of forest-dependent communities), and, therefore, are not subject to detection by satellite sensors. On the other hand, many sustainable forestry and ecosystem management measures can be monitored substantially or partially using remote sensing technologies; these include fire damage, land conversion, and forest area managed for conservation. Again, Gap Analysis Program and MRLC spatial databases can be used to speed the data collection, analysis, and reporting process.

But these efforts only represent a first step: To meet the objectives of sustainable forestry and ecosystem management, federal authorities must make a long-term commitment to ensure that a nationwide forest land cover/land use classification (through an enhanced FIA, GAP, or MRLC) is repeated periodically (for instance, every five years) using consistent methods. Consistency and cost-effectiveness would be enhanced by the development of a uniform national forest classification system using satellite data.

Looking abroad, experts in British Columbia have investigated the potential of using remote sensing for measuring sustainable forestry and have concluded that 25 of 83 Canadian sustainable inventory indicators could be monitored substantially or partially using remote sensing (see Table C.4). This research suggests that remote sensing could play a significant supporting role in the United States’ implementation of the Santiago Agreement.

**LONG TERM (2008- BEYOND): MONITORING FOR CLIMATE CHANGE**

The US faces the challenge of enhancing its forest monitoring capabilities to address climate change concerns and to meet the commitments set forth in the Kyoto Protocol which was recently signed by President Clinton.

Forest Monitoring tasks to this end include determining forestry sector carbon accounting in order to establish a 1990 carbon inventory baseline and to make annual inventory
Forest Monitoring and Remote Sensing: Opportunities for Integration

reports beginning in 2008. In addition, some measure of forest measurement will be required to evaluate and verify carbon offset and joint implementation projects and to supply data needed to support carbon markets. The appropriate role of remote sensing in climate change-related monitoring policy can be determined only with prior clarification of the terms of reference in the Protocol (i.e. the objectives) and refinement of the scientific understanding of carbon flux, forest impacts, and mitigation. In the meantime, research may address important process questions.

One question is the role of remote sensing in forest inventories. A national forest type map using AVHRR imagery has been completed (Zhu, et al., 1993), but as we have seen in Chapter 3, significant in situ monitoring is still required to complete the characterization of those forests. The use of Thematic Mapper imagery for FIA forest stratification on a nationwide basis (as recommended above) would have a potentially significant impact on the nations ability to generate accurate and timely forest inventory, biomass, and carbon flux estimates. Accordingly, researchers in British Columbia have concluded that remotely sensed data can contribute to the development of estimates of biomass by forest type, age, succession stage (see Table C.2). Cooperative research in the Amazon Basin sponsored in part by NASA may also provide insights on the potential for using remote sensing to monitor land-use change and for measuring forest inventory across different scales (see Appendix B).

A second question is the role of remote sensing in understanding carbon flux. The role of satellite monitoring in this area may be more modest. As noted in Chapter 4, Thematic Mapper imagery has only a limited ability to resolve subtle forest changes over time. The Boreal Ecosystem-Atmosphere Study (BOREAS), a large-scale US-Canadian field experiment, has focused on the potential for integrating satellite, airborne, and in situ monitoring to improve models that can predict the effects of global change on forest behavior. Most monitoring in the project to date, though, has not involved satellite imagery, suggesting that the opportunities for remote sensing integration currently are modest. Experts in Finland have determined that, despite their active imagery-based inventory process, they do not need to rely on remote sensing to estimate carbon flux. Rather, they are using existing field data (Tomppo, 1998).

A third research challenge is to determine the most cost-effective approach to monitor, evaluate, and verify joint implementation projects in the US and abroad. For example, the capability to monitor the success of new forest plantations with remote sensing within their first decade is likely to be limited, given the difficulty of determining forest health and distinguishing young trees from other vegetation.

A fourth question is the feasibility of using remote sensing in a climate change treaty regime. Remote sensing technologies raise the possibility of the US being able to monitor other countries’ forest management activities. Yet, as we have seen with the use of remote sensing to monitor old-growth forest inventories in the Pacific Northwest, satellite data is subject to dispute over its interpretation. Remotely-sensed data may be challenged in a similar manner if it were to be used for verification purposes under an international treaty. Finally, the US and other countries may interpret third-party satellite monitoring of their territory as an unwanted intrusion on national sovereignty.

Given the potential limitations in using remote sensing to address climate change concerns noted above, investments to develop space-based carbon accounting capabilities should be carefully weighed against the continuing need to improve monitoring and the scientific
understanding of forest carbon flux from the ground with investigations such as Ameriflux (Kaiser, 1998). Indeed, the US Global Change Research Program has come under criticism (National Research Council, 1998; Lawler, 1998) for overinvestment on expensive satellite hardware to the detriment of in situ monitoring. We extend this cautionary note to the forest inventory, ecosystem management, and sustainable forestry areas also.

INSTITUTIONAL ISSUES RELATED TO INTEGRATION

The future of the Forest Service, and federal forest management in general, has been called into question, with proposals circulating to radically restructure the system. This period of flux offers a valuable opportunity for top-level decision makers to reappraise federal forest monitoring policy and the role of remote sensing.

Reappraise the Federal Commitment to Monitoring

Forest monitoring and reporting in the US may be described as a bottom-up system. A more a top-down approach to forest measurement may be required for the future.

Most forest monitoring historically has been funded, conducted, and used to support activities at the stand, National Forest unit, and state levels. Information for national reporting and decision making, such as the five-year RPA Assessment, is aggregated from diverse sources that use divergent methodologies and operate at different levels of effort. Thus, while the US has national forest surveys in place (FIA, FHM, and FHP), it does not have a nationwide forest monitoring program or uniform forest data base.

Recent federal initiatives to promote ecosystem management and new demands for national-scale reporting on forest resources and management called for by the National Report Card initiative, Santiago Criteria and Indicators, the Kyoto Protocol, and the Government Performance Reporting Act suggest the need for a significantly more ambitious and qualitatively different measurement system than currently exists. To obtain statistically valid forest estimates at the national level, requires greater coordination and integration of the nation’s measurement activities as well as a long-term, sustained level of effort in order to produce more consistent, timely, and reliable information.

While efficiencies may be gained though better management of programs such as FIA and FHM, federal funding for measurement, in real terms, has been decreasing over the past two decades and has come under pressure more recently with sharp cuts in the Forest Service’s budget. Given that the intended users of this information reside predominantly at the national level, federal decision makers should consider augmenting the federal funding of forest monitoring and assessment.

Involve the Private Sector

The private sector has expressed its strong interest in an efficient and timely national forest inventory, and it has advocated for increased use of advanced technologies such as remote sensing (American Forest Council, 1992; American Forest & Paper Association, 1998). The private sector is a principle consumer of FIA data, which it uses for market analysis and strategic planning. The private sector has shown its willingness to contribute resources to improve the forest inventory process in the Great Lakes region (Heinzen, 1998). Federal
officials should consider encouraging private sector contributions to help fund the reform of the FIA program.

Set National Forest Priorities

Despite White House, Forest Service, and Bureau of Land Management objectives to apply the principles of ecosystem management and sustainable development, forest monitoring and analysis remains constrained to timber production and commodities markets—a function of statutory requirements and institutional traditions (General Accounting Office, 1997). Forest management practices, meanwhile, have changed dramatically in the 1990s as a result of Administration policy (e.g. FEMAT), regulatory actions (e.g. under the Endangered Species Act), and lawsuits from environmental and other non-governmental entities. Efforts to reduce data gaps over the years have met with modest success: Until the fundamental management mandates and funding mechanisms for the Forest Service (and other federal land managers) are changed to recognize the primacy of ecosystem management, agency officials will not have an incentive to reorient measurement efforts away from the existing narrower objectives. This, though, requires the development of a new consensus on several issues.

The crafting and implementation of a national forest monitoring system useful to decision makers first requires specification of the management objectives that monitoring is to guide. Agreement is required among foresters on clearly defined and coherent forest management objectives. These objectives are arrived at based on a consensus among the general public as well as top-level decision makers on the broader direction of forest policy and agreement on the science of forest ecosystem dynamics. These bases for forest monitoring are lacking in the US. The current forest management goals stated in law—multiple use and sustained yield—are in many cases incompatible. This shortcoming is reflected in growing concerns within the scientific and regulatory communities about forest ecosystem health and biodiversity preservation. This incompatibility also is manifested in increasing conflicts over forest use in the political arena, between government agencies, and in the courts. As we have noted, many interim improvements in forest monitoring can be implemented. However, a fundamental reform must wait until clear policy and management objectives are established.

In recent years, officials in Canada have fundamentally reappraised national and provincial forest policy and they are instituting new management goals and monitoring efforts to promote sustainable forestry (see Appendix C). Concerted efforts to identify and implement the Santiago Criteria and Indicators for sustainable forest management as well as a unique set of Canadian measures were one means of facilitating the discussion the forest priorities.

Study Market Demand for Remote Sensing

In Chapter 4, we examined the supply of remote sensing technologies and concluded that performance and cost barriers have resulted in essentially limited and ad hoc applications of space imagery by forest managers. In this section, we examine the other side of the market equation: the modest demand for remotely sensed data in forestry.

The application of remote sensing has been limited because, unlike in situ or aerial forest monitoring missions, there are no purpose-built space systems dedicated to forest
management purposes. Satellite sensors, because of their substantial development and support costs, are designed to meet many demands. Although Forest Service experts have worked with NASA in the development of the Landsat sensors, Landsat was optimized to serve many fields: agriculture, geology, geography, civil engineering, water resources, oceanography, and global change. The system also was developed to appeal to many types of users—in the public sector, industry and commerce, and education and research. Since the information may be used for many purposes and at different levels of scale, there will be varying requirements for data in terms of attributes, timeliness, accuracy, and cost. Moreover, these requirements are changing over time as needs develop, policies evolve, and users become familiar with the technology. In short, multi-purpose systems, while flexible, tend to perform a specific task less efficiently than a specialized technology.

The application of satellite imagery to forestry (as well as other sectors) largely has been addressed as an engineering issue, concerning orbitology, data transmission and storage, performance in space, and, most importantly, sensor features. This is understandable: Landsat, other satellites in service, were developed before the advent of a remote sensing market. However, when the development of a product or service is governed primarily by technological concerns rather than market demand, its marketability is likely to be constrained. These technical constraints, though, do not fully explain the limited application of remote sensing in forestry to date.

High-level efforts to integrate satellite imagery into forest monitoring largely have been pursued using a similar supply-side approach: increasing the number and quality of sensors (i.e. the capabilities of hardware). As one regional FIA official noted, this scenario approximates a case of “the cart pushing the horse.” Now that a substantial fleet of satellites is in place and extensive forest data archives are being built, future integration efforts should return to Earth and take a different approach.

One approach for technology purveyors would be to implement focused market research to identify the most likely users and their specific information needs. The last chapter highlighted some promising experiences and possible directions for study. As we also noted in the previous section: satellite imagery, to be most useful and cost-effective, needs to be strategically integrated with in situ and aerial forest monitoring activities, and remote sensing purveyors need to be well informed of potential synergies and user needs in this regard. Effective market research will require close collaboration between remote sensing specialists and foresters working on operational issues in the field to appropriately match capabilities with forest decision maker needs. Based on this market understanding, a national strategic plan for remote sensing in forestry could then be developed.

Like remote sensing hardware, the development of satellite data processing and interpretation capabilities on the ground (by analogy, the software) requires significant up-front costs. With a strategic plan, national resources can be allocated to develop and share the most promising data processing and interpretation capabilities. Such planning and coordination could offer greater economies of scale than the current decentralized, ad hoc

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28 As noted in Chapter 4, initial market research commissioned by NASA (Warnecke, 1997) indicated that remote sensing data was hardly understood at the state-level officials.
approach and, thus, lower the cost of remote sensing data to forest management and policy decision makers.

Promote Institutional Reinvention

Research on technology transfer suggests that the success of a new technology introduction depends as much on the capabilities of the technology (the hardware), as the process of implementation and organizational context in which it occurs (i.e. institutions). Accordingly, equal attention should be placed on what remote sensing can do as well as how and where it is applied.

Remote sensing imagery providers focus on technology features and capabilities while its users in forestry are typically concerned with questions about how to apply the new technology and associated organizational changes. The former typically are based in the fields of aerospace, engineering, computer science, and statistics, while the latter are commonly foresters and environmental scientists. Because of the different professional orientations and objectives of remote sensing providers and users, miscommunication can easily occur. Therefore, it is crucial to have a constant dialogue between technology developers and users. In cases where a technology is still improving, such as remote sensing, implementation should be viewed as a process that continues beyond the initial introduction. This suggests a possible explanation why forest ecologists and managers commonly express the sentiment that remote sensing has been oversold. Successful technology introductions entail thorough and comprehensive planning for implementation; user involvement in implementation decisions; availability of training and other learning assistance; and positive attitudes of leaders (Bikson and Eveland, 1992).

One potential remedy is a process of “mutual adaptation,” where a developer and user work together to apply a technology and then use information derived from this collaboration to shape both the technology development as well as the user environment (Leonard-Barton, 1995). Mutual adaptation may help mitigate the disconnect between the aerospace engineering orientation of the remote sensing providers (with their focus on optimizing technical capabilities for a broad audience) and the resource management focus of forest managers (with their increasing focus on issues of science and regulatory compliance), who have a greater need for technology validation.

It is generally understood that organizations exhibit more resistance to changes such as new technology diffusion than individuals. Forestry in America has well-set and highly regarded professional traditions (Kaufman, 1960). Forest measurement is associated with a ranger sketching maps in a plane and itinerant crews “ground-pounding” an inventory. This process has been organized in a decentralized manner, and it is dependent, in particular, on the professional esteem and loyalty of Forest Service field crews.

Monitoring using remote sensing uses a new set of methods and people: laboratory technicians working at a computer manipulating and analyzing discrete bands of a spectrum. Encouraging the use of remote sensing by public and private forest managers, therefore, not only will require convincing individuals of its superior capabilities and cost-effectiveness, but also will necessitate designing new work methods and acquiring new skill sets to take advantage of the capability, and the lengthy process of modifying (or abandoning) durable professional institutions.
### APPENDIX A

**SPECIFICATIONS OF REMOTE SENSING SATELLITES AND SENSORS WITH POTENTIAL FORESTRY APPLICATIONS**

<table>
<thead>
<tr>
<th>Platform</th>
<th>Principal Operator</th>
<th>Archive/Launch</th>
<th>Sensor Name/Type</th>
<th>Spectral Bands</th>
<th>Spatial Resolution (meters)</th>
<th>Swath Width (km)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADEOS-1</td>
<td>Japan</td>
<td>1996 (failed)</td>
<td>Advanced Visible and Near-Infrared Radiometer (MS)</td>
<td>5</td>
<td>8-16</td>
<td>80</td>
<td>To monitor tropic forest cover and other global change measures. Part of integrated Earth Observation System (EOS).</td>
</tr>
<tr>
<td>ADEOS-2</td>
<td>Japan</td>
<td>est. 1999</td>
<td>Global Imager (MS)</td>
<td></td>
<td>250-1000</td>
<td></td>
<td>For ocean sensing missions, but potentially useful for determination of vegetation indices. High temporal resolution: 4 day orbit cycle. Part of EOS.</td>
</tr>
<tr>
<td>ALMAZ</td>
<td>Russia</td>
<td>1991</td>
<td>SAR</td>
<td>5-7</td>
<td>15, 150</td>
<td>30</td>
<td>Intended for coverage of Japan and Asia-Pacific region</td>
</tr>
<tr>
<td>ALOS</td>
<td>Japan</td>
<td>est. 2002, est. 2002</td>
<td>Low Resolution (MS) High resolution (Pan) SAR</td>
<td>10, 2.5, 10 spot 100 scan</td>
<td>70, 35</td>
<td>Intended for coverage of Japan and Asia-Pacific region</td>
<td></td>
</tr>
<tr>
<td>CBERS</td>
<td>China</td>
<td>est. 1999</td>
<td>High Resolution Charge-Coupled Device Camera (MS, Pan) Infrared Multispectral Scanner</td>
<td>5</td>
<td>20, 80</td>
<td>113</td>
<td>Pointing, stereo capability reduces revisit cycle to 3-4 days. Intended to zoom in on features identified by Wide Field Imager.</td>
</tr>
<tr>
<td>China</td>
<td>est. 1999</td>
<td></td>
<td>Infrared Multispectral Scanner</td>
<td>4</td>
<td>78-156</td>
<td>120</td>
<td>For vegetation mapping.</td>
</tr>
<tr>
<td>Brazil</td>
<td>est. 1999</td>
<td></td>
<td>Wide Field Imager (MS)</td>
<td>2</td>
<td>260</td>
<td>890</td>
<td>For low-resolution, wide-swath imaging. Wide swath produces short 3-5 day return cycle.</td>
</tr>
<tr>
<td>Clark</td>
<td>USA</td>
<td>est. 1999</td>
<td>Worldview (MS, Pan)</td>
<td></td>
<td>30 MS 15 Pan</td>
<td>30</td>
<td>Cloud-editing capability.</td>
</tr>
<tr>
<td>Earlybird</td>
<td>USA</td>
<td>1997 (failed)</td>
<td>MS</td>
<td>3</td>
<td>15 MS 3 Pan</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>Platform</td>
<td>Principal Operator</td>
<td>Archive/Launch</td>
<td>Sensor Name/Type</td>
<td>Spectral Bands</td>
<td>Spatial Resolution (meters)</td>
<td>Swath Width (km)</td>
<td>Comments</td>
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</tr>
<tr>
<td>EOS AM-1</td>
<td>Japan</td>
<td>est. 1999</td>
<td>Advanced Spaceborne Thermal Emission and Reflection Radiometer (MS)</td>
<td>11</td>
<td>15-90</td>
<td>60</td>
<td>4 cameras. 16 day revisit cycle. Part of EOS</td>
</tr>
<tr>
<td>EOS AM-1</td>
<td>USA</td>
<td>est. 1999</td>
<td>Multi-angle Imaging Spectroradiometer (MS)</td>
<td>4</td>
<td>240-1920</td>
<td></td>
<td>Intended to measure canopy structure and state; photosynthesis and transpiration rates. Nine cameras, one pointed at nadir, four forward and four aft adds functionality.</td>
</tr>
<tr>
<td>EOS AM-1</td>
<td>USA</td>
<td>est. 1999</td>
<td>Moderate Resolution Spectroradiometer (MS)</td>
<td>36</td>
<td>250-1000</td>
<td>11.5</td>
<td>Pointable sensor reduces revisit to 1-2 days. Spatial resolution varies by band. Large data storage requirements.</td>
</tr>
<tr>
<td>EROS</td>
<td>USA</td>
<td>est. 2000</td>
<td>Pan</td>
<td></td>
<td>1.5</td>
<td>13</td>
<td>Narrow swath, 228 day return cycle.</td>
</tr>
<tr>
<td>ERS-1</td>
<td>ESA</td>
<td>1991</td>
<td>SAR</td>
<td>C-band</td>
<td>30</td>
<td>100</td>
<td>Intended for monitoring oceans, coastal regions, and ice caps, but some land coverage will be included.</td>
</tr>
<tr>
<td>ERS-2</td>
<td>ESA</td>
<td>1991</td>
<td>SAR</td>
<td>C-band</td>
<td>30</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>FY-1A FY-1B</td>
<td>China</td>
<td>1988</td>
<td>Multichannel Visible and Infrared Scan Radiometer</td>
<td></td>
<td>30</td>
<td>100</td>
<td>May be used to observe forest fires and vegetation cover.</td>
</tr>
<tr>
<td>FY-2</td>
<td>China</td>
<td>est. 1998</td>
<td>MS, Pan</td>
<td>4</td>
<td>1.0 Pan</td>
<td>4.0 MS</td>
<td></td>
</tr>
<tr>
<td>FY-2</td>
<td>USA</td>
<td>1999 (failed)</td>
<td>MS, Pan</td>
<td>4</td>
<td>23 MS</td>
<td>142 MS</td>
<td></td>
</tr>
<tr>
<td>IRS-1C</td>
<td>USA</td>
<td>1995</td>
<td>Linear Imaging Self Scanner-3 (MS)</td>
<td>4</td>
<td>23 MS</td>
<td>142 MS</td>
<td>Designed for land resources management.</td>
</tr>
<tr>
<td>IRS-1D</td>
<td>USA</td>
<td>1995</td>
<td>Panchromatic WiFS (MS)</td>
<td>2</td>
<td>188</td>
<td>800</td>
<td>Designed for vegetation index mapping.</td>
</tr>
<tr>
<td>Platform</td>
<td>Principal Operator</td>
<td>Archive/ Launch</td>
<td>Sensor Name/ Type</td>
<td>Spectral Bands</td>
<td>Spatial Resolution (meters)</td>
<td>Swath Width (km)</td>
<td>Comments</td>
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</tr>
<tr>
<td>IRS-P3</td>
<td></td>
<td>1996</td>
<td>WIFS (MS)</td>
<td>2</td>
<td>188</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>IRS-P5</td>
<td></td>
<td>1996</td>
<td>OCM</td>
<td>10</td>
<td>250-500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRS-P4</td>
<td></td>
<td>1996</td>
<td>Vegetation (MS) Pan</td>
<td>4</td>
<td>10</td>
<td></td>
<td>High spatial resolution will allow vegetation species-level discrimination.</td>
</tr>
<tr>
<td>IRS-P5</td>
<td>Japan</td>
<td>1992</td>
<td>Optical radiometer</td>
<td>8</td>
<td>18</td>
<td>75</td>
<td>For agriculture and forest surveys, environmental protection and disaster prevention, fisheries and coastal monitoring. 44 day revisit cycle.</td>
</tr>
<tr>
<td>JERS-1</td>
<td>Japan</td>
<td>1992</td>
<td>SAR</td>
<td>8</td>
<td>18</td>
<td>75</td>
<td>16-18 day revisit cycle.</td>
</tr>
<tr>
<td>Landsat 1–5</td>
<td>USA</td>
<td>1972-1992</td>
<td>Multispectral Scanner</td>
<td>4</td>
<td>80</td>
<td>185</td>
<td>Optimal mix of synoptic coverage, high spatial resolution, and spectral range.</td>
</tr>
<tr>
<td>Landsat 4</td>
<td>USA</td>
<td>1982</td>
<td>Thematic Mapper (MS)</td>
<td>7</td>
<td>30 MS 120 IR</td>
<td>185</td>
<td>Same as previous Landsats with added panchromatic band.</td>
</tr>
<tr>
<td>Landsat 5</td>
<td>USA</td>
<td>1999</td>
<td>Enhanced Thematic Mapper+ (MS, Pan)</td>
<td>7</td>
<td>30 MS 5 Pan 60 IR</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td>Landsat 7</td>
<td>USA</td>
<td>1999</td>
<td>Hyperspectral Imager</td>
<td>5 Pan 384 MS</td>
<td>1100</td>
<td>2399</td>
<td>Broad swath and polar orbit affords global coverage, synoptic view, and frequent revisits. Low cost imagery suitable for land cover mapping at continental scale.</td>
</tr>
<tr>
<td>Lewis</td>
<td>USA</td>
<td>1997 (failed)</td>
<td></td>
<td>4/5</td>
<td>1100</td>
<td></td>
<td>Highest resolution civilian multispectral imager planned. Narrow swath, long revisit interval: 370-740 days</td>
</tr>
<tr>
<td>NOAA 6 to 12, 14</td>
<td>USA</td>
<td>1979</td>
<td>Advanced Very High Resolution Radiometer (MS)</td>
<td>4</td>
<td>8 MS 1 Pan 8 MS 4 Pan</td>
<td>2399</td>
<td></td>
</tr>
<tr>
<td>Orbview-3</td>
<td>USA</td>
<td>est. 1999</td>
<td>MS</td>
<td>4</td>
<td>8 MS 1 Pan 8 MS 4 Pan</td>
<td>2399</td>
<td></td>
</tr>
<tr>
<td>OrbView-2</td>
<td>USA</td>
<td>1997</td>
<td>Sea-Viewing Wide Field-of-View Sensor (MS, Pan)</td>
<td>8</td>
<td>1.0-2.0 Pan, 8 MS</td>
<td>2399</td>
<td>For monitoring ocean phytoplankton activity, with potential applications for forestry. 16 day return cycle. First private MS sensor.</td>
</tr>
<tr>
<td>Platform</td>
<td>Principal Operator</td>
<td>Archive/Launch</td>
<td>Sensor Name/ Type</td>
<td>Spectral Bands</td>
<td>Spatial Resolution (meters)</td>
<td>Swath Width (km)</td>
<td>Comments</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------</td>
<td>----------------</td>
<td>-------------------</td>
<td>----------------</td>
<td>-----------------------------</td>
<td>------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Quickbird-1</td>
<td>USA</td>
<td>est. 1999</td>
<td>MS, Pan</td>
<td>4</td>
<td>3.2 MS, 0.82 Pan</td>
<td>22</td>
<td>Pointable +/- 30 degrees fore-and-aft with stereo imaging capability. Large data storage requirements.</td>
</tr>
<tr>
<td>Quickbird-1</td>
<td>USA</td>
<td>est. 2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radarsat-1</td>
<td>Canada</td>
<td>1995</td>
<td>Carterra-10 (SAR)</td>
<td>10-100</td>
<td>50-100</td>
<td>7 beam shapes and 25 positions. Revisit interval 0.5-10 days. High power allows radar to peer through clouds and darkness.</td>
<td></td>
</tr>
<tr>
<td>Radarsat-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resource 21</td>
<td>USA</td>
<td>est. 2001</td>
<td>MS</td>
<td>6</td>
<td>10, 20, 100</td>
<td>205</td>
<td>Bands have different spatial resolution.</td>
</tr>
<tr>
<td>Resurs-O1 N3</td>
<td>Russia</td>
<td>1994</td>
<td>MSU-E1 (MS)</td>
<td>5</td>
<td>170 VNIR, 600 TIR</td>
<td>600</td>
<td>Data storage capability allows coverage over entire range.</td>
</tr>
<tr>
<td>SPOT-1</td>
<td>France</td>
<td>1986</td>
<td>High-Resolution Visible (MS, Pan)</td>
<td>3</td>
<td>20 MS, 10 Pan</td>
<td>60-80</td>
<td>For monitoring vegetation health, land use, ecosystems. 26 day orbit cycle.</td>
</tr>
<tr>
<td>SPOT-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPOT-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPOT-4</td>
<td>1998</td>
<td>High Resolution Visible—Infrared (MS, Pan)</td>
<td>4</td>
<td>20 MS, 10 Pan</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1998</td>
<td>Vegetation Monitoring Instrument</td>
<td>4</td>
<td>1,100-1,700</td>
<td>2000</td>
<td>Combination of high and low spatial resolutions allows measurement of temporal changes over a few points or at certain times.</td>
</tr>
<tr>
<td>SPOT-5a</td>
<td>est. 2002</td>
<td>High Resolution Geometry</td>
<td>4</td>
<td>10 MS, 5 Pan</td>
<td>60</td>
<td>3 cameras: fore, aft, down.</td>
<td></td>
</tr>
<tr>
<td>SPOT-5b</td>
<td>est. 2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FOREST MONITORING AND REMOTE SENSING IN BRAZIL

BACKGROUND
Brazil accounts for over fifteen percent of the world's forests, and two-thirds of the world's tropical forests. These forests and the land they occupy are valued for their timber resources; as habitat for a rich array of endemic species; as room for expansion of settlement, agriculture, and grazing; and, increasingly, for their role in global hydrologic and atmospheric systems. Given this significance, both domestic and international monitoring efforts in the Amazonian rain forests region have rapidly evolved.

Historically, Brazil did not have a systematic forest resources monitoring program: Monitoring activities were carried out on a project-by-project basis or were of limited temporal and geographical extent. However, policy changes since the 1980s have moved Brazil quickly from having very little reliable national-scale information about its forests to having sophisticated analyses based on aerial and satellite data.

This transition has involved significant investments in technology, notably remote sensing of both domestic and international origin; in building long-term cooperative bilateral relationships with other countries such as the US and China; and in engagement in international research activities. For example, through collaboration with China's space agency, Brazil plans to launch a series of sensors aboard the China-Brazil Earth Resources Satellite in the near future that will combine wide-field scanning capability with medium-resolution imagers optimized for viewing vegetation. A second, future platform, the Brazilian Remote Sensing Satellite, would gather Landsat TM-type data but would make six passes over the region daily.

In the discussion below, we outline three examples of forest measurement in Brazil and the role of remote sensing in these activities.

FOREST ASSESSMENT
Brazil has cooperated with the US and other countries to acquire funding and technology to conduct national forest assessments using remote sensing. Since 1988, this project, conducted by the space research agency Instituto Nacional de Pesquisas Espaciais (INPE), has used Landsat TM imagery to assess the extent of forest cover and its rate of change. An important output of the INPE assessment revealed that, throughout the 1980s, the gross annual rate of deforestation in the Amazon due to land conversion decreased by almost 50 percent. This trend apparently was interrupted in the early 1990s with a surge in deforestation occurring in 1994–95.
While INPE has developed estimates of the conversion of forest to agricultural and range land, the extent of more discrete changes, such as selective logging and forest recovery and growth, may be underestimated (Alves et al., 1995). This information gap is significant, as recent work by Skole and Tucker (1993) has shown that factors such as edge effects and fragmentation may impact the aerial extent and integrity of the Amazonian ecosystem to a greater extent than conversion. In this NASA sponsored work, Skole and Tucker arrived at estimates of the rate of deforestation similar to those of INPE, but went on to highlight areas in which the survey could be improved. They showed that analyzing the spatial patterns could help characterize the area of forest which are degraded due to edge effects and fragmentation—alterations that affect an area more than double that of deforestation. More recently, Nepstad et al. (1999) concluded: “Present estimates of annual deforestation for Brazilian Amazonia capture less than half of the forest area” impacted by logging and forests each year. They arrived at this conclusion by supplementing space imagery analysis with detailed in situ data and other information such as timber mill volumes and landowner interviews. Researchers are attempting to demonstrate the application of satellite data to improve the process of characterizing these more subtle dynamics. For example, researchers at INPE are attempting to use Landsat TM and aerial images to identify forest regrowth and successional stages of secondary forests (dos Santos et al., 1997).

Finally, satellite imagery has been instrumental in communicating to a broad audience the characteristic “fish bone” pattern of roads in certain regions. This has helped to focus attention on the need to change policies concerning infrastructure development and subsidies for agricultural settlement which are thought to be a primary driver of deforestation (Glantz et al., 1997).

FIRE DETECTION AND MONITORING

Another significant determinant of forest change in Brazil is fire. The US Forest Service also is assisting with in situ and aerial monitoring of fires. The Smoke, Clouds, and Radiation in Brazil (SCAR-B) aerial campaign conducted during the early 1990’s has led to sustained collaboration on aerial sensors, mapping fire risk assessment, fire response, and the evaluation of risks to human health from exposure to smoke. The Brazilian Ministry of Environment also has been collaborating with NASA and NOAA on near-real time detection and monitoring of fires for the 1998 burning season. The goal of this effort is to characterize fire susceptibility, active fires, burned areas, and smoke and trace gasses across the region using NOAA’s AVHRR sensor, the Defense Meteorological Satellite Program online scanner system, and Geostationary Operational Environment Satellite (GOES) instruments (elvidge et al., 1999). Brazil receives daily data feeds derived from all three instruments.

LARGE-SCALE BIOSPHERE ATMOSPHERE PROJECT

The Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is an international research initiative led by Brazil and framed within the International Geosphere-Biosphere Program (IGBP). Research on forests and terrestrial ecosystems within the LBA fall primarily under the Land Use and Land Cover Change (LU/LCC) component. Research questions within this component include:
• What are the rates and mechanisms of forest conversion to agricultural land uses; and what is the relative importance of these land uses?

• At what rate are converted lands abandoned; what is the fate of these abandoned lands, and what are the overall dynamic patterns of land conversion and abandonment?

• What area of forest is subject to selective logging each year?

• What are scenarios of future land cover change in Amazonia? (Alves et al., 1995)

Another objective of the component is to determine the carbon flux in undisturbed Amazonian ecosystems as well as from changes in land use and other processes across the entire region (Houghton, 1997).

The LU/LCC component makes use of three scales of analysis in its research, and project developers have identified numerous ways aerial and remote sensing as well as in situ may be integrated into the LU/LCC component (see Table B.2). The basin-wide scale monitoring will be similar to that of the INPE forest management and Skole and Tucker work described earlier. At the local scale, a case study approach will combine extensive in situ investigations with multi-temporal, high-resolution satellite imagery. Remote sensing is seen as particularly useful in identifying appropriate study sites relative to their geographic and ecoclimatological context, and for analyzing vegetation dynamics over a wide areas (Prince et al., 1995). Potential uses of remote sensing within LU/LCC also include the analyzing patterns of change, especially landscape patchiness and fragmentation, and the understanding the forest recovery and succession dynamics. However, the prevalence of atmospheric smoke, water vapor, and cloud cover can limit the utility of satellite observations, as has occurred in the case of the INPE forest assessment (Glantz et al., 1997).
Table B.2
Potential Applications of Remote Sensing for LU/LCC Component of the LBA

<table>
<thead>
<tr>
<th>Objective</th>
<th>Temporal Scale</th>
<th>Spatial Scale</th>
<th>Potential Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation classification</td>
<td>Once</td>
<td>Basin/Site</td>
<td>Aerial, TM, CBERS, SPOT, AVHRR, IRS, EOS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Site</td>
<td>Aerial, JERS, Radarsat, ERS</td>
</tr>
<tr>
<td>Flooding</td>
<td>Monthly</td>
<td>Basin/Site</td>
<td>Aerial, JERS, Radarsat, ERS</td>
</tr>
<tr>
<td>Regrowth forest classes</td>
<td>Annual</td>
<td>Basin</td>
<td>TM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Basin/Site</td>
<td>Aerial, ERS, Radarsat, JERS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Site</td>
<td>Aerial</td>
</tr>
<tr>
<td>Percent of radiation absorbed by</td>
<td>10-30 day</td>
<td>Basin/Site</td>
<td>Aerial, AVHRR, TM, SPOT, EOS</td>
</tr>
<tr>
<td>canopy</td>
<td>Continuous</td>
<td>Site</td>
<td>Aerial</td>
</tr>
<tr>
<td></td>
<td>Periodic</td>
<td>Site</td>
<td>Aerial</td>
</tr>
<tr>
<td>Leafy Biomass</td>
<td>Once</td>
<td>Basin</td>
<td>Aerial, JERS, ERS, Radarsat</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td>Site</td>
<td>Aerial, JERS, ERS, Radarsat</td>
</tr>
<tr>
<td>Woody Biomass</td>
<td>Once</td>
<td>Basin</td>
<td>Aerial, JERS, ERS</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td>Site</td>
<td>Aerial, JERS</td>
</tr>
<tr>
<td>Phenology</td>
<td>10 day</td>
<td>Basin/Site</td>
<td>Aerial, AVHRR, TM, SPOT, EOS</td>
</tr>
<tr>
<td>Roughness</td>
<td>Annual</td>
<td>Basin/Site</td>
<td>Aerial, JERS, ERS, Radarsat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Site</td>
<td>Aerial, JERS, ERS, Radarsat</td>
</tr>
</tbody>
</table>


**OBSERVATIONS**

Brazilian and international experts have concluded that remote sensing can play an important role in tracking past changes in Amazonian forests. An important factor that contributes to this finding is that, in comparisons with other regions, deforestation and development in tropical areas generates a stronger, “tell-tale” spectral signal which can be more easily interpreted in satellite imagery (Czaplewski, 1998c). Given the relative lack of ground monitoring in Brazil, remote sensing has offered a rich opportunity to gain a first
approximation understanding of basic forest attributes and trends such as gross deforestation rates. This basic understanding has contributed to changing domestic policy agendas as well as international understanding of the status and trends of Brazil’s forests. Nonetheless, analysis of remote sensing data has raised questions that require further data collection on the ground.

Because Brazil has lacked an aerial and in situ monitoring infrastructure, local foresters have “leapfrogged” over conventional approaches to space technologies. By drawing on available remote sensing data and expertise from the international community, Brazil has been able to improve its basic understanding of forest status and trends without going through the lengthy and costly process of training and implementing a ground monitoring campaign. Thus, Brazil’s experience offers insights on a “top-down” monitoring approach and on the technology transition process.

On the other hand, such a strategy has its useful limits. Remote sensing remains constrained in Brazil due to weather and in detecting more subtle yet environmentally significant trends such as reforestation, fragmentation, and selective logging. The absence of a ground monitoring and verification capability ultimately limits the extent to which remotely-sensed forest information can be developed to meet the needs of decision makers addressing complex forest management issues in Brazil and other similar countries.
APPENDIX C

FOREST MONITORING IN CANADA

BACKGROUND

Canada is home to ten percent of the world's forests, about thirty-five percent of the world's boreal forests, and twenty percent of the world's temperate rain forests. Forests in Canada cover roughly half of the landscape—over 1.7 million square miles or 1.1 billion acres. In sharp contrast with the US, 94 percent of Canadian forests are publicly owned—of which 71 percent is controlled and managed by provincial authorities and 23 percent by federal and territorial authorities (see Figure C.1).29 The Canadian forest products industry employed more than one-in-seventeen workers in 1997 and 350 communities depend almost exclusively on the forestry sector for their well being. Canada accounts for almost twenty percent of the world's forest products trade (Canadian Forest Service, 1998; Canadian Council of Forest Ministers, 1997a).

Figure C.1

Forest Ownership in Canada, 1995


The organization of forest management in Canada is significantly different than in the US. Each province is highly autonomous and maintains its own forest regulations and

29 Private forest landowners in Canada number just 425,000 compared with over 10 million in the US. While the federal government owns 23 percent of the forested lands, only two percent of the commercial timber land is included in this area (Canadian Forest Service, 1997).
legislation and, as a result, most forest monitoring in Canada is performed at the provincial level. At the national level, the Canadian Forest Service does not engage in direct forest management, rather it has responsibility for research and development, international trade negotiations, and assembling and reporting on national forest statistics.

LEGISLATIVE AND POLICY DRIVERS OF FOREST MONITORING

Forest monitoring activities in Canada in recent years have been influenced by several policy trends.

The concept of sustainable forest management has gained broad currency in the Canadian forestry sector. The issue was raised in the 1989 Canadian Forestry Act, which required the Minister of Forestry to promote sustainable development. Three years later, a provincial-level coordinating body, the Canadian Council of Forest Ministers (CCFM), ratified the National Forest Strategy for 1992-1997. However, an end of term review (Canadian Forest Service, 1997) found that many activities, including monitoring, were slow to be implemented:

Much more work is required in the areas of completing an ecological classification of forest lands, completing a network of protected areas representative of Canada’s forests, establishing forest inventories that include information on a wide array of forest values, and developing a system of national indicators of sustainable forest management.

In addition to national legislation, provincial legislation passed in the mid-1990s, notably in British Columbia, Ontario, Quebec, and Saskatchewan, mirrors an increasing emphasis on balancing ecological and social objectives to forest management with environmental assessments, integrated land-use planning, preservation, and other practices (Canadian Forest Service, 1997).

On the international level, Canada was the first country to ratify the Convention on Biodiversity and is a member of the Intergovernmental Panel on Forests, which was established in 1995. Since 1993, Canada has hosted the Montreal Process—an international effort that created seven criteria and 67 indicators of sustainable forest management for boreal and temperate forests (Santiago Declaration, 1993). Finally, an important issue for Canada is to ensure all forest products trading nations manage their forests consistent with sustainability principles and climate change agreements and, in 1996, Canada was the first country to adopt voluntary management standards for sustainable forest management fashioned after the ISO 14001 generalized environmental management standard (Canadian Forest Service, 1997 and 1998).

IN SITU MONITORING AND INVENTORY PRACTICES

As in the United States, Canada has a range of forest measurement activities in place, the implementation of these activities are rather decentralized, and practices have been evolving in recent years in response to the changing policy environment. Like the US, Canada has relied on in situ, and to a lesser extent, aerial and satellite forest measurement methods.
Canadian Forest Inventory

The Canadian National Forest Inventory is an aggregation of inventories from the ten provinces, two territories, and federal lands. The inventory, compiled by the Canadian Forest Service, is a rather recent initiative, first prepared in 1981. Most of the data are stored in a relational data base and some is in a GIS (Gray and Power, 1997; Gillis and Leckie, 1996). The national inventory is revised every five years, yet as Table C.1 shows, the underlying data are not necessarily updated to coincide with the national reporting cycle.

Table C.1
Characteristics of the 1991 Canadian National Forest Inventory

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean year of information</td>
<td>1980</td>
</tr>
<tr>
<td>Oldest data included</td>
<td>1950</td>
</tr>
<tr>
<td>Area inventoried</td>
<td>560 million hectares</td>
</tr>
<tr>
<td>Source inventory data</td>
<td>93 percent area inventoried by aerial photography</td>
</tr>
<tr>
<td>Time from photo acquisition to completed interpretation</td>
<td>3 years</td>
</tr>
<tr>
<td>Average inventory cycle</td>
<td>10—15 years</td>
</tr>
</tbody>
</table>


At the provincial level, the inventory, together with other information, is used by the chief forester of each province to determine the annual allowable cut. Because of the unevenness of its constituent data, the inventory is not suitable for year-to-year, or even decade-on-decade comparisons.

In contrast with the United States, Canada does not have a nationwide field plot monitoring system, and as we see in Table C.1 Canada relies heavily on aerial data. Given that the provinces own and manage their forested lands, measurement practices differ by province as to the specific attributes collected, definitions of these attributes, and standards for data collection. Even within a province, data collection can vary at the district level. However, the strength of this inventory system is that provinces can relate their data to the national aggregate so assembling and validating the data is easier. Moreover, the national inventory process is perceived as cost-effective because it uses data already collected for local management purposes.

The national inventory is being revised in recognition of sustainable forest management objectives, forest non-tree vegetation values, and international commitments, such as the Santiago Agreement (Magnussen and Bonnor, 1998). For example, one problem with existing provincial forest inventories is the relative lack of information on non-commercial
types of vegetation. Currently, British Columbia and other provinces are seeking to expand their monitoring activities to include a vegetation inventory. On the timber production side, there is greater emphasis on consensus-building with the provinces to develop national monitoring standards and protocols for national and international reporting. Other change objectives for the national inventory include: developing standard protocols for data collection; defining a consistent set of attributes that are less value-laden and include more non-timber attributes; and employing a national grid for improved data integration and to create a statistically valid sample. A new inventory, using the revised approach is set for completion in 2005 with planned updates on a ten-year cycle thereafter.

Other Forest Monitoring Activities

Several other activities to monitor forests have been ongoing in Canada:

- The *National Forest Fire Research Program* has archived annual forest fire statistics for 75 years, although prior to 1975 data are incomplete. Currently, the Canadian interagency Forest Fire Centre compiles national operational data throughout the fire season (Montreal Protocol Liaison Office, 1997).

- The *Forest Health Monitoring Program* is a new effort (circa 1996) of the Canadian Forest Service to create a streamlined, centralized organization that provides top-down leadership to the provinces to standardize ongoing data collection efforts. One outcome is the Canadian Forest Service’s Forest Insect and Disease Survey, which assembles data on pests, diseases, and their impacts on forest vegetation dating to the 1930s, most of which were collected by the provinces (Montreal Protocol Liaison Office, 1997).

- Emphasizing federal-provincial cooperation, a new *Forest Health Monitoring Network* plans to collect the data necessary to report on insect and disease disturbances in a statistically valid manner. The federal role will emphasize quality assurance and scientific and methods research through intensive in situ monitoring at select sites, relying on cooperation with the provinces to obtain aerial survey data on insect and disease disturbances (Canadian Forest Service, 1998c). Members of the network also hope to address identified gaps in atmospheric pollution research such as the lack of information on cause-effect links, trends in symptomology, and dose-response studies in the future. Analogous to efforts in the US, the Canadians hope to co-locate forest health monitoring plots with forest inventory plots.

- Historical data on forest disturbances including harvesting, fire, and insects are reported at the national level in the *National Forestry Database*, which is supported jointly by the Canadian Council of Forest Ministers, Canadian Forest Service, and Environment Canada. Historical data for forests from 1920 to 1975 have been compiled and documented, while the Canadian Forest Service has

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been updating the database for the period from 1975 to 1992. The database includes annual data on area of harvest (Crown and private land); volume of wood harvested; area of land affected by fire and insect disturbances; natural disturbance trends; and cumulative area successfully and unsuccessfully regenerated to commercial species (Environment Canada, 1998).

- The Acid Rain National Early Warning System (ARNEWS), has gathered data from 150 plots since 1984. Originally designed to monitor acid rain, it has been expanded to include more general indicators of forest health (Canadian Forest Service, 1994).

CRITERIA AND INDICATORS DEVELOPMENT

Canada has been involved in two efforts to develop forest Criteria and Indicators (C&I)—one at the national level and the other at the international level.

Following its Canadian National Forest Strategy for 1992-1997, the Canadian Council of Forest Ministers in 1993 began an effort to identify, define, and report on criteria and indicators for sustainable forest management. The indicators were developed in a public consultative process and generated six criteria and 83 indicators (Canadian Council of Forest Ministers, 1997b; Canadian Forest Service, 1998). There currently is no national program in place in Canada to gather and report on all of the CCFM indicators, but a review of available data has been performed and an initiative to report on forty-nine indicators in 2000 is underway (Canadian Council of Forest Ministers, 1997a). One of the critical early challenges seen is to ensure that the indicators reflect current management practices (Gilbert, 1998).

After a working group was established by the CCFM to develop criteria and indicators nationally, Canada spearheaded an international effort at the UN Conference on Environment and Development in Rio de Janiero to develop criteria and indicators for conservation and sustainable forest management of temperate and boreal forests. Known as the Montreal Process, the international group eventually developed a set of seven criteria and 67 indicators for the conservation and sustainable forest management of temperate and boreal forests (Santiago Declaration, 1995). These measures are largely consistent with those of the CCFM process.

A summary of Canada’s ability to report on the Montreal Process criteria and indicators is presented in Table C.2. This assessment is somewhat more optimistic—for instance, in areas such as biodiversity conservation and ecosystem health—than the analogous review conducted by the US Forest Service of US reporting abilities (Table 2.2).
Table C.2
Overview of Canada’s Ability to Report on Montreal Process Criteria and Indicators

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Reporting Capability</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Biological Diversity</td>
<td>Reasonably well</td>
<td>Some proxy data used (e.g. road density for forest fragmentation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Need standard land cover classification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forest age class data not available; maturity used as proxy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>More precise definition of forest-dependent species needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Definitive list of species to be monitored by forest age class or ecozones being developed</td>
</tr>
<tr>
<td>2. Productive Capacity</td>
<td>Reasonably well</td>
<td>Emphasis has been on commercial species; little information on stocks of native species</td>
</tr>
<tr>
<td>3. Ecosystem Health and Vitality</td>
<td>Reasonably well</td>
<td>No quantitative data on floods, storms, land clearance or domestic animals</td>
</tr>
<tr>
<td>4. Soil and Water resources</td>
<td>Limited</td>
<td>No quantitative data</td>
</tr>
<tr>
<td>5. Global carbon cycles</td>
<td>Proxy</td>
<td>A carbon budget model is only available for 1920 to 1989 for boreal and subarctic forests</td>
</tr>
<tr>
<td>6. Socio-economic benefits</td>
<td>Variable</td>
<td>Proxies and case studies are only data available for subsistence and non-consumptive uses</td>
</tr>
<tr>
<td>7. Institutional and economic framework</td>
<td>Reasonably well</td>
<td>Information may vary by province; incomplete data on forest research and development investments</td>
</tr>
</tbody>
</table>


REMOTE SENSING APPLICATIONS

Remote sensing is considered to be an important method of forest data acquisition in Canada because many changes in forest conditions occur over very large, unpopulated, and inaccessible areas. Canada has operational experience with remote sensing data for forest inventory purposes at the provincial level. It also has several federal and international projects underway to develop the analysis tools and infrastructure required to incorporate remote sensing data into a range of forest monitoring efforts. However, the lack of an established field plot monitoring system ultimately limits the country’s ability monitor many forest attributes as well as to accurately verify their remote sensing data.
National Forest Inventory

Remote sensing imagery was used in limited fashion for the 1994 update of the 1991 national forest inventory. For example, Landsat imagery was used for some of the inventory for the Northwest Territories. NOAA’s AVHRR imagery was used in a previous mapping project was utilized to determine the northern limit of forest cover in Ontario and Manitoba (Gray and Power, 1997).

The draft redesign for the 2005 national forest inventory recommends an augmented role for the application of remote sensing imagery, including the following roles:

- To cover remote areas, land with little or no vegetation cover, and to fill gaps in map data for territories that might otherwise not be covered by aerial or in situ monitoring;
- To verify that aerial and ground sampling are not biased; and
- To detect disturbances and change significant enough to trigger intensified aerial or ground sampling.

Such applications may include determining the boundaries of forested areas in the Northwest Territories, Saskatchewan, and Manitoba (using AVHRR imagery) and in Ontario and Quebec (using Landsat TM imagery). Labrador has obtained Landsat data but its officials are more confident with using older map data augmented with AVHRR (Gillis, 1998).

The draft inventory redesign also identifies several data points that will be collected through remote sensing, in some cases to augment other techniques: area by land class; disturbance, regeneration and afforestation by forest type; mortality, vegetation indices, and classification statistics (Gillis, 1998; Magnussen and Bonnor, 1998).

Researchers at the Canadian National Forest Service Pacific Research Centre (Goodenough et al., 1998) have suggested that 19 of the 25 attributes to be reported in the national forest inventory can be either largely or partially informed using remote sensing. The attributes and the ability of satellite remote sensing to inform them are identified in Table C.3.
Table C.3
Potential Applications of Space Imagery in the Canadian National Forest Inventory

<table>
<thead>
<tr>
<th>Substantial role for these measures</th>
<th>Partial role for these measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Area by forest type</td>
<td>• Area and severity of disease infestation</td>
</tr>
<tr>
<td>• Forest types by protection status</td>
<td>• Area and percent of forest land with significant soil erosion</td>
</tr>
<tr>
<td>• Other wooded land by protection</td>
<td>• Total biomass by forest type, age, succession stage</td>
</tr>
<tr>
<td>status and type</td>
<td>• Total volume of all species on timber producing land</td>
</tr>
<tr>
<td>• Area and percent of forest managed</td>
<td>• Current volume growth (annual) of forest (gross, net)</td>
</tr>
<tr>
<td>primarily for protective functions</td>
<td></td>
</tr>
<tr>
<td>(watersheds, flood protection,</td>
<td></td>
</tr>
<tr>
<td>avalanche protection, riparian</td>
<td></td>
</tr>
<tr>
<td>zones)</td>
<td></td>
</tr>
<tr>
<td>• Regeneration and afforestation</td>
<td></td>
</tr>
<tr>
<td>area by type</td>
<td></td>
</tr>
<tr>
<td>• Area of surface water in forests</td>
<td></td>
</tr>
<tr>
<td>• Forests undisturbed by human</td>
<td></td>
</tr>
<tr>
<td>activity</td>
<td></td>
</tr>
<tr>
<td>• Other wooded land undisturbed by</td>
<td></td>
</tr>
<tr>
<td>human activity</td>
<td></td>
</tr>
<tr>
<td>• Area available for timber</td>
<td></td>
</tr>
<tr>
<td>production</td>
<td></td>
</tr>
<tr>
<td>• Area converted to non-forest use</td>
<td></td>
</tr>
<tr>
<td>• Area and severity of insect attack</td>
<td></td>
</tr>
<tr>
<td>• Area and severity of fire damage</td>
<td></td>
</tr>
<tr>
<td>• Area of forest disturbance</td>
<td></td>
</tr>
</tbody>
</table>


Criteria and Indicators

According to the Canadian Forest Service (1998), satellite imagery is considered critical to criteria and indicator reporting:

The ability to measure the direction of change and to compare measurements over time is essential for determining progress toward sustainable management. Information that might previously have been generated in separate localities from estimates derived by extrapolation (rather than actual field measurement) may now be produced by a few centres of excellence that can efficiently treat large amounts of data and disseminate the results with ease.

Goodenough et al. (1998) reviewed the potential for remote sensing to supply data for sustainable forestry indicators. They concluded that satellite imagery could be used to monitor 25 of the 83 CCFM indicators in a substantial or partial capacity (see Table C.4).
### Table C.4
Potential Applications of Space Imagery for CCFM Indicators

<table>
<thead>
<tr>
<th>Substantial role for these indicators</th>
<th>Partial role for these indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Percent and extent of forest types relative to historical condition and to total forest area</td>
<td>1. Area and severity of disease infestation</td>
</tr>
<tr>
<td>2. Percent and extent of area by forest type and age</td>
<td>2. Percent area successfully naturally regenerated and artificially regenerated</td>
</tr>
<tr>
<td>3. Area, percent, and representativeness of forest types in protected areas</td>
<td>3. Mean annual increment by forest type and age</td>
</tr>
<tr>
<td>4. Level of fragmentation and connectedness of forest ecosystem components</td>
<td>4. Tree biomass volume</td>
</tr>
<tr>
<td>5. Area and severity of insect attack</td>
<td>5. Participation in the climate change conventions</td>
</tr>
<tr>
<td>6. Area and severity of fire damage</td>
<td>6. Annual removal of forest products relative to the volume of removals</td>
</tr>
<tr>
<td>7. Percent and extent of area by forest type and age</td>
<td>determined to be sustainable.</td>
</tr>
<tr>
<td>8. Area of forest converted to non-forest land use</td>
<td>7. Distribution of and changes in the land base available for timber production</td>
</tr>
<tr>
<td>9. Percent of forest managed primarily for soil and water protection</td>
<td>8. Availability of habitat for selected wildlife species of economic importance</td>
</tr>
<tr>
<td>10. Area, percent, and representativeness of forest types in protected areas</td>
<td>9. Area and percent of protected forest by degree of protection</td>
</tr>
<tr>
<td>11. Percent canopy cover</td>
<td></td>
</tr>
<tr>
<td>12. Percent biomass volume by general forest type</td>
<td></td>
</tr>
<tr>
<td>13. Area of forest depletion</td>
<td></td>
</tr>
<tr>
<td>14. Area of forest permanently converted to non-forest use</td>
<td></td>
</tr>
<tr>
<td>15. Semi-permanent or temporary loss or gain of forest ecosystems, such as grasslands, agriculture</td>
<td></td>
</tr>
<tr>
<td>16. Surface area of water within forested areas</td>
<td></td>
</tr>
</tbody>
</table>

However, remote sensing will not be used for the 2000 reporting initiative for but there are plans are to incorporate remote sensing in the future (McAfee, 1998).

**Use of Remote Sensing by Provinces**

Remotely-sensed forest information has been used by several provinces in an operational setting in inventory updates concerning harvests, fires, insect and disease, and other changes (see Table C.5 below). The differing requirements for timeliness, accuracy, and precision, in addition to available expertise and funding has influenced each province’s approach. Landsat Thematic Mapper data has been the source for the majority of applications, while Radarsat is used when needed during cloudy periods. Ikonos and SPOT data also have been considered and used to a limited extent (Ahern, 1998). With the exception of New Foundland, when remote sensing is not used (indicated by the blank cells in Table C.4), aerial photography and sketchmapping are employed. The provinces that do not employ satellite remote sensing at all most often rely on aerial photography to estimate changes.

British Columbia, which accounts for approximately forty percent of Canada’s annual timber harvest, has been the most extensive user of remote sensing data in an operational setting in Canada. The province has used satellite remote sensing imagery to generate updates to forest cover maps. British Columbia started by using Landsat Multispectral Scanner data, but found that the images were too coarse and could not meet their requirement for accuracy within 20 meters. From the mid-1980s to the mid-1990s, Landsat Thematic Mapper imagery was used as a major source for forest depletion data. This was possible, in part, because most of the depletion in the province were from clear cuts or fires, and thus boundaries were readily visible in satellite images. In 1995-1996, remote sensing image data for the province was audited to benchmark accuracy and evaluate these images. Indeed, errors were discovered in both the image acquisition and interpretation processes, revealing that the data did not meet accuracy requirements. These errors led to an accuracy only in the 60 meter range and were due in part to sensor resolution and geocoding techniques. In consequence, Landsat Thematic Mapper images are only used for broad overviews. Some districts are using SPOT and IRS imagery (they meet the ±20 meter accuracy requirements), while many of the forty districts within the province have explored other ways of gathering these data (Gillis, 1998; Wakelin, 1998; Gilbert 1998).

31 Approximately one third of all Canadian forest inventory maps need to be revised each year; In some provinces this figure can be as low as 10–15 percent or as high as 75–80 percent.
Table C.5

Use of Remotely-Sensed Data in Forest Change Mapping by Provinces

<table>
<thead>
<tr>
<th>Province</th>
<th>Harvest Update</th>
<th>Fire Update</th>
<th>Insect and Disease Update</th>
<th>Other Updates†</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>TM, SPOT-Pan transparencies</td>
<td>TM, SPOT-Pan transparencies</td>
<td>TM, SPOT-Pan transparencies</td>
<td>TM, SPOT-Pan transparencies</td>
</tr>
<tr>
<td></td>
<td>TM digital precision geocoded</td>
<td>TM digital precision geocoded</td>
<td>TM digital precision geocoded</td>
<td>TM digital precision geocoded</td>
</tr>
<tr>
<td>New Foundland</td>
<td>TM, SPOT transparencies</td>
<td>TM, SPOT transparencies</td>
<td>TM, SPOT transparencies</td>
<td>TM, SPOT transparencies</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>TM, SPOT transparencies</td>
<td>TM, SPOT transparencies</td>
<td>TM, SPOT transparencies</td>
<td>TM, SPOT transparencies</td>
</tr>
<tr>
<td>Ontario</td>
<td>TM transparency</td>
<td>TM transparency</td>
<td>TM transparency</td>
<td>TM transparency</td>
</tr>
<tr>
<td>Quebec</td>
<td>Landsat††</td>
<td>TM digital enhancement†††</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


† Includes new roads, trails, rights-of-way, and seismic lines.

†† For special cases only, such as large forest burns.

††† A survey using Landsat Thematic Mapper imagery is performed every 2–3 years to help determine spray blocks and salvage logging.

Federal and International Remote Sensing-Based Research

Two major projects to develop and implement remote sensing applications for forest monitoring are being managed by Canada research organizations.

The Earth Observation for Sustainable Development of Forests Project (EOSD) is a three-phase project to develop techniques to use space imagery to provide an accurate and objective picture of the status and trends of Canada’s forest resources as well as to assist with compliance monitoring under international agreements. EOSD will entail research on and development of methods for: image calibration and processing; data fusion and analysis; and change detection. The techniques developed will be used to identify and construct temporal and spatial data bases of fire, insect, and disease disturbances and a comprehensive picture of forest cover and land-use change (Goodenough et al., 1998). It primarily will employ Landsat and Radarsat imagery with supplementary data from IRS-
EOSD is being managed by the Canadian Forest Service’s Pacific Forestry Centre in British Columbia with funding from the Canadian Space Agency, the Canadian Forest Service and in-kind funding from the provinces. It is scheduled to begin in local fiscal year 1999 (Goodenough, 1998).

The Canadian Center for Remote Sensing (CCRS) in Ontario is leading one of six Global Observations of Forest Cover (GOFC) pilot projects under the auspices of the international Committee on Earth Observing Satellites. The five-year project, which began in 1997 and currently is in the design phase, has a broad set of objectives:

GOFC will produce high quality, multi-resolution, multi-temporal global data sets and derived products of forest cover and attributes; with particular attention to areas of rapid change and fragmentation; to be repeated for quantitative analysis of variation on a three to ten year cycle; with associated regional applications and methodological investigations; for the benefit of multiple user communities; and ultimate transition to routine operational use (Janetos and Ahern, 1997, p.7).

Moreover, project documentation specifically emphasizes that GOFC is less a research-oriented exercise than an experiment to develop operational measurement capabilities.

A GOFC workshop in mid-1997 scoped the potential role of remote sensing for forest monitoring. The workshop participants noted a broad range of needs for greater application of remote sensing to forest monitoring: global change, timber, fuel, and fiber production; biodiversity preservation; tourism and recreation; and sustainable forest management. In addition to the broad range of needs for remote sensing is an equally broad set of potential users including: parties to international environmental conventions and agreements; institutions concerned with international policy and operations; national and sub-national organizations; and the scientific community. This review of drivers, data requirements, and the user community was used to develop the core requirements for remote sensing data. Meeting the needs will require data on a set of core indicators--baseline land cover, land cover change, land cover net primary productivity, biomass, fire depletion, and harvest depletion.

Barriers to wider use of remote sensing data were also identified the GOFC workshop. These included:

- The high cost of remote sensing data, which may be alleviated by the new US Landsat data policy
- Investments required to identify and locate data sources that are the most suitable for a particular task
- Developing an alternative data analysis approach that entails a coarser, top-down approach using remote sensing imagery rather than the traditional detailed, bottom-up monitoring based approaches
- The apparent complexity of using remotely-sensed data and the cost of building the required expertise (Janetos and Ahern, 1997).
OBSERVATIONS

The experience of Canada in the use of remote sensing and the lessons this experience may hold for US decision makers is mixed.

On the one hand, Canadian forest managers, such as those in British Columbia have garnered lengthy experience with using satellite imagery in an operational capacity in the forest sector. On the other hand, the lack of a systematic in situ monitoring system limits the extent that remotely sensed data can be used without ground verification.

And, the forest monitoring experience in British Columbia also shows continued limitations with using satellite imagery. In consequence, the consensus among forest managers in Canada continues to hold that traditional policy and forest management decisions can be met cost-effectively with aerial photography. As the demand for forest information increases in terms of scope (national, temporal changes) and complexity, and the supply of imagery improves in terms of cost, spatial, spectral, and temporal resolution, and consistency, the demand for remote sensing may increase (Gillis, 1998; Gillis and Leckie, 1996; and Ahern, 1998).

A review of forest measurement techniques suggests that remote sensing may be cost-effective for updating inventories, and perhaps for regeneration monitoring and verifying ground data. Many change activities can be covered by one scene and satellite imagery is archivable. These benefits are offset by coarse resolutions which cannot discern partial timber cuts and residual stand features, and existing imagery does not meet standards for 1:10,000 to 1:20,000 scale mapping required by most Canadian provinces. In addition, effort must be expended to preview satellite data for quality—to indicate haze or thin cloud cover, for example. Finally, investments in remote sensing applications development has been deterred by concerns about consistent sensor and data base availability over the long term, as has been prompted by recent mishaps involving high-resolution satellites (Gillis and Leckie, 1996; Gilbert, 1998).

One notable difference between the US and Canada is data policy: Canadian policy appears to impose greater impediments to integration than the US. Goodenough et al. (1998) have observed that the Radarsat International firm has exclusive rights to sell Landsat, SPOT, and Radarsat imagery of Canada, and its price structure effectively increases the cost of satellite data. Domestic copyright restrictions limit the use of an image to one application, even within an agency. Moreover, Natural Resources Canada scientists have exclusive rights to data collected for research projects for an unlimited period of time.32

Canada may serve as a model for how the US might approach reviewing its forest monitoring policy. Canadian officials have focused first on developing a consensus around the strategic objectives for forest management—the National Forest Strategy. Then, they have sought to further elaborate these objectives by developing criteria and indicators of sustainable forest management—by both participating in the Montreal Process and undertaking the Canadian Council of Forest Ministers initiative. While a national program is not yet in place to implement the criteria and indicators, these management objectives

32 In the US, such exclusivity is granted for 1–2 year periods.
and information requirements will help experts and decision makers determine the appropriate measurement methods required to meet these needs.

Finally, the Canadian Forest Service lies within Natural Resources Canada, the same organization that operates the Canadian Center for Remote Sensing. As a result, organizational barriers and cultural differences between federal foresters and satellite remote sensing imagery providers, in principle, should be lower than in the US.
REFERENCES


Befort, Bill, Resource Assessment Unit, Minnesota Department of Natural Resources, Grand Rapids, telephone communication, September 1998.


Canadian Council of Forest Ministers, *Criteria and Indicators of Sustainable Forest Management in Canada*, Ottawa, Canada, 1997a.


Cannon, Lincoln, Director, Forest Resources and Taxation, Oregon Forest Industries Council, Salem, telephone communication, July 1998.

Committee on Earth Observation Satellites, *Coordination for the Next Decade*, 1995.


Edwards, Thomas, Utah Cooperative Fish and Wildlife Research Unit, Logan, telephone communication, September 23, 1998.


Gilbert, David, Director, Forest Inventory Branch, British Columbia Ministry of Forests, telephone communication, October 1998.


Gillis, Mark, Manager, National Forest Inventory, Canadian Forest Service, telephone communication, October 1998.

Gillis, Mark, and Donald Leckie, “Forest Inventory Update in Canada,” Forestry Chronicle, March/April, 1996, pp. 138-156.


Goodenough, David, Natural Resources Canada Pacific Forestry Centre, Victoria, British Columbia, telephone communication, September 1998.


Hansen, Mark, Research Forester, Forest Service, Forest Inventory and Analysis, St. Paul, MN: North Central Forest Experiment Station, telephone communication, September 1998a.

Hansen, Mark, Research Forester, Forest Service, Forest Inventory and Analysis, St. Paul, MN, e-mail communication, September 1998b.

Hansen, Mark, Research Forester, Forest Service, Forest Inventory and Analysis, St. Paul, MN, written communication, March 1999.


Heinzen, David, Supervisor, Resource Assessment Unit, Minnesota Department of Natural Resources, Grand Rapids, telephone communication, September 1998.


Levien, Lisa, Forest Service, Sacramento, California, telephone communication, June 1998a.


Moisen, Gretchen, Forest Service Rocky Mountain Research Station, Ogden, UT, email communication, June 21, 1999.


Prisley, Steve, Westvaco Corporation, Summerville, South Carolina, telephone communication, August 5, 1998.

Raines, Charley, Sierra Club, Cascades Chapter, Seattle, Washington, telephone communication, July 1998.


Sader, Steven, University of Maine, Orono, and former Chair, Society of American Foresters, Working Group on Remote Sensing, telephone communication, September 15, 1998.


Tompson, Erkki, Director, Finnish National Forest Inventory, Finnish Forestry Institute, Helsinki, telephone communication, October 1998.


Tompson, Janice, Wilderness Society Center for Landscape Analysis, Seattle, Washington, telephone communication, September 15, 1998.


Wakelin, John, Manager, Inventory Technical Applications Branch, British Columbia Ministry of Forests, Canada, telephone communication, October 1998.

Warbington, Ralph, Forest Service Remote Sensing Laboratory, Sacramento, California, telephone communication, September 1998.

