



# CURRENT AND FUTURE USE OF REMOTE SENSING TOOLS FOR OPERATIONAL FOREST INVENTORY

## CANADA'S SITUATION

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Forest Inventory is a main user of remote sensing tools and technologies. Major inventory applications can be summarized into several categories: 1) Forest Inventory Mapping; 2) Forest Inventory Update; 3) Forest Surveys; 4) Canada's National Forest Inventory; and, 5) Special Applications. The approach taken here is to illustrate the role remote sensing by general category of application (Table 1).

**Table 1. Remote sensing technologies used in forest inventory applications:**

APPLICATION	AVHRR	Landsat TM Spot IRS	HI-RESOLUTION MULTISPECTRAL (Airborne)	LIDAR	RADAR	PHOTOGRAPHY
Inventory Mapping		0	0	0		0
• Broad area classification	0	0				
Inventory Update		0				0
Forest surveys						
• Regeneration			0			0
• Insect and Disease		0				0
National Forest Inventory	0	0				0

to base maps and then digitized to produce forest type maps. The implementation of Geographic Information Systems (GIS) in the 1980s has resulted in a number of opportunities in the production of forest type maps. GIS has provided a framework for other digital survey technologies to use. Digitized aerial photography and softcopy analysis<sup>1</sup> is being used in the production of digitized orthophotos and is being examined for a number of inventory applications including inventory mapping and update. High resolution multi-spectral imagery from airborne platforms (e.g., Casi (Compact airborne spectrographic imager), MEIS (Multi-spectral electro-optical imaging sensor), digital frame cameras) providing digital data at a resolution of 1m or less, have only been studied for inventory mapping in research and development projects. Other digital technologies, such as airborne Light Detection and Ranging (LIDAR) have also been studied and is commercially available. LIDAR permits terrain mapping under canopies, and canopy profiles can be done, but translation into tree or stand height has not been tested operationally.

Satellite imagery, from Landsat TM, SPOT and Indian Remote Sensing Satellite, have been used for broad area classification and mapping projects: Baseline Thematic Mapping in British Columbia; Peace River Woodlot, Central Woodlot, Native Prairie Inventory and the Earth Observation Pilot Project Program in Alberta; South Digital Land cover in Saskatchewan; and, Land Cover Classification in Ontario. Classification systems identify broad cover types (e.g., conifer, deciduous, mixed wood) as well as broad land uses (e.g., urban, agriculture). Satellite imagery, primarily Landsat TM has also been used to provide area overviews and for reconnaissance inventory for northern areas. Various ancillary data (e.g., maps aerial photographs and ground data) are used for reference to help identify some class labels.

Satellite imagery from AVHRR, has been used for very broad are classification projects, such as the Land Cover Classification of Canada produced by Beaubien and Cihlar. Again broad cover types are used.

References: Gillis, M.D.; Leckie, D.G. 1993. Forest inventory mapping procedures across Canada. PNFI Information Report PI-X-114

Leckie, D.G.; Gillis, M.D. 1995. Forest inventory in Canada with emphasis on map production. For. Chron. 71: 74-88

## **FOREST INVENTORY UPDATE**

Remote sensing tools and technologies are also commonly used to update forest inventory maps. Once again aerial photography is one of the mainstays for this application. The common practice is to acquire conventional aerial photography (9x9 format), at inventory map scale, only for the area of the disturbance, delineate the boundary of the disturbance, and transfer the boundary to the base map. The photo interpreter also examines adjacent stands to determine if the characteristics have been modified by the disturbance, and makes the necessary changes to the classification. Conventional photography is also acquired at smaller scales (1:30 000 to 1:60 000) to cover and map changes over broad areas (e.g., fire perimeter mapping and land use change). The chief advantage of the smaller scale photography is the cost. It also provides a good permanent overview record of change activity. Digitizing conventional photography and softcopy analysis is being used by some organizations whose inventories have been fully implemented on a GIS.

more because of the ability to use the images as a backdrop to GIS-based inventory maps. The digital data must be geometrically corrected for orientation and terrain effects. Another advantage of digital satellite imagery is the potential to use automated techniques to capture change information. Subtle changes such as partial cuts, composition changes, and many forest damages are difficult to capture using either aerial photography or satellite imagery.

Other, less common, methods to update inventory maps include the use of supplemental aerial photography, digital frame cameras, video, global positioning system technology, and aerial reconnaissance surveys. Field surveys or traverses are another less common method of capturing change information.

Reference: Gillis, M.D.; Leckie, D.G. 1996. Forest inventory update in Canada. *For. Chron.* 72:138-156

## FOREST SURVEYS

Remote sensing technologies have been widely used in a variety of forest surveys. The mainstays again are aerial photography and satellite imagery. Higher resolution data from airborne platforms are required to assess regeneration conditions (e.g., satisfactorily stocked, free-to-grow). High resolution multispectral data from airborne platforms (Casi) have been used operationally to determine stocking levels and to develop stem density maps, used to direct thinning operations.

Satellite data is being used to map insect and disease infestations. A digital enhancement technique was used in Quebec to map cumulative defoliation. Newfoundland also uses satellite imagery in transparency and digital format to visually map forest damage.

Reference: Leckie, D.G. 1990. Advances in remote sensing technologies for forest surveys and management. *Can. J. For. Res.* 20:464-483

Brand, D.G.; Leckie, D.G.; Cloney, E.E. 1991. Forest regeneration surveys: Design, data collection and analysis. *For. Chron.* 67:649-657

## NATIONAL FOREST INVENTORY

Remote sensing data is being used in the current version of the National Forest Inventory to provide information for areas not covered by air photo-based forest inventories. Some examples are:

- The Peace River Woodlot, Central Woodlot, Native Prairie Inventory and the Earth Observation Pilot Project are used to fill in gaps in provincial inventory coverage in Alberta.
- Land Cover Classification is being used to provide information beyond the extent of inventory in Ontario.
- Land cover classification of Canada produced from AVHRR data is being used to provide

condition. Integrating remote sensing in the National Forest Inventory could result in a calibrated forest resource cover type map for all of Canada with the National Forest Inventory attributes.

Reference: Gillis, M.D. [2001] Canada's National Forest Inventory (Responding to current information needs). Environmental Monitoring and Assessment 67:121-129.

Wulder, M., 1999; Preliminary Guide to the Digital Estimation of Canadian National Forest Inventory Attributes, Version 2.2. Canadian Forest Service, Pacific Forestry Centre. Internal Document. 51p.

## **SPECIAL APPLICATIONS**

Remote sensing data has been used operationally for a number of special applications. These include: AVHRR for mapping hot spots (Fire M3); and, the use of multiscale approach involving Landsat TM, high resolution imagery, and AVHRR for mapping and monitoring NPP (ECOLEAP).

References: Bernier, P.Y., R.A. Fournier, C.H. Ung, G. Robitaille, G.R. Larocque, M.B. Lavigne, R. Boutin, F. Raulier, J. Beaubien and C. Delisle. 1999. Linking ecophysiology and forest productivity : An overview of the ECOLEAP project. For. Chron. 75: 417-421.

Fournier, R., J. Luther, M. Wulder, C. Ung, S. Magnussen, L. Guindon, M. Lambert, J. Beaubien, 1999; Mapping forest biomass from inventory and remotely sensed data. Fourth International Airborne Remote Sensing Conference and 21st Canadian Symposium on Remote Sensing. Ottawa, Ontario, June 21-24. Vol. II, pp. 171-178.

## **FUTURE USE**

Remote sensing tools will continue to be widely used in operational forest inventory. There will likely be greater use made of digital remote sensing data to take advantage of the digital nature of the inventory database. As a result, the use of digitized aerial photography and softcopy analysis will likely increase for both the mapping and update applications. The use of high resolution imagery, from airborne or space platforms, will also increase. The main application areas will be in visual interpretation, automated tree isolation and stem counting, species classification, damage/health assessment, crown size, closure and gap determination. The study of other tree and forest parameters from high-resolution digital imagery will continue.

The role of satellite imagery (Landsat TM) will also increase, primarily in the area of broad scale classification, and mapping. There will likely be a greater or expanded role for satellite imagery to monitor forest change. Satellite imagery will be used to capture change directly by visual techniques, as a difference between successive broad scale classifications, or through the use of annual coverages to monitor the time trend in spectral signatures.

Support will continue for the development of other remote sensing technologies, such as LIDAR, and for spatial data fusion that will enhance inventory attribute estimation.

## **RESEARCH PRIORITIES**

The research priorities include development of:

References: Leckie, D.; Fournier, R.; Beaubien, J.; Wulder, M.: Remote Sensing Scientists with CFS

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## United States Situation

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### Forest Inventory and Analysis Program

Forest Inventory and monitoring is a main user of remote sensing tools and technologies. The major inventory applications can be summarized into several categories. The approach taken here is to illustrate the role of remote sensing in: 1) Forest Inventory Mapping; 2) Forest Inventory Update; 3) Forest Surveys; 4) The US Forest Inventory and Analysis (FIA) program, and, 5) Special Applications. Table 1 illustrates the role of some of the technologies by the general category of application.

**Table 1. Remote sensing technologies used in forest inventory applications:**

APPLICATION	AVHRR	Landsat TM Spot IRS	AIRBORNE VIDEOGRAPHY	LIDAR	RADAR	PHOTOGRAPHY
<i>Inventory Mapping</i>		✓				✓
• <i>Broad area classification</i>	✓	✓				
<i>Inventory Update</i>		✓	✓			✓
<i>Forest surveys</i>						
• <i>Regeneration</i>						✓
• <i>Insect and Disease</i>		✓	✓			✓
<i>National Forest Inventory</i>	✓	✓				✓
<i>Special Applications</i>	✓	✓	✓	✓	✓	✓

### FOREST INVENTORY MAPPING

Large area forest inventory mapping in the US is generally done by private land owners or public land managers. The most common means of mapping involves delineation of forest stands and vegetation polygons on aerial photographs, then photo-interpretation of the vegetation type and condition. Vegetation polygons typically range from 10- to 100-acres in size, and each vegetation map can cover a million acres or more. Vegetation polygons are manually digitized and entered into geographic information systems. Photo-interpreted vegetation maps exist for most of the 156 US National Forests and National Grasslands managed by the US Forest Service<sup>2</sup>. Approximately nine percent of US forestlands are owned and managed by private industrial owners who use a variety of remote sensing

## **FOREST INVENTORY UPDATE**

For lands where good base maps and vegetation coverage data exist, it is increasingly common to use satellite imagery (generally 30 m LANDSAT TM imagery, aerial photography or videography) for change detection and to produce broad maps of land cover. This is particularly common in the aftermath of a major disturbance such as a fire, hurricane, ice storm or windstorm, which affects large areas. Aerial photography is used less commonly due to the costs of chartering specific flight missions

## **FOREST SURVEYS**

Remote sensing technologies are widely used in a variety of forest surveys of insect or disease outbreaks and aftermath of major disturbances. The mainstays in the US are aerial photography, airborne video, and airborne observation/sketch mapping. The platform and resolution of the imagery depends on the objective of the survey. For example, many US states will over-fly their forests at a particular time of year with a trained observer who sketches polygons onto maps or aerial photographs of the over-fly area, denoting evidence of insect or disease outbreaks. Use of videography increases the objectivity of the resulting data, and aerial photography is used for special cases where more precise observations and documentation are required.

## **NATIONAL FOREST INVENTORY**

The Forest Inventory and Analysis (FIA) program of the US Forest Service is the Nation's most comprehensive large area forest inventory program. Since the 1950s, the FIA program has used aerial photography to improve accuracy of statistical estimates using double sampling for stratification. FIA has established nearly 10,000,000 photo sample points on a 1-km grid that covers the entire USA<sup>3</sup>, including public and private lands<sup>4</sup>. Each point is photo-interpreted as "forest" or "non-forest," although more detailed classifications are made in some geographic areas<sup>5</sup>. However, the use of aerial photographic is waning because interpretation and processing is laborious, and aerial photography is often out of date. The repeatability, continuity, and wide availability of digital satellite imagery contributed to the current development of remote sensing, image processing, and Geographic Information Systems (GIS) technologies.

Recently, several regional FIA units have been experimenting with a variety of satellite based platforms to replace the use of air photo s<sup>6</sup>. The interior western FIA unit has used a combination of AVHRR and topographical modelling for forest stratification purposes. This approach works well in the western US where elevation and aspect are excellent predictors of forest type. The North Central FIA unit has used forest coverages derived from the US Gap Analysis Program (GAP). GAP produces state-specific land cover maps based on a variety of (generally existing and available imagery including aerial photography and satellite imagery).

## **SPECIAL APPLICATIONS**

Several different staffs within the USDA Forest Service are involved in remote sensing technology

### **A. Forestry And Watershed Applications Of Lidar Remote Sensing**

This technology involves pulsing the earth's surface with lasers and collecting the reflected electromagnetic energy. By precisely timing the interval between the emission of the pulse and the detection of the reflected energy, distances and relative heights of objects can be determined. Research is currently underway into the use of these models to monitor sediment input into streams and geomorphic changes in watersheds.

### **B. Detecting Ozone Symptoms Using Remote Sensing**

High concentrations and prolonged exposures of vegetation to ground-level ozone is a concern to resource managers. Current ozone exposures in many portions of the eastern United States are large enough to cause visible symptoms, seen as red stippling, on the upper surface of sensitive plant species. The objective of this project was to evaluate the use of remote sensing techniques to detect ozone symptoms, i.e., a reddening of the foliage. The following describes the techniques and results of a survey using color infrared digital camera imagery to determine if ozone symptoms could be detected.

### **C. Mapping And Monitoring Noxious Weeds Using Remote Sensing**

The Nez Perce National Forest and the Remote Sensing Applications Center examined the feasibility of detecting and mapping noxious weeds using various types of aerial remote sensing data; including a colour infrared digital camera, a multi-spectral camera, and conventional cameras (70 mm and 35 mm). Four noxious weeds, yellow star thistle, spotted knapweed, rush skeleton weed, and leafy spurge, were selected for this project.

## **FUTURE USE**

The Forest Service in general and the FIA program in particular will continue to evolve towards emphasizing satellite imagery and reducing reliance on aerial photography, primarily due to the costs involved. As satellite sensors produce higher resolution imagery at lower costs, and as our imagery analysis techniques evolve to handle the increased data flow, satellite imagery will eventually largely supplant aerial photography. Higher resolution airborne sensors will also continue to increase in application for special uses.

The FIA program has resolved to move completely to satellite based phase 1 inventory by 2003. This means FIA will need to produce a wall to wall coverage of at least forest vs. non-forest, and preferably forest by major forest type groups, and intervals of five to 10 years. To accomplish this, FIA plans to participate strongly in the Multi Resolution Land Characteristics consortium, pooling resources with other US partners to reduce costs and to work from a standardized product.

The Forest Service will also continue to conduct research and development into the use of other sensors including LIDAR, RADAR, and in the creative analysis of remotely sensed data.

## **MEXICO'S SITUATION**

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Remote sensing in Mexico is being done in several Federal institutions and some investigation centers basically with Landsat 5 and 7 some efforts are underway to work with image classification (supervised and unsupervised) INEGI, UNAM, PEMEX, IMTA, and Energy Ministry, Department of NAVY, to provide products for several federal needs like:

-  Soil type
-  Coastal water temperatures
-  Weather
-  Crop prediction
-  Mining
-  Ecological Ordering
-  Fire risk and heat spots

Some other government and investigative agencies work with visual interpretation like UNAM, SEMARNAT, PEMEX, SAGARPA, ENERGY MINISTRY, UNIVERSITY OF CHAPINGO, UNIVERSITY OF COLIMA, all these institutions rely on visual interpretation, also providing several products like:

-  Mapping in several scales
-  Geology
-  Land use and vegetation cover
-  Deforestation rates
-  Edafology

 Water well drillings

 Weather forecasts

Some efforts are done using high resolution imagery like SPOT, IKONOS, IRS, in panchromatic mode, and the most widely used software is ERDAS, PCI, IDRISI.

AVHRR, GOES and MODIS are widely used for weather and vegetation indexes by CONABIO and meteorological institutions.

Some State governments like Jalisco - Colima inventory and monitoring program for the assessment and sustainable management of ecosystem resources.

This initiative links remote sensing with field data from national, state, regional, and local surveys and monitors ongoing projects to produce geo-spatial assessments and management applications at multiple scales and resolution levels for the states of Jalisco and Colima. Because the program outputs are expected to be spatially continuous, information and assessments can be reported by watershed units, counties, or any other geopolitical/ecological boundary. Coordinated by the Consortium for Advancing the Monitoring of Ecosystem Sustainability in the Americas (CAMESA), and in partnership with CAMESA's federal partners, the program is designed to be a collaborative/cooperative effort building upon existing inventory and monitoring actions in North America. As a Learning Center for the Americas, the program provides opportunities for technology transfer and education, and most importantly, it will generate data and information to advance the understanding of ecosystem condition and resource sustainability at scales where policy and management decisions are most effectively made.

In Mexico, the program is funded by the state governments of Jalisco and Colima, through FIPRODEFO (Fideicomiso para la Administración del programa de Desarrollo Forestal del Estado de Jalisco) and the University of Colima. Other state (SEDER) and federal government agencies (CONAFOR, SEMARNAT, SAGARPA, INIFAP, CONABIO, INEGI, CONAGUA) are also participating and providing in-kind support. The program continues evolving into a multi-institutional effort where all partners and participants are benefiting from the synergy of working in partnership.

Chihuahua, Guanajuato, Puebla, Durango, Queretaro, Sinaloa are all working in remote sensing projects .