C | Appendix C: Applications of Remotely Sensed Data for Forestry[1]

Nearly one-third of the land area of the United States, some 737 million acres, is forested. The world's forests account for nearly two-thirds of global photosynthesis. Indeed, forests are complex, long-lived ecosystems that are critical to Earth's ecological well-being. Forests replenish the air, conserve the soil, and maintain its fertility, store water, and serve as a habitat for wildlife. Forest assets provide the necessary wood and fiber products that contribute to a nation's development. Moreover, the world's forests play a critical role in regulating the climate. Forests, therefore, are consequential to the economic, social, and environmental health of all nations.

The need to conserve the planet's forests, balanced against proper use of these resources for development, has increasingly raised concerns about their vitality. Threats to the forests do not rest within the boundaries of any one country; forest problems in one nation can impact the forest resources in another.[2] Today's industrial world has placed varying degrees of stress on both temperate and tropical forests. Be it the ravages of air pollution in the form of acid rain, the unconstrained cutting down of trees for timber, or the clearing of forests for agricultural pursuits—forests are

[1] Prepared by Leonard David, Space Data Resources & Information.

[2] H. Gyde Lund *How to Watch the Forests—IUFRO Guides for World Forest Monatoring*, USDA Forest Service, Washington, DC, 1992 ;see also *Photogrammetric Engineering & Remote Sensing*, Vol. LVIII, No. 8, August 1992. The entire issue is devoted to a national repro on photogrammetry, remote sensing, and geographic information systems in the United States.

considered by many to be under siege. Many believe the ecological consequences of forest loss will have global repercussions.

Satellite remote sensing provides one important technique for monitoring the status of trees and determining the role they play, not only on a local, regional and national level, but also on a global scale. Since the early 1970s civilian spacecraft have provided, in ever-increasing detail, knowledge about the world's vegetation cover—including forests.

The following two sections detail programs that focus on the monitoring of forest reserves. These programs are discussed in broad terms, but should provide the reader an appreciation of the utility of spaceborne remote sensing tools for overseeing the status of the world's forests.

FOREST INVENTORY

Forests on Maine's Remote Islands[3]

Thousands of islands dot the coastline of Maine, creating a challenging problem in inventorying and managing the state's coastal forests. Many of the over 3,000 islands are remote, reducing the number of onsitc inventories that can be conducted economically. As a result, past inventories could only approximate the size of Maine's coastal forests. For 100 percent coverage, aerial photography of the islands was considered too expensive and time-consuming. Additionally, many of the islands could not be reached year round by surveying aircraft.

State forestry managers purchased seven SPOT Imagc scenes to create up-to-date maps of the rich spruce forests and other forest lands along Maine entire coastline. The area covered by the images totaled 5,000,000 acres of marine and terrestrial habitaits.Making use of software developed by The Island Institute of Rockland, Maine, planners classified the 20-meter multispectral data gathered by SPOT into 11 land cover types. This information included old growth and younger spruce, hardwoods like maples and oak, other vegetative covers, wetlands, and waterways. The resolution gleaned from the SPOT satellite (one-tenth acre pixels) improved classification accuracy over previous surveys, particularly for smaller islands. Ground truth in accessible locations gave planners assurances they were able to distinguish tree species reliably using the satellite data, allowing them to estimate species acreages by tallying pixels in the computer.

Vegetation Covering in Bighorn National Forest, Wyoming and Montana[4]

The U.S. Forest Service has used Landsat thematic mapper (TM) data for mapping vegetation covering some 1.2 million acres of the Bighorn National Forest. Using July 1988 TM data purchased from EOSAT, Forest Service personnel mapped specific vegetation types. They merged digitized data from their inventory with the classification and computed acreage summaries of each vegetation class per area. The Landsat data and services cost about $100,000. The Forest Service estimates that an equivalent survey using traditional manual survey methods would have cost at least $500,000.

Vegetation Classification of Old Growth Forests in New Mexico[5]

The U.S. Forest Service's Nationwide Forestry Applications Program used Landsat TM data to produce a geographic information system (GIS) database containing vegetation characteristics of a portion of the Jemez Mountains in northern New

[3] SPOT FactSheets, 1989- 1991, "*Forest Inventory-SPOT Helps Maine Manage Its Forested Islands.*" SPOT Image Corp., Reston, VA.

[4] *Forest Service Remote Sensing Summary—1991*, compiled by Stan Bain. U.S. Department of Agriculture, Forest Engineering Staff. EM 7140-33, Washington, DC.

[5] Jessica Gonzales et. al., *Vegetation Classification and Old Growth Modeling in the Jemez Mountains*—Santa Fe National Forest New Mexico, Prepared for The Remote Sensing Steering Committee of the USDA Forest Service. Final Repro, May 1992.

Mexico. The study demonstrated that Landsat TM data can provide useful vegetation data for GIS, even when used in the widely varying vegetation conditions in New Mexico. The Forest Service produced relatively accurate crown cover and tree size classifications from Landsat TM data over large areas, although some vegetation characteristics were found to be easier to derive than others. For example, developing accurate estimates of tree size proved to be difficult because of the spatial resolution limitations of Landsat data and the variability of average tree size over the study area.

The study showed Landsat TM data have several desirable qualities as a data source for GIS. Each Landsat TM scene covers a large area (170 kilometers by 188 kilometers); therefore, information derived from Landsat data fills the gaps that may exist in other data bases. For instance, areas with little or no vegetation data, such as large tracts of private land or wilderness areas, may contain information that can significantly affect estimates of distribution and abundance of old growth trees.

Furthermore, the study reported that collection of Landsat TM data is repeatable and consistent through time, which provides for both current and future data needs. Not only can current old growth conditions be assessed, but changes in these conditions can also be detected using Landsat imagery acquired at a later date. Because the data are already in digital form, they provide accessible and flexible data sources for GIS.

I Conifer Forest Regeneration in the Western Cascade Mountains of Oregon[6]

The Environmental Remote Sensing Applications Laboratory at Oregon State University in Corvallis, Oregon has completed an analysis of conifer forest regeneration using Landsat TM data. Standard forestry practices call for harvested timber areas to be reforested. Once replanted, the reforested areas need continual monitoring to determine their progress.

The laboratory study compared spectral data from well-regenerated Douglas-fir stands with those from poorly regenerated conifer stands. Using the satellite data, poorly-regenerated stands were found to be spectrally distinct from well regenerated Douglas-fir stands after they reached an age of approximately 15 years. The researchers concluded that although TM satellite data were incapable of assessing regeneration in Douglas-fir plantations younger than 15 years, the success in identifying poorly regenerated stands should be high after this initial period.

TM satell ite data were also found to be useful in identifying stages of succession as a forest regenerates and useful for analyzing the condition of wildlife habitat. Herb and shrub stages provide important habitat and forage areas for some wildlife species. Identifying poorly regenerated stands can thus help in estimating wildlife and plant biodiversity.

Old Growth Forest Monitoring in the Pacific Northwest[7]

The U.S. Forest service has been working with Pacific Meridian Resources of Emery vine, California, to assess a region of forest resources in the Pacific Northwest that has been the site of disputes over environmental, economic, and recreational uses of the forest.

Fourteen layers of GIS data derived from satellite imagery and other sources covering more than 20 million acres of forestland in Washington and Oregon, have been entered into a GIS database. This permits forest managers quick and accurate access to information that should prove useful in resolving management and policy disputes in the area. The GIS layers include: slope of areas, eleva-

[6] Maria Fiorella, and William Ripple. "Analysis of Conifer Forest Regeneration Using Landsat Thematic Mapper Data," *Photogrammetric Engineering & Remote Sensing*, September 1993, pp. 1383-1388.

[7] Russell G. Conga ton, Kass Green, and John Teply. *'Mapping Old Growth Forests on National Forest and Park Lands in the Pacific Northwest from Remotely Sensed Data," *Photogrammetric Engineering & Remote Sensing,* April 1993, pp. 529-535.

(ions, hydrology, current vegetation type, suitable spotted owl habitat, suitable lands for timber production, habitat conservation areas, forest boundaries, and historical distribution of vegetation and old growth.

The study relied primarily on 12 Landsat TM data that had been geocoded[8] and corrected for the effects of terrain. Study managers also purchased SPOT panchromatic imagery (l O-meter resolution) for use on the Olympic Peninsula. The study demonstrated that a powerful marriage of satellite imagery, GIS, and statistical software is now possible. Fully integrating these disparate capabilities allows researchers to analyze relationships between spectral variation on the image and land-cover variation on the ground.

Because today computers are far more powerful than in prior years, image classifications can be completed in mere hours rather than weeks. This merging of technologies into an integrated whole permits their use by numerous disciplines,—foresters, geographers, and ecologists, among others. Finally, the Oregon work illustrates that the spatial resolution of SPOT imagery and the spectral and spatial resolution of Landsat TM data are high] y desirable compared to earlier multispectral scanner (MSS) data, and far more useful than the single layer of data that results from traditional aerial mapping.

The Forest Service has concluded it can use the resulting information to address many issues such as:

- fragmentation of old growth and its implications for wildlife habitats;
- developing initial estimates of the biological diversity of forest vegetation;
- and detailing how much old growth acreage is presently in National Parks and wilderness areas.

Perhaps the most important benefit of packaging satellite imagery, GIS, and appropriate software together lies in the ability to model the implications of varying management decisions regarding forests *before they are put into effect.*

AVHRR Sensors in Forestry Studies[9]

Dedicated Earth remote sensing satellite systems are not the only spacecraft that can provide useful data for forest mapping procedures. A forest cover map for the United States has been created using Advanced Very High Resolution Radiometer (AVHRR) data collected from the sensor aboard the National Oceanic and Atmospheric Administration's NOAA- 11, an afternoon crossing satellite in the Polar-orbiting Operational Environmental Satellite program.

AVHRR data have the advantage that they are collected daily. The satellite passes over the continental United States in early afternoon, collecting five channels of data, ranging from the visible and reflected infrared to the emitted (thermal) infrared portions of the electromagnetic spectrum. They have the disadvantage that AVHRR imagery yields a maximum of only 1.1 kilometer geospatial resolution.

The AVHRR data used in this study were compiled by the Earth Resources Observation Satellite (EROS) Data Center in Sioux Falls, South Dakota, which developed the "normalized difference vegetation index" (NDVI). The NDVI is effective for vegetation classification because it is highly correlated to the amount of vegetation (chlorophyll and leaf reflectance) present and it is relativel y independent of solar and sensor scan angles.

The first phase of the mapping project produced data sets from different seasons: two spring, one summer, and two fall. Each composite covers the lower 48 states of the continental United

[8] I.e., registered to ground control points in such a way that each pixel on the image corresponds to a known geographic location.

[9] Zhiliang Shu, and David L. Evans. "Large Scale Forest Land Mapping with AVHRR Data—A Support Project for the 1993 RPA Update," presented at the Fourth Biennial USDA Forest Service Remote Sensing Application Conference, Orlando, Florida, April 6- I(J, 1992. Also, "Summary of Forest Type Mapping procedures For RPA Purposes at SO-FIA." Provided by Roy Beltz of U.S. Forest Service, Southern Forest Experimental Station, Starkville, MS.

States. A second phase of the mapping project began in 1993 to support the U.S. Forest Service's Resources Planning Act (RPA) update.

Use of AVHRR data---combined with Landsat TM data—is expected to augment continental and global resource surveys and climatological models. The AVHRR images have already been used to derive forest-density values and forest types, particularly in the Midsouth. The AVHRR maps are expected to provide unprecedented detail on forest cover distributions of the United States.

Utility of GIS and GPS for Forest Management[10]

Geographic information system (GIS) technologies and Global Positioning System (GPS) satellites have enhanced the utility of satellite remote sensing for forestry management. For instance, GPS and SPOT digital imagery was used in a GIS database to classify 16 vegetation types within the 69,000 acre Everglades National Park, near Homestead, Florida. National Park Service managers wanted to understand how plant cover in the slash pine forests of the Everglades affects tire management practices.[11]

GPS was used to geocode the SPOT imagery, as well as navigate to sites within the study area for ground-truthing the vegetation classifications. The availability of GPS signals made ground-truthing 30 randomly chosen locations hundreds of meters apart much easier, as many of the sites were kilometers from the nearest road and hidden by thick underbrush.

Using a GPS data receiver, researchers verified the accuracy of both the standard U.S. Geological Survey quad map of selected areas and the SPOT Image geocoded image. They used GPS readings of 16 identifiable features within the Everglades, such as surveying benchmarks, roads, and plant community boundaries. At the selected sites, field analysts recorded pertinent plant community information for comparison with the computerized vegetation classification yielded by satellite imagery. The merger of satellite imagery and GPS proved invaluable in creating and updating GIS databases quickly and accurately. Doing so saved time and money compared to the use of traditional methods such as field surveying and aerial photography.

In the GIS arena, the U.S. Forest service has made use of SPOT 10-meter panchromatic imagery coupled to a GIS database to update forest vegetation maps. The Forest Service requires these updates to show harvest activities and areas affected by fires, as well as the location of conifer plantations. One area in need of updating was primarily confined to Six Rivers National Forest and the western portions of Klamath and Trinity National Forests.[12] SpOT imagery in the form of SPOT QuadMaps was selected to meet the 1:24,000 scale requirement and was chosen over aerial photography because the necessary imagery could be obtained in a timely manner and within budget for these large forested areas.

The images were incorporated into a database derived primarily from 1980 aerial photography. The newer data were used to create a "change layer" GIS database indicating areas harvested, those touched by fire, locations of new plantings compared to old growth forests, and roads accessing new clearcut locales.

This updated GIS database assisted the U.S. Forest Service in managing forest lands, planning timber sales, inventorying forests, and selecting suitable habitats for wildlife. Furthermore, this

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10 Paul V. Bolstad, "GPS Basics: Forestry Applications," 7-he *Compiler*, A Forest Resources Systems Institute Publication, vol. 11, No. 3, Fall 1993, pp. 4-8.

11 "SPOT and GPS—Space Technologies for Down-to-Earth Applications, " SPOT Image Cm-p., Reston, VA, 1991.

12 .. Map and GIS Updating for the U.S. Forest Service—-SPOT Shows a New View of Old Growth in California's Douglas Fir Region," SPOT Image Cm-p., Reston, VA, 1990

GIS database can now be updated more cost-effectively.

The Forest Service has provided yet another demonstration of remote sensing and GIS use in the Tongass National Forest in Alaska. Beginning in 1984, the Forest Service created GIS databases by digitizing field maps and aerial photographs taken in the early 1980s to help establish a forest management plan. Later. to update and enhance the accuracy of the maps, it used geocoded, ortho-corrected SPOT imagery in 15 minute x 20 minute quadrangles. Using the satellite and GIS data, the Forest Service found almost 30 percent of the land, covering over 2.5 million acres of forest, had been previously miscoded in terms of clearcut size, unmapped clearcuts, and forests mapped as clearcuts. The errors had little effect on the overall statistics, because they tended to cancel each other, but these data flaws were not known prior to use of the satellite data.

Combining satellite imagery and a GIS database delivered ready-to-use information for one-seventh the cost and in about one-tenth the time required for aerial photo prints. Previously. the U.S. Forest Service updated the Tongass National Forest site every 10 years, due to the expense involved and necessary time needed for the update. using satellite and GIS data sets, The forest Service now plans to update their databases of the area every three years, to better manage this forest asset.

FOREST PROTECTION

Gypsy Moth Damage in the Shenandoah

SPOT imagery of Shenandoah, Virginia was acquired by the U.S. Forest Service for four consecutive years, starting in 1987. The images were collected as part of the Forest Service's 13.5 million acre pest management project. The focus of the project was to monitor defoliation by gypsy moths and assess the effectiveness of eradication techniques in the national forests of Virginia and West Virginia. The project defined a procedure that delineates forest susceptible to gypsy moth attack. The approach taken in the project also involved the "masking out" of nonsusceptible forests and areas with clouds or cloud shadows for a given year. A vegetation index was calculated for the susceptible forests with a range of index values describing each defoliation class. Spatially processing and "clumping" the pixel data allowed restoration of the data, facilitating GIS coverage.

Use of satellite imagery for the project replaced field and aerial photographic surveys. These techniques were considered too inefficient, inaccurate, and time consuming to be effective in tracking the gypsy moth—a fast-acting pest. A single SPOT scene allowed investigators to identify and map defoliation up to 25 times more quickly than aerial photography, according to SPOT officials.

On the other hand, the U.S. Forest Service notes that the cost of geocoded terrain-corrected SPOT imagery at $2.60 per square mile is somewhat higher than the average project cost for NASA photography at $2.00 per square mile, although still less than the cost of conventional photography. Using SPOT is now considered a viable technique for gathering relatively detailed defoliation information for areas of up to 10,000 square miles. By comparing year-to-year SPOT images, the effects of a topographical y controlled appl ication of pesticide to control the gypsy moth population could be assessed.

1 Deforestation Monitoring

Portions of Brazil tropical forests are being eradicated due to population growth. The Amazon Basin, in particular, has been under stress due to the encroachment of people. To monitor the growth of deforestation patterns in the area, a combination of satellite data sets have proven useful.

As an example, the coarse resolution of AVHRR from NOAA polar-orbiting meteorological satellites can spot fires and smoke in the rain

[13] "Tongass National Forest—SPOT Fills the Information Void," SPOT Image Corp., Reston, VA., 1991.

forest. AVHRR images cover a land area of approximately 260,000 square kilometers. In 1993, NASA and the seven Central American nations began a program to preserve and protect that region's rain forest by expanding use of AVHRR satellite data by Central American scientists.

For a more exacting view of deforestation patterns, Landsat and SPOT satellites are used. In the case of SPOT, the spacecraft's 20-meter resolution multispectral imagery can assess exact levels of deforestation. A typical SPOT image of a deforested area is 60 x 60 kilometers. SPOT data is of such clarity as to delineate vegetated and non-vegetated parcels of land--data useful in the existing AVHRR classification scheme. Use of SPOT can denote individual clearings that rarely approach the size of a single AVHRR 1 -kilometer pixel. Typical clearings range only from 10 to 20 percent of this size.

The use of Landsat imagery has proven effective in the Pan Amazonia Project. Institutions of several Amazon countries, including Bolivia, Colombia, Ecuador, Peru, Venezuela, and the Guianas have coordinated efforts to gather near wall-to-wall coverage of the countries participating.

U.S. Landsat imagery was used in the survey taken in two time periods: from 1984 to 1987 and from 1988 to 1991. The project was directed by the National Institute for Space Research (NIPE), of the Secretariat of Science and Technology of the Presidency of the Republic of Brazil.

The focus of the project was to determine the extent of gross deforestation in the sequence of Landsat surveys. This data was then used to estimate the annual rate of gross deforestation in Brazilian Amazonia between consecutive surveys.

A survey of the entire Legal Amazonia—which covers 5 million square kilometers-consisted of hundreds of black-and-white images and color composites taken by Landsat multispectral scanner and thematic mapper sensors. Both dense tropical forest and thick savannah were surveyed.

Data presented in 1992 showed that the peak of deforestation in the region in the second half of the 1980s was much less severe than higher estimates projected by some groups, such as the United Nations Forest Resource Assessment, which indicated more than 80,000 square kilometers per year were lost to deforestation. Using the Landsat satell ite survey, estimates of the mean rate of deforestation were lowered to 21,500 square kilometers.

The results of the Brazilian Amazonia work was corroborated by independent analysis completed at the University of New Hampshire in Durham. That assessment also made use of Landsat thematic mapper data and was presented in May 1992 to the World Forest Watch, a conference held in Sao Jose dos Campos, Brazil.

Integrating Forest Monitoring Surveys

The Tropical Ecosystem Environment Observations by Satellites (TREES) project is considered by many to offer the best evaluation of satellite remote sensing of forestry assets. TREES is jointly carried out by the European Communities' Joint Research Centre in Ispra, Italy and the European Space Agency (ESA). A first phase of TREES was concluded in 1993.

The objectives of the TREES project are two-fold:

1. to provide quantitative space data sets and information on the spatial distribution and temporal evolution of the tropical ecosystems (e.g., rate of change in forest cover, forest cover, biomass burning) for an improved scientific assessment of their impact on global climate change issues, such as the greenhouse effect; and
2. to establish an integrated satellite observational program for a long-term, continuous and operational monitoring of forest cover and rate of deforestation in the tropical regions to provide for the implementation of various European Communities policies.

Under assessment in the TREES endeavor is the value of ESA's ERS- 1 Synthetic Aperture Radar to provide data useful in monitoring tropical forest vegetation. A test image was displayed for the first time at the May 1992 World Forest Watch, making use of ERS- 1's radar to show deforestation in the Amazonian rain forest. The test image clearly shows rectangular patches of destroyed forest extending over areas as large as 20 square kilometers.

TREES research has concentrated on the use of low resolution AVHRR data generated by the polar-orbiting NOAA satellites of the Tires series. This AVHRR data provides 1 -kilometer resolution, as well as 4-kilometer resolution for global area coverage, to assess changes in tropical forest canopy.

The first phase of the TREES project involved use of NOAA AVHRR data at 1-kilometer resolution to assemble "wall-to-wall" coverage of Southeast Asia. This tests the feasibility of analyzing the low resolution multi spectral data set for forested areas where both evergreen and seasonal formations are to be found. A similar assessment of West Africa was completed in 1990. The results of these studies are to be integrated into a Tropical Forest Information System.

AVHRR image analysis for the TREES effort is grouped into several categories that permit a spectral study of differences and contrasts between forest features; a spatial assessment of textural forest features, such as patterns; temporal discriminators, such as seasonality: and indicators of deforestation, such as fires and roads.

The analysis of 1 -kilometer resolution multispectral AVHRR data will be later compared with 4-kilometer resolution AVHRR data, as well as high resolution images produced by Landsat and SPOT spacecraft. This work will be undertaken by scientists at the European Communities Joint Research Centre in Ispra.

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