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Integrating Satellite Imagery and GIS into Natural Resource Management

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Abstract

This paper demonstrates the utility of geographic information systems (GIS) and image processing as information tools in forest management. The application of GIS to address management issues of old-growth forest in the Pacific Northwest is used to assess the utility of GIS. Improvements in technology are considered, including improved resolution of the data from earth resources satellites. Computer hardware is becoming more cost-effective, and significant increases in operating speeds make interactive data processing much more responsive to management needs. Software is becoming more sophisticated and much more integrated so that vector and raster data sets are more easily used together. All of these improvements have made it possible to meet map accuracy standards and to identify sources and types of error occurring in thematic classification. This leads to three main types of use: (1) the combination of image data and GIS information to produce image maps, (2) the use of images from aircraft or satellites to update GIS information, and (3) the use of GIS data layers as ancillary information in image classification to increase accuracy and reliability. A variety of specific applications—including mapping and recording landscape characteristics using digital elevation models, updating maps, and identifying changes—is discussed. The present demand for these applications is seen as a small fraction of the future requirement for GIS information about land use and land management. Data capture and the generation of global data sets and management techniques are identified as issues of growing importance. These activities generate a growing need for training and support of GIS if the power of the technology is to be applied effectively to natural resources issues.

INTRODUCTION

As the world's population has grown, so have demands on forests and rangelands to provide multiple resources for diverse clientele groups. Rapid land-cover and land-use decisions are often made in the courtroom rather than on the ground. As a result, the management of wildlands has become increasingly complex, requiring sophisticated information-management tools and timely, detailed data.

This paper demonstrates the utility of geographic information systems (GIS) and image processing as information tools in forest management. The paper first discusses changes in the demand for information concerning wildland resources that invite the spatial analysis capabilities of GIS. Next, it presents advances in technology and education that have fostered the integrated use of GIS and image processing.

The final portion of the paper discusses opportunities for integrating GIS with image processing to assist in resource management and planning. The paper concludes with a discussion of the status of GIS and remote sensing.

WHY GIS?

Over the last ten years, GIS has emerged as an extremely effective tool for prioritizing and analyzing resource-management alternatives. Geographic information systems provide a link between spatial data (x, y coordinates on maps) and attributes information that describes the spatial data (see Congalton and Green [1992] for a detailed explanation of the concepts of GIS). Because conflicts over land use are by definition spatial, a GIS provides a powerful tool

for defining and focusing discussion of the advantages and disadvantages of alternative land-use allocations.

The controversy over old-growth management in the Pacific Northwest is a recent example of the use of GIS in forest management. In an effort to gain badly needed information regarding old-growth forestlands, the Forest Service built a GIS database for the national forests of Oregon and Washington. Not only did the database provide them with the ability to estimate and display locations of remaining areas of old growth but the GIS data set allows planners and decision-makers to answer questions such as

- What is the average acreage of individual oldgrowth stands and how continuous or fragmented are they?
- 2. What tree species are found in existing oldgrowth stands? Which stands are ecologically diverse? Which are homogeneous?
- 3. How does a change in the definition of old growth affect estimates of the extent and amount?

The flexible design of the GIS gave analysts the ability to simulate the results of changes in management and policy before they were put into effect (Teply and Green 1991).

WHY GIS AND IMAGERY?

Every GIS has four components:

- 1. Computer software to enter, store, manipulate, analyze, and display the spatial data and their associated attributes
- 2. Computer hardware (e.g., plotters, central processing units, digitizing boards) needed to run the software
- 3. Data used as inputs for the analysis of alternative management decisions
- 4. People to operate the system

Increasing conflicts over land use have created a demand for immediate access to accurate information about land status and the spatial interrelationships of forest resources. While the costs of GIS software and hardware have dramatically decreased over the last decade, GIS data is still the most expensive component of a GIS, often comprising 60 to

90 percent of the total system cost. The need for inexpensive, accurate, and timely GIS data has created a collateral demand for digital imagery.

Historical failures associated with the use of digital imagery as a base for forestland mapping are abundant and well known (Meyer and Werth 1990). However, recent technological innovations have dramatically altered the methods available for forest mapping (Teply and Green 1991, Congalton et al. 1993). The integration of GIS and image processing into natural resources management directly results from five recent technological and organizational advances.

First, the imagery has improved. The minimum unit of area (pixel) sensed by the satellites has decreased in size, allowing for the derivation of much greater spatial detail. The imagery initially used to map forestlands, Landsat Multispectral Scanner (MSS) data, has a spatial resolution of only 80 meters. Satellite imagery presently available and fully integrated into forest mapping includes Landsat Thematic Mapper (TM) data (with a spatial resolution of 30 meters) and both multispectral and black and white SPOT data (with spatial resolution of 20 and 10 meters, respectively). In addition the types of electromagnetic energy sensed by the satellites (analogous to numbers of colors "seen") have also increased from four spectral bands in MSS data to seven bands (three visible and four infrared) in Landsat TM data. Numerous other sources of digital imagery are being investigated and integrated into forest mapping, including scanned aerial photography, airborne scanners, video, and radar (Lachowski et al. 1992).

Second, computer hardware has become more powerful and less expensive. With the advent of UNIX workstations and the increasing power of personal computers, processes that used to take two weeks to finish can now be completed in two hours, creating the ability for interactive processing and evaluation of image classification and increasing the accuracy at each step. In addition the decrease in the cost of peripherals, such as scanners and electrostatic plotters, allows the input and output of completely integrated image and GIS data.

Third, GIS and image-processing software has become fully integrated and more sophisticated. Only in the last four years has it become possible to reliably register satellite imagery and to link that registered image both visually and statistically in a computer software system. The integration makes possible the analysis of relationships between spatial location, spectral variation in the image, and land-cover variation on the ground.

Fourth, procedures for the assessment of map accuracy have been fully implemented and accepted as critical elements in the production of any GIS layer derived from remotely sensed data (Story and

Congalton 1986, Congalton and Green 1991). Past mapping efforts, including both photo interpretation and image processing, left map accuracy unassessed and unknown. The correctness of map data was usually judged by qualitative impressions that followed initial use of the map. The introduction of accuracy assessment procedures has resulted in the development of unbiased, quantitative measures of map accuracy. The measures make it possible (1) to set accuracy standards that must be met prior to the adoption of a GIS data layer and (2) to identify possible sources and types of confusion occurring in the layer.

Finally, training in GIS and image processing is now offered in mainstream university courses, resulting in professionals who understand computer concepts and the relationships between variation in vegetation and variation in spectral response. The people producing maps are now foresters, ecologists, wildlife biologists, etc., who have mastered not only their specific resource field but also the concepts of GIS and image processing.

The result of these advancements is the integration of image processing with GIS layers for resource mapping. Accompanying the integration is a decrease in the cost to produce traditional maps required for forest management, a decrease in the amount of time required to produce the GIS layers, an increase in the detail of information linked to the layers, and an increase in the variety of maps and outputs available from the GIS database.

OPPORTUNITIES FOR INTEGRATING GIS WITH IMAGERY FOR FOREST AND RANGE RESOURCE MANAGEMENT

Imagery can be integrated with GIS for forest management in three basic ways:

- 1. The imagery and GIS layers can be combined to produce image maps.
- 2. The imagery can be used to produce and update GIS coverages.
- 3. GIS layers can be used as ancillary information to increase the accuracy of image classification.

IMAGE MAPS

The simplest and perhaps most effective way to integrate GIS layers and imagery is in the production of image maps. In this technique, imagery is combined with map information to create a photo-like

product that displays both imagery and map information. Image sources usually include satellite imagery or digital aerial photography. Image maps increase the utility of a map because the map information displayed includes an actual representation of the landscape.

Image maps greatly increase the amount of information available to field personnel by combining two key field tools, i.e., maps and photography. They can also (1) reduce the amount of time it takes to locate specific sites in the field; (2) increase the accuracy of delineation of areas that have changed since the image or that are anticipated to change (e.g., harvest units); and (3) allow a finer visualization of the distribution of land-cover variation across a mapped polygon. The increased information of an image map is particularly important to land managers interested in assessing or altering a specific area (e.g., a pocket of pest mortality or a group of snags) that is smaller than the minimum mapping unit. Image maps are also effective tools for conveying information in public meetings where a picture is literally worth a thousand words.

The key to image maps is the complete and accurate co-registration of the imagery to the GIS map layer. In the past, image registration was usually both difficult and inaccurate, often resulting in degradation of the data. New software developments (such as ERDAS's Ortho Digital Module) integrate photogrammetric techniques into image registration by performing an orthogonal rectification that incorporates terrain correction. The software advances have brought image maps into the hands of the forest or ecosystem manager.

GIS COVERAGES

Digital imagery can be effective primary information for (1) the production of GIS coverages of landscape characteristics, such as vegetation, land use, roads, and harvest units; (2) the creation of digital elevation models; and (3) the change in detection and updating of existing GIS coverages.

Landscape Characteristics

Aerial photography and satellite imagery are useful for the characterization of landscapes because variation in the photo or satellite image is usually highly correlated with variation in the landscape. Aerial photography has long been used to delineate and classify forest vegetation and land-use type. Turning classified and delineated photography into a GIS layer requires the transfer of the classification to a planimetric base, followed by the entering of the information into the computer by either digitizing or scanning. The four steps of classification, delinea-

tion, transfer, and data entry can be extremely time intensive.

Teply and Green (1991), Bernath et al. (1992), Gonzales et al. (1992), Miller et al. (1992), and others have shown that digital processing of satellite imagery, combined with field visits and the use of aerial photography as ancillary data, can accurately produce both detailed and broad GIS coverages of forest and range vegetation type. Four advantages of using satellite imagery versus aerial photography as the primary information base exist:

- A substantial reduction in the time and cost to produce the GIS layers. For example, the abovementioned project to map old growth in the Pacific Northwest was completed in fourteen months, an effort that would have required several years using traditional photo interpretation techniques.
- 2. The production of a GIS layer much richer than that resulting from photo interpretation because the GIS layer can contain both traditional vegetation polygon labels and information about each spatial unit sensed by the satellite sensor (i.e., pixel).
- 3. The opportunity to perform interownership analyses, such as cumulative impacts, because the economies of scale in digital image processing are great, making it relatively inexpensive to map large expanses of land. Thus, mapping an entire region is feasible.
- 4. The fast and inexpensive updating of GIS coverages by directly comparing the satellite images used to create the coverages with those taken at a later date.

In addition to vegetation and land-use mapping, several national forests and industrial concerns are presently using SPOT 10-meter panchromatic data to map and create GIS coverages of roads and harvest units. Digital orthophotography can be used for the same purpose. Using this technique, roads or harvest units are digitized by the operator directly on the computer screen through "heads up" digitizing.

Satellite imagery is not suitable for every project. Those applications requiring a scale larger than 1:12,000, covering an area 5000 acres or smaller or requiring identification of resources that are smaller than the spatial resolution of the imagery will be better accomplished with large-scale aerial photography. Recent advances in orthocorrection software, however, make it possible to use scanned digital aerial photography in the production of GIS coverages.

Finally, GIS coverages derived from remotely sensed data (including both satellite imagery and aerial photography) will never supply or replace the detailed resource information that can only be captured through field investigations. A map of GIS coverage is a stratification of the variation in landscape characteristics. It can be used to model existing, past, and future conditions, to analyze possible management activities, and to allocate field samples; but it will never replace the field information required for site-specific management. Once site-specific information is gathered, however, the data can be entered into a GIS as an attribute of the site and thereby retained indefinitely for future reference.

DIGITAL ELEVATION MODELS

Recent software developments have made it possible to use either stereo satellite imagery or stereo digital photographs to generate digital elevation models (DEMs). Digital elevation models are digital grids of points of known latitude, longitude, and elevation. The grids can be used to generate GIS coverages of topographic conditions such as slope. elevation, and aspect. While digital elevation models at a 1:250,000 scale are available for the entire United States from USGS, large scale DEMs are often difficult and expensive to obtain using traditional photogrammetric techniques. The new software greatly facilitates the creation of high-resolution DEMs for both small and large projects. Threedimensional perspectives can be created from integrating digital elevation models with GIS coverages, satellite imagery, or digital orthophotos.

CHANGE DETECTION AND UPDATING

Change detection, the comparison of differences in the landscape over time, is easily and inexpensively accomplished through the overlay of two images that vary only by their dates. Image-to-image change detection is also superior to map-to-map comparisons because two maps of different dates often differ more because of differences in mapping techniques and/or classification systems than because of landscape changes.

However, image-to-image comparison requires the isolation and control of all factors causing differences over time. Thus, atmospheric and seasonal variation must be accounted for and the images to be compared must be precisely registered to one another.

The cost and time savings realized by image-to-image change detection also promote rapid updating of GIS databases to reflect changes in resource condition. Use of image-to-image comparisons to assess change and to update GIS coverages is growing. Lachowski et al. (1992) present an example of the use of image-to-image change detection to monitor forest-plan implementation. Similar techniques are also

being adopted by regulatory agencies to assess the cumulative impacts of forest-management activities.

GIS COVERAGES AS ANCILLARY DATA

Classification of aerial photography for the creation of forest vegetation maps requires that the photo interpreter understand the relationship between forest vegetation type and the various colors, tones, and textures of the photo. The photo interpreter must also be knowledgeable of the location of each photo and the relationship of vegetation type to location, aspect, slope, and elevation. Finally, the photo interpreter will use all reliable existing information, including vegetation maps, inventory plots, stand examinations, and harvest and fire history to aid photo classification.

A satellite image contains qualities of color, tone, and texture similar to those found in aerial photography. Like photo interpreters, image processors also consider location when classifying an image by using GIS layers as ancillary data to increase the accuracy of information derived from satellite imagery. Thus, existing GIS layers are often used as aids in the production of new GIS layers.

GIS layers can be used as ancillary information in image classification in three basic ways:

- 1. As aids in locating areas of interest on the imagery. One of the most time-consuming tasks in image processing is determining precise locations on the imagery. GIS layers of photo flight lines, streams, existing vegetation classes, and/or roads overlaid on the image either on the computer screen or in maps provide direct links between locational or informational attributes and the image.
- 2. As coverages for stratifying the image prior to classification to control spectral variation. For example, GIS coverages of aspect and elevation can be used to cut the image into areas of broad ecological homogeneity (Green 1990).
- 3. As layers in post-classification modeling for quality control. Classification of conifer species is as difficult in image processing as it is in photo interpretation. Conifer species are often spectrally confused. However, because conifer species distribution is highly correlated with aspect and elevation, GIS coverages of aspect and elevation can be used to check for unallowable species occurrences. Classifications can also be directly compared to existing GIS coverages, and differences can be further investigated (Golden and Lackey 1992).

CONCLUSIONS

- 1. The present demand for integrating GIS with image processing into forest management is only a small fraction of what the demand will be in future years. Increasing conflicts over land use and land management will accelerate the demand for fast, accurate, and inexpensive information about the landscape.
- Currently, users tap only a minimal amount of existing information in the imagery and in the relationships between GIS layers. Perhaps the largest gap in GIS is the relatively small amount of analysis performed. GIS has evolved through two steps and is presently entering a third. The first step required the acquisition of GIS hardware and software. Organizations committed large funds to the formidable tasks of acquiring a GIS system and training personnel to use the system. The second step involves capturing data into the GIS. Most of this paper has concentrated on new methods for capturing GIS data and for integrating the data into resource management. This step is not entirely complete, but universal data sets are becoming available, at least in the United States. The third step is the analysis of relationships in GIS data layers to help extract and identify some of the complex interrelationships that exist within forest and range landscapes. The third step will enable resource managers to test management assumptions through sensitivity analysis.
- 3. Increased training of personnel is critical to the application of these powerful information tools to resource-management problems. Only with competent analysis and capable managers can the benefits of the high-investment costs in GIS hardware, software, and data be fully realized.

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