

Spatial Imagery and GIS

Integrated data for natural resource management



By Kass Green

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

This article presents ways in which GIS and image processing can be integrated to assist resource management and planning. Effective integration of these tools can decrease the costs of gathering resource information, reduce the time required to capture the information, and increase the detail of the information.

Why GIS and Imagery?

Over the last 10 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 attribute information that describes the spatial data (Congalton and Green 1992). Because conflicts over land use are by definition spatial, GIS provides a powerful tool for defining and focusing discussion of the advantages and disadvantages of alternative land use allocations. The flexible design of a GIS gives analysts the ability to simulate the impact of changes in management and policy before they are put into effect.

The controversy over old-growth management in the Pacific Northwest provides a recent example of the use of GIS in forest management. In an effort to gain badly needed information regarding old-growth forestlands, the USDA Forest Service built a GIS database for the national forests of Oregon and Washington. Not only did it provide the ability to estimate and display locations of remaining areas of old-growth, the GIS data set allowed planners and decisionmakers to answer specific questions: What is the average acreage of individual old-growth stands, and how continuous or fragmented are they? What tree species are found in existing old-growth stands? Which stands are ecologically diverse? Which are homogeneous? How does a change in the definition of old-growth affect estimates of the extent and amount (Teply and Green 1991)?

Such 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 GIS software and hardware costs have dramatically decreased over the last decade, GIS data is still the most expensive component of a GIS, often comprising 60%–90% of the total system cost. The need for inexpensive, accurate, and timely GIS data has created a collateral demand for digital imagery.

Recent Improvements

Historical failures associated with the use of digital imagery as a base for forestland mapping are abundant and well known (Meyer and Werth 1990). How-

ever, recent technological innovations have dramatically altered the methods of forest type mapping (Teply and Green 1991; Congalton et al., in press). The ability to integrate GIS and image processing for natural resource management is a direct result of five 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 much greater spatial detail. Landsat Multispectral Scanner (MSS) data has a spatial resolution of only 80 meters. Present satellite imagery integrated into forest mapping includes Landsat Thematic Mapper (TM) data with a resolution of 30 meters, and both multispectral (20 meters) and black-and-white (10 meters) SPOT data. In addition, the types of electromagnetic energy sensed by the satellites (analogous to numbers of colors "seen") have 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 integrated into forest mapping including aerial photography, airborne scanners, video, and radar (Lachowski et al., in press).

Second, computer hardware has become more powerful and less expensive. Processes that once took two weeks can now be completed in two hours. This allows interactive processing and evaluation of image classification, increasing accuracy at each step. In addition, the decreased cost of peripherals, such as scanners and electrostatic plotters, allows input and output of completely integrated

image and GIS data.

Third, GIS and image processing software have become fully integrated and more sophisticated. Only in the last four years has it become possible to register satellite imagery reliably, and to link that registered image visually and statistically in a software system. This makes it possible to analyze relationships among spatial location, the image's spectral variation, and land cover variation on the ground.

Fourth, procedures to assess map accuracy have been fully accepted as critical elements in the production of any GIS layer from remotely sensed data (Story and Congalton 1986, Congalton and Green 1991). In the past, accuracy of maps from both aerial photography and imagery was unassessed and unknown: map data was usually judged by qualitative impressions. New assessment procedures have allowed the development of unbiased, quantitative measures for map accuracy. It is now possible to set mandatory accuracy standards for a GIS data layer, and to identify possible sources and types of confusion occurring in the layer.

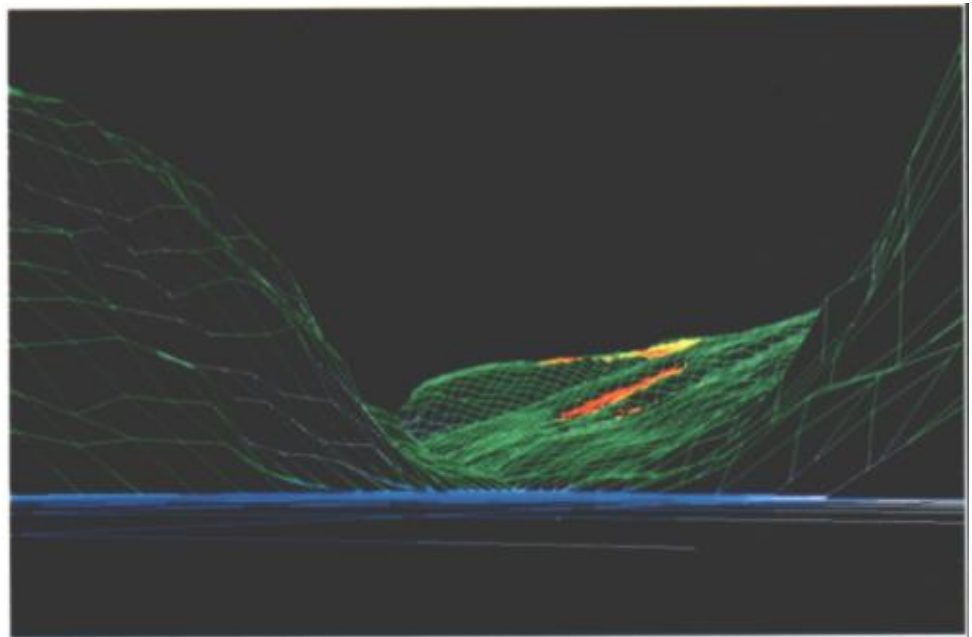
Finally, university courses offer training in GIS and image processing. The people producing maps are now foresters, ecologists, or wildlife biologists who have mastered not only their specific resource field but also the concepts of GIS and image processing.

All these advancements have increased our ability to integrate image processing with GIS layers for resource mapping; decreased the cost of traditional forest management maps; lowered the time needed to produce GIS layers; expanded the amount of detail linked to the layers; and increased map variety and output available from the GIS database.

Imagery can be integrated with GIS for forest management in three basic ways: the imagery and GIS layers can be combined to produce image maps; the imagery can be used to produce and update GIS coverages; and 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 to produce image maps—photo-



GIS can be used to determine the visual impact of timber harvesting. This perspective rendering and view from the Trans-Canada Highway in British Columbia, using the PAMAP GIS[®] Topographer, shows a visible clearcut on the ridge (center, orange). Data courtesy of BC Ministry of Forests/Ministry of Environment, Lands, and Parks.

like products that display both imagery and map information. Image sources usually include satellite imagery or digital aerial photography. Image maps increase the usefulness of a map because they include an actual representation of the landscape by combining two key field tools—maps and photography.

The key to image maps is complete and accurate coregistration of the imagery to the GIS map layer. Image registration used to be difficult and inaccurate, but new software (such as ERDAS's Ortho Digital Module) can perform an or-

thogonal rectification that incorporates terrain correction.

Image maps can reduce the time needed to locate specific sites in the field; increase delineation accuracy for areas that have changed or are anticipated to change (e.g., harvest units); and allow finer visualization of land cover variation across a mapped polygon. The greater amount of information in an image map is particularly important to land managers assessing or altering a specific area (e.g., a pocket of pest mortality or a group of snags) that is smaller than the mini-

mum mapping unit. Image maps are also effective tools in public meetings, where a picture is literally worth a thousand words.

GIS Coverages

Digital imagery provides effective information for producing GIS coverages of landscape characteristics such as vegetation, land use, roads, and harvest units; creating digital elevation models; and updating existing GIS coverages (including change detection).

Landscape characteristics. Aerial photography and satellite imagery are useful in characterizing landscapes because variation in the 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. To turn it into a GIS layer, however, this information must be transferred to a planimetric base and entered in the computer. The four steps of classification, delineation, 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 aerial photographs as ancillary data, can accurately produce both detailed and broad GIS coverage of forest and range vegetation type. Using satellite imagery as the primary information base has four advantages:

—Substantially less time and cost is needed to produce the GIS layers. For example, the project to map old-growth in the Pacific Northwest was completed in 14 months; traditional photointerpretation techniques would have required several years.

—A much “richer” GIS layer is produced because it can contain both traditional vegetation polygon labels and information about each spatial unit (i.e., pixel) from the satellite sensor. *Figure 1* illustrates the depth of a database produced from satellite imagery.

—Interownership analyses can be performed. The great economies of scale provided by digital image processing make it relatively inexpensive to map large expanses of land, making cumula-

tive effects analyses.

—Fast and inexpensive updating is possible, since satellite images used to create the landscape delineation can be directly compared with those taken at a later date.

In addition to mapping vegetation and land uses, several national forests and industrial concerns are presently using SPOT 10-meter panchromatic data to map and create GIS coverage of roads and harvest units. Digital orthophotography can be used for the same purpose, as roads or harvest units are digitized directly on the computer scene.

Satellite imagery is not suitable for every project. Large-scale aerial photographs are more appropriate for applications that require a scale larger than 1:12,000, cover an area 5,000 acres or less, or must identify resources smaller than the spatial resolution provided by satellite images. Recent advances in orthorectification software, however, make it possible to use scanned digital aerial photography to produce GIS data.

GIS coverage derived from remotely sensed data (including both satellite im-

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agery and aerial photography) will never supply or replace the detailed information that is only available through field investigations. A map or GIS coverage can be used to model existing, past, and future conditions; analyze possible management activities; and allocate field samples. But it will never replace the field information required for site-specific management. Once that information is gathered, however, the data can be entered into a GIS as an attribute of the site and retained indefinitely.

Topographic models. Recent software developments have made it possible to use either stereo satellite imagery or stereo digital photographs to generate digital elevation models (DEM). DEMs are digital grids of points of known latitude, longitude, and elevation that can be used to generate GIS coverage of topographic conditions such as slope, elevation, and aspect. While the US Geographic Survey has 1:250,000-scale DEMs for the entire United States, large-scale DEMs are often difficult and expensive to obtain using traditional photogrammetry. New software makes it much easier to create high-resolution DEMs for both small and large projects. Three-dimensional perspectives can be created by integrating DEMs with GIS coverages, satellite imagery, or digital orthophotos.

Change detection. Change detection—comparing differences in the landscape over time—can be done easily and inexpensively by overlaying images that vary only by date. Image comparison is superior to map comparison, because two maps often differ more because of varying techniques or classification systems than because of landscape changes.

However, image-to-image comparison requires isolating and controlling all factors that cause differences over time. It must account for atmospheric and seasonal variation, and the images must be precisely registered.

The cost and time savings possible with image-to-image change detection mean that GIS databases can be rapidly updated to reflect changes in resource condition. The applications of image-to-image comparisons are expanding. Lachowski et al. (in press) present an example of the use of change detection to monitor forest plan implementation. Similar techniques are being adopted by regula-

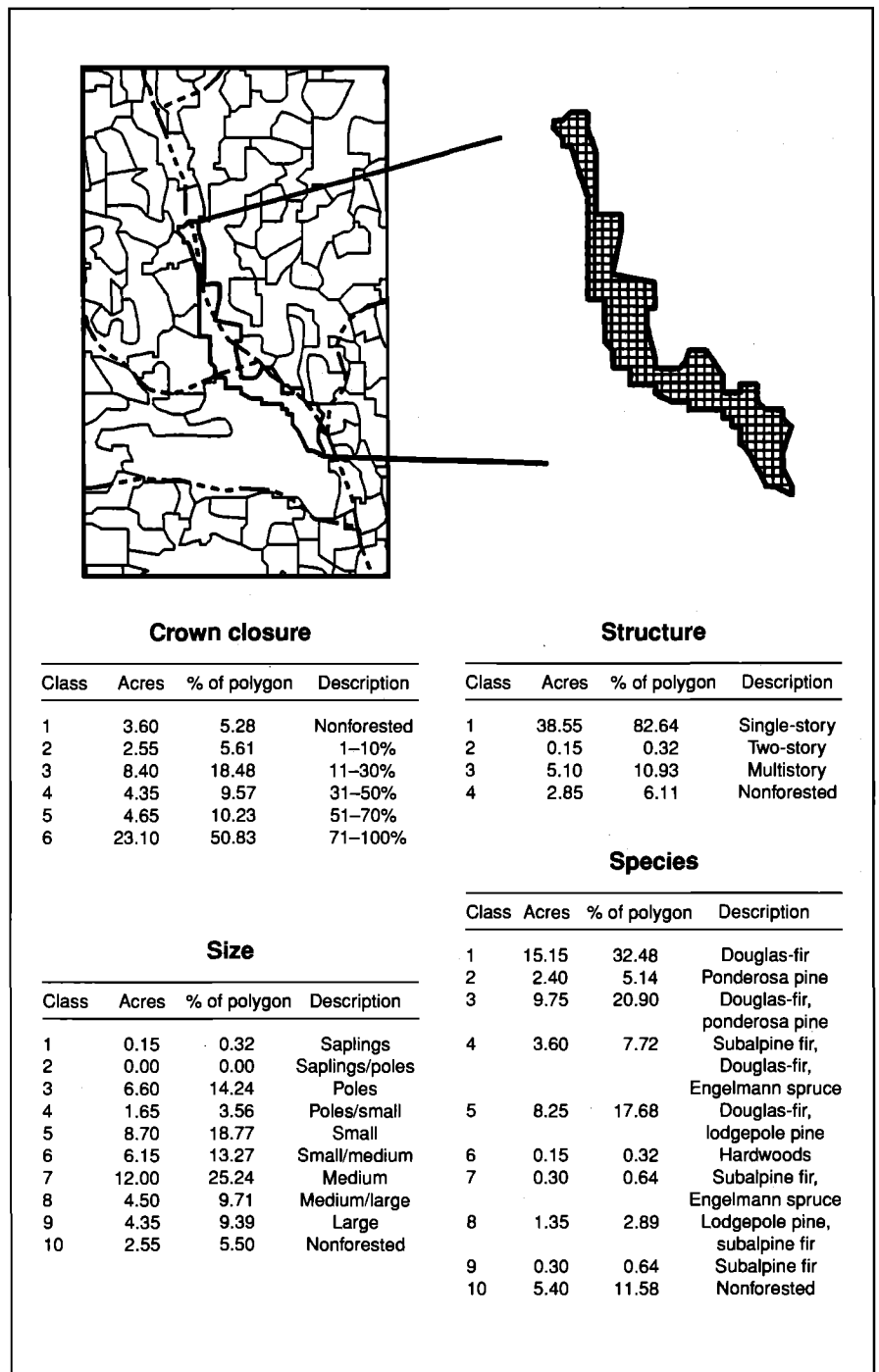


Figure 1. Data summary with vegetation polygons (Green and Congalton 1990, p. 719).

tory agencies to assess the cumulative impact of forest management.

Ancillary Data

In creating forest vegetation maps from aerial photographs, photointerpreters must understand the relationship between forest vegetation type and the vari-

ous colors, tones, and textures in the photo. They must also be aware of the location of each photo and the relation of vegetation type to location, aspect, slope, and elevation. Old vegetation maps, inventory plots, stand examinations, and harvest and fire history are just some of the ancillary information that must be re-

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lied on to aid photo classification.

Processors of satellite images must also consider the same supplementary data to increase the accuracy of information derived from satellite imagery. Existing GIS layers are often used to produce new GIS layers in three basic ways:

—to help locate areas of interest. One of the most time-consuming tasks in image processing is determining precise locations. GIS layers of photo flight lines, streams, existing vegetation classes, 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.

—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).

—as layers in postclassification modeling for quality control. Classifying conifer species is as difficult in image processing as it is in photointerpretation. However, because species distribution is highly correlated with aspect and elevation, GIS coverages of aspect and elevation can be used to check for unallowable species occurrence. Classifications can

also be directly compared to existing GIS coverages (Golden and Lackey 1992).

Conclusions

The present demand for integrating GIS with image processing into forest management is only a fraction of the future demand. Increasing conflicts over land use and land management will accelerate the need for fast, accurate, and inexpensive information about the landscape.

Implementation of GIS has evolved through two steps and is entering a third. The first step was to acquire GIS hardware and software. Organizations committed large funds to purchase GISs and train personnel. The second step involves capturing data. Most of this article has concentrated on the new methods available for capturing GIS data and for integrating the data into resource management. This step is far from complete, but universal data sets are becoming available.

The third step is to analyze relationships among GIS data layers to help identify some of the complex interactions within forest and range landscapes. Currently, users tap only a minimal amount of the information available in the imagery and in the relationships among GIS

layers. Taking this third step will enable resource managers to test management assumptions through sensitivity analysis.

Increased training is critical before personnel can apply these powerful information tools to resource management problems. Only with competent analysts and managers can the benefits of the high investment costs in GIS hardware, software, and data be fully realized. ■

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