# Mapping Old Growth Forests on National Forest and Park Lands in the Pacific Northwest from Remotely Sensed Data


## Abstract

*This project incorporated the use of remotely sensed data to produce a GIS database and map of old growth forest lands on National Forest and Park lands in Oregon and Washington. The GIS layers include slope, aspect, elevation, hydrology, location of research and inventory plots, crown closure, size class/stand structure, species, current vegetation type polygons, suitable spotted owl habitat, suitable lands for timber production, flight line maps, habitat conservation areas, forest boundaries, potential Pacific yew habitat, historical distribution of vegetation, and old growth. The mapping was performed using field measurements, aerial photography, and Landsat Thematic Mapper satellite data. Methods included (1) extensive field reconnaissance to determine the causes of variation in vegetation; (2) in depth spectral analysis to identify variation in the imagery; (3) integration of a geographic information system for image processing analysis and final products; and (4) detailed accuracy assessment using both photo and field reference data.*


## Introduction

As the nation's population has grown, so have the demands on the nation's forest lands to provide multiple resources for diverse clientele. Management of National Forest lands has become increasingly complex, requiring sophisticated technologies and accurate information to serve a diverse range of environmental, economic, and recreational needs. Nowhere is the competition for scarce forest resources more evident than in the Pacific Northwest where conflicts over the management of old growth timberlands have divided communities, often resulting in violence.

To help manage its forest resources, Region 6 of the USDA Forest Service has undertaken a project to produce a Geographic Information System (GIS) database for 20 million acres of forestland in Washington and Oregon (Green and Congalton, 1990; Teply and Green, 1991). Geographic information systems link computerized maps (locational data) to computerized databases which describe a particular location. The linkage makes it possible for managers to simultaneously access both location and attribute data to simulate the effects of management and policy alternatives. GIS is a powerful tool because a single user can quickly search, display, analyze, and model spatial information. In addition, updating of maps and other data can be performed more efficiently and accurately with a GIS than by conventional methods. Because conflicts concerning land use and land management are by definition spatial issues, a geographic information system can focus discussion on these critical issues/needs.

This project was divided into two phases. The first phase, described in this paper, involved production of a GIS database and map of old growth forest lands on National Forest and Park lands in Oregon and Washington. The second phase will produce detailed GIS data layers for **all** National Forest lands in Washington and Oregon. The primary objective of both phases is to produce GIS coverages and maps of homogeneous units of vegetation, based on crown closure (four classes), species (over 20 classes), and size class/stand structure (30 classes). GIS layers produced include slope, aspect, elevation, hydrology, flight line map, location of research and inventory plots, training site location, crown closure (raster format), species (raster format), size class/stand structure (raster format), current vegetation type (polygon format), suitable spotted owl habitat, suitable lands for timber production, habitat conservation areas, forest boundaries, potential Pacific yew habitat, historical distribution of vegetation, and old growth.

Two questions are of critical importance in resolving the conflict over old growth forest management. First, what is old growth and, second, where is the old growth? Historically, there has been very little agreement about what constitutes an old growth forest. However, most old growth definitions rely on variations of at least four forest vegetation characteristics: crown closure, tree size, species, and stand structure. In this project the U.S. Forest Service Region 6 decided to build a GIS of vegetation characteristics, thereby enabling them to create various maps of old growth depending on the definitions nominated by different constituency groups. Figure 1 illustrates the forest vegetation classification scheme employed in this project.

The specific goal of this project was to develop baseline information about National Forest lands that can be used to manage all forest resources, including old growth. Five requirements for the project resulting from this objective were as follows:

- Use vegetation characteristics as the basic elements to be mapped. Vegetation is the common denominator of all forest resources;
- Involve National Forest personnel and all resource disciplines in map/database development;

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- Compile a flexible, easily "updatable" database which is compatible with future Forest Service GIS equipment and data requirements;
- Incorporate extensive field verification to insure map accuracy; and
- Produce a map of old growth forest lands by 1 October 1990.

While the GIS is being built as a result of the old growth controversy, it is important to the region that the information be usable for total resource management.

## Methods

### Study Site

The study site for this phase of the project was all National Forests and Parks west of the Cascades (Figure 2). These National Forests included the Olympic, the Gifford Pinchot, the Roque, the Siuslaw, the Mt. Baker-Snoqualmie, the Mt. Hood, the Umpqua, the Willamette, and the Siskiyou. The National Parks included Crater Lake, Olympic, North Cascades, and Mt. Ranier. In total, over 12.5 million acres of land were mapped.

### Imagery

The imagery selected for use in this project was Landsat Thematic Mapper satellite data acquired in geocoded and terrain corrected format from EOSAT Corporation of Lanham, Maryland. Geocoded and terrain corrected data are registered to some ground coordinate system (UTM or state plane, for example) and made planimetrically correct so as to precisely overlay with existing map data. Twelve TM scenes, acquired during the summer of 1988, were required to cover the study area. Panchromatic SPOT imagery was also purchased for use on the Olympic Peninsula.

### Innovative Techniques

The techniques developed to assure the success of this project fall into three categories: (1) image classification, (2) polygon creation, and (3) accuracy assessment. Image classification emphasizes (a) identification of causes of variation in the vegetation and in the image, and (b) identification of correlations between the two different types of variation. Following image classification, the raster maps were converted into vegetation type polygons which are homogeneous

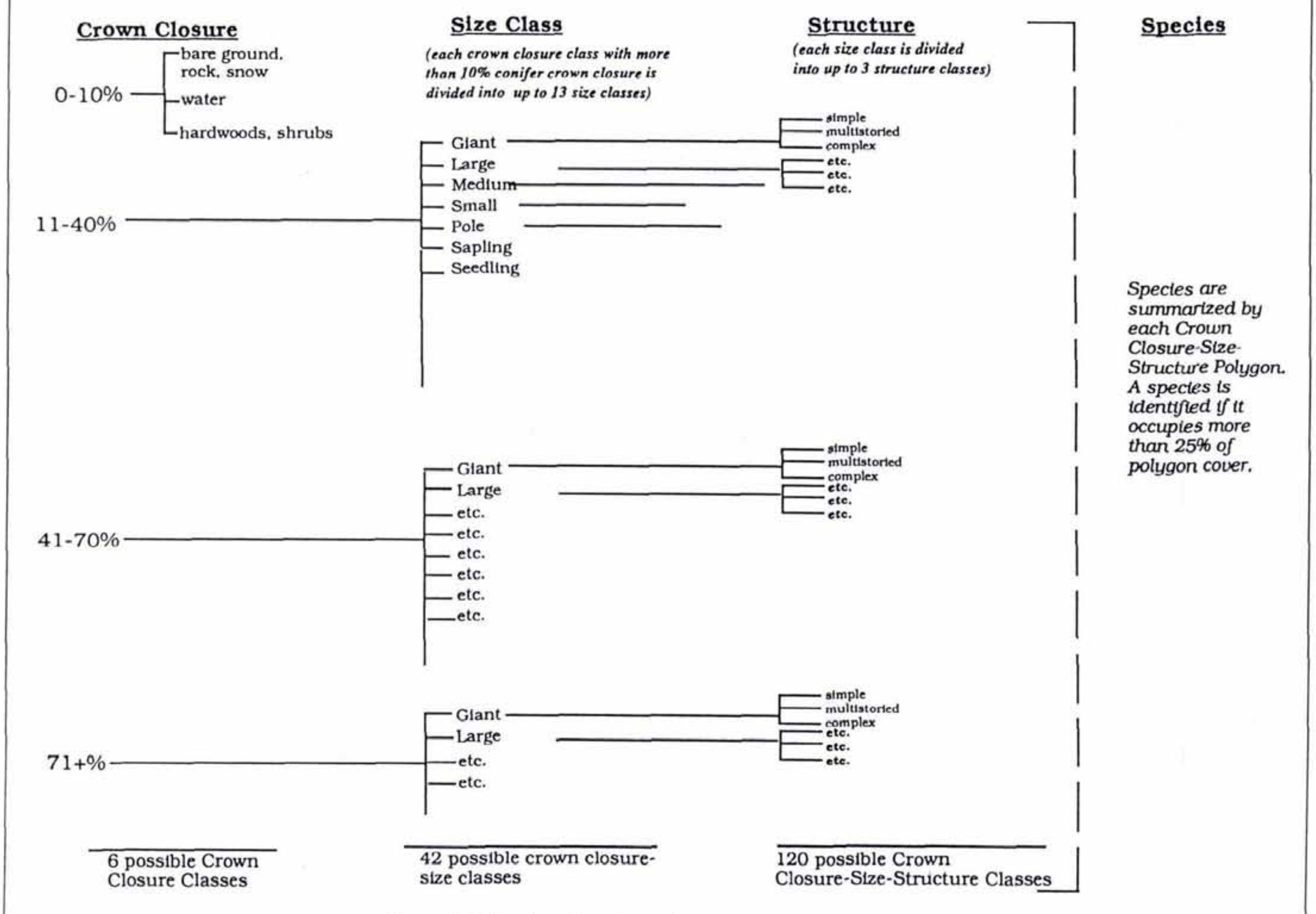


Figure 1. The classification scheme used in this project.

by size class, species, structure, and crown closure. Finally, accuracy assessment was performed on the resulting polygons.

### Image Classification

All classifications were performed on SUN and PC-based workstations with Landsat TM data which had been geocoded and terrain corrected.

A complex set of image classification methods have been developed that emphasize

- integration of analog and digital ancillary data using the ERDAS image processing system, SAS statistical analysis software, and ARC/INFO geographic information system;
- identification and analysis of causes of spectral variation;
- identification and analysis of causes of variation in vegetation type and distribution; and
- assessment of the strength of the correlation between these two types of variation.

The ancillary data used in support of this project are

- Digital slope, aspect, and elevation GIS coverages developed from 1:250,000-scale Defense Mapping Agency data;
- Digital line graphs of roads and hydrology developed from 1:100,000-scale USGS data;
- Location of and attribute data for Forest Service inventory, ecology, and research plots;
- 1:12,000- and 1:24,000-scale natural color aerial photos;
- 1:24,000-scale 7 1/2-minute orthophotos;
- Existing and historical vegetation maps; and
- Extensive field information collected in detail on training sites and, in general, throughout each National Forest and Park.

In addition to the ancillary data, Forest and Park Service personnel familiar with each area to be mapped were relied upon to provide information about the causes of vegetation variation. The forest ecologists have been important sources of information for both potential training site locations and definition of ecologically distinct zones of vegetation.

Spectral and vegetation variation were analyzed using a combination of Pacific Meridian programs which integrate data in ARC/INFO, ERDAS, and SAS. Information which describes the vegetation of each training site was entered into ARC/INFO. The information was then passed to SAS. The location and spectral signatures of each training site were captured in ERDAS and ARC/INFO and the attribute data were also passed to SAS. SAS was then used to (1) identify variables (e.g., aspect, elevation) significantly affecting vegetation distribution, and (2) relate spectral variation to vegetation variation. In addition, spectral pattern analysis (Stenback and Congalton, 1990) was used as a diagnostic tool to aid in selecting the best spectral bands to use for each classification (i.e., best bands for species, for structure, for crown closure, and for size class). Figure 3 shows an example of a typical spectral pattern analysis, including the derivative bands such as ratios, texture bands, and principal components, as well as the raw data. A supervised and unsupervised classification were performed in ERDAS, and similarities between the spectral statistics for each classification were compared using a clustering algorithm and methodology developed by Chuvieco and Congalton (1988).

An example of the methodology is presented in Figure 4. The analyses result in (1) the choice of the best Landsat TM band combination to map each vegetation characteristic (i.e., species, size class, stand structure, and crown closure), (2) the development of a set of spectrally and informationally unique training signatures, and (3) the identification of training signatures which may be informationally unique but spectrally confused.

Spectrally confused vegetation types (e.g., pole stands of Douglas-fir and subalpine fir) were further analyzed to determine if ancillary data could be used to stratify the imagery. For example, spectral confusion typically occurs between

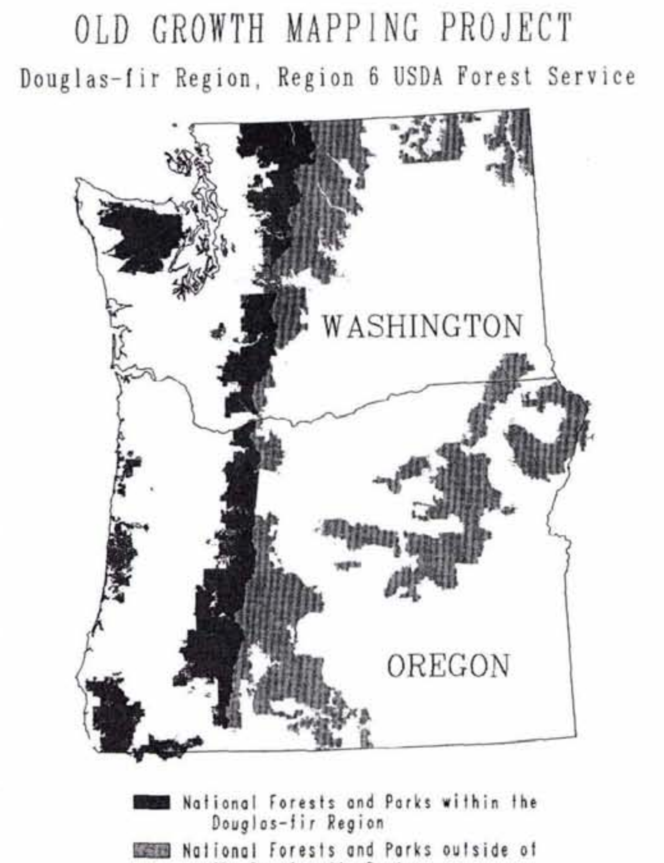


Figure 2. The study area used in this project.

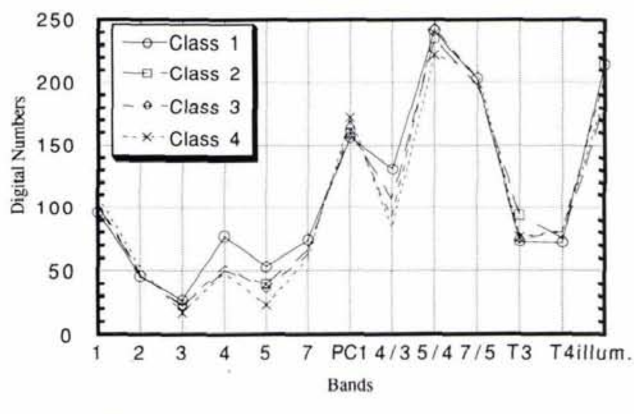


Figure 3. An example of spectral pattern analysis.

similar species (e.g., Sitka spruce and Pacific silver fir). Fortunately, the distribution of species usually is a function of factors such as aspect, elevation, and latitude which can be used as ancillary data in a GIS.

### Polygon Creation

The image classification resulted in four pixel maps: one for each vegetation characteristic (crown closure, species, structure, and size class). The four maps must be brought together to create the vegetation type polygon map. Polygons were delineated so that size class, crown closure, species, and structure were homogeneous across each polygon.

Polygon creation algorithms were developed jointly by Pacific Meridian and Forest Service personnel. The algorithms attempt to replicate the decision rules generally applied by photo-interpreters to delineate vegetation types on stereo photography.

First, the crown closure pixels were delineated into polygons of homogeneous crown closure classes. Crown closure was then held constant and size class and structure were delineated within each crown closure class. Finally, species was summarized within each crown closure, size class/structure polygon.

The polygon map was then overlaid with each of the three pixel maps to produce an attribute file which described the pixel distribution within each polygon of species, size class/structure, and crown closure. The attribute file (1) provides the map user with an indication of the vegetation diversity of each polygon and (2) allows the user to query and model the data based on any of the pixel types within each polygon. The final set of vegetation maps shows the pixel distribution of the three vegetation characteristics; sizeclass/structure, species, and crown closure (in ERDAS), each circumscribed within a polygon with attribute information (in ARC/INFO).

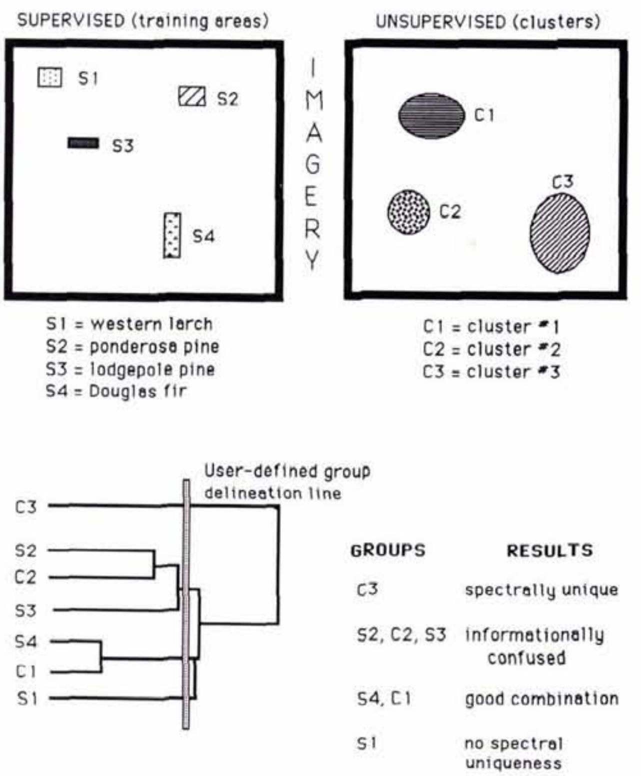


Figure 4. Example of methodology for merging supervised and unsupervised statistics.

### Accuracy Assessment

A requirement of all phases of this project was that the classification accuracy equal or exceed 80 percent.Extensive procedures and sample designs were developed for map accuracy assessment. Two types of procedures were designed: guided and random. The advantage of the guided approach was that it could be conducted in conjunction with the field work for training data collection, thereby reducing the costs of data collection. In other words, the data could be collected prior to the final creation of the vegetation polygons. The random approach must be conducted after the image classifications were complete and therefore require additional field work. Using a combination of approaches maintained the statistical validity of the assessment while balancing the practical aspects of the project. Both procedures employed multi-stage sampling.

The guided approached relied upon a systematic sample in which the center two polygons of every twentieth aerial photo were delineated and classified by a photointerpreter. At least 15 percent of these polygons were ground checked in the field. Finally, a comparison was made between the field and/or photo classifications and those of the map. An error matrix was generated for each vegetation characteristic (Story and Congalton, 1986).

## Results

The following spectral bands and derivatives were considered for use in classifying the Landsat Thematic Mapper satellite data for deriving old growth maps: band 1, band 2, band 3, band 4, band 5, band 7, ratio 5/4, ratio 7/5, ratio 4/3, PC1 (the first principal component of bands 1,2, and 3), T3 and T4 (texture bands from TM bands 3 and 4, respectively), and Illum.(a sun illumination band created using the digital elevation model and the sun angle at the date and time the image was taken). The spectral analysis resulted in the choice of bands 3, 5, 7. Following field checking of the draft maps, problems with the classification of shadowed slopes was noted and further spectral analysis was performed. Final size class and structure classifications were performed on bands 3, 4, 5, a ratio of 3 to 4, and an illumination band (used only in steep areas).

Plate 1 shows an example of the resulting old growth map for the Willamette National Forest. Because of the level of detail in these maps, it is not possible to show the old growth map for the entire study area. Instead, a representative example has been selected. The criteria used in this mapping were designed to mimic as closely as possible the canopy characteristics of old growth, as described by the U.S. Forest Service Pacific Northwest Report #447, and were developed based on the following criteria:

- all old growth stands must be multistoried;
- an old growth stand must have at least 10 percent crown closure in trees 32 inches or more in diameter at breast height (DBH) in low elevations, or at least 10 percent crown closure in trees 21 inches or more DBH in high elevation zones;
- if the stand is in the Umpqua, Roque, or Siskiyou National Forests or Crater Lake National Park, it must have at least 55 percent total crown closure to be considered old growth. For the remaining six national forests and three national parks in the Douglas fir region of Oregon and Washington, a stand


Plate 1. An example of an old growth map for the Willamette National Forest.

TABLE 1. ACREAGE ESTIMATES OF OLD GROWTH FOR EACH NATIONAL FOREST.

| Forest Name | Old Growth Acreage |
|---|---|
| Olympic | 147,650 |
| Mt. Baker-Snoqualmie | 725,280 |
| Gifford Pinchot | 447,150 |
| Mt. Hood | 363,250 |
| Willamette | 783,550 |
| Siuslaw | 91,860 |
| Umpqua | 619,340 |
| Rogue | 267,950 |
| Siskiyou | 277,890 |
| Total: Oregon Forests | 2,403,840 |
| Total: Washington Forests | 1,320,080 |
| Regional Total | 3,723,920 |

must have at least 70 percent total crown closure to be considered old growth; and
- All old growth stands must be at least 10 acres in size.

Based on this definition, 3.7 million acres or approximately one third of the 9.4 million acres of national forest land in the Douglas fir region of Oregon and Washington are old growth. Of this 3.7 million acres of old growth, almost 22 percent is in wilderness areas. Another 742,020 acres have been designated unusable in the National Forest Management plans and a possible 541,790 acres is currently being considered for non-timber use if the Habitat Conservation Area (HCA) plan as proposed by the Interagency Science Committee is implemented. Table 1 presents the acreage estimates of old growth for each National Forest in the Douglas fir region.

Plate 2 illustrates the process of polygon creation for a small portion of the classified map. The original classified map is represented on a pixel basis and must be generalized to produce a vegetation type (e.g., old growth) polygon as a result of the guidelines presented in the methods section under Polygon Creation and the definition of the particular vegetation type. However, it is particularly important for many applications, such as wildlife and biodiversity, that the pixel

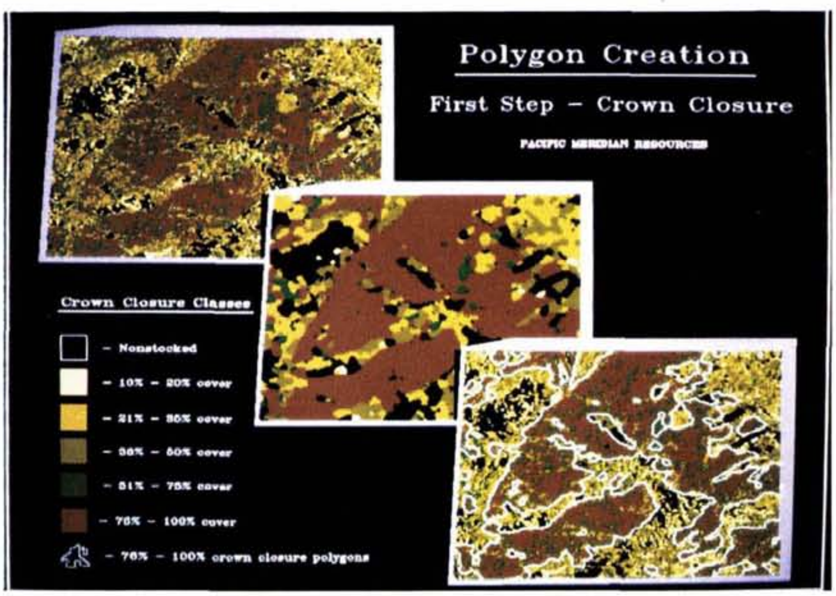


Plate 2. An example of the results of polygon creation.

information within a polygon be retained. Plate 2 clearly shows the polygon delineated on the pixel image, but it also presents a summary of the very important pixel information within the polygon.

The accuracy or quality of the old growth maps have been assessed both qualitatively and quantitatively. In the Spring and Summer of 1990, two sets of approximately 600 draft, 7 1/2-minute quadrangle maps of the classified data were produced at 1:24,000 scale for use in a qualitative assessment. One set was used by Pacific Meridian personnel to ground check the map classification. The other set was checked by Forest Service personnel on each National Forest. All errors detected were noted and corrected. Systematic errors, such as those from shadows on northwest slopes, were explored in detail and resulted in a reclassification of the image to fix the problems. Errors with no apparent pattern were simply corrected in the classified image.

In addition, quantitative accuracy assessment was performed to statistically describe the accuracy of the classification. In total, over 2600 sites were established to provide a comparison between the classified old growth map and the reference data (determined either from the ground or from aerial photointerpretation). Table 2 presents the number of field visited and photointerpreted sites used in the quantitative assessment. Table 3 shows the error matrix that was generated for the all the National Forests combined. Table 4 presents the overall classification accuracies for each forest by comparing the classified map to a reference data set consisting of both photointerpretation and ground visits and to a reference data set consisting of just the ground visited sites alone.

Finally, the Forest Service commissioned an independent panel to provide an outside peer review of the project (Mikuni *et al.*, 1991). The conclusion of this panel was that the methodology developed for this project was sound and that the results were well documented and adequately demonstrated. The panel then recommended that the Forest Service consider implementing this methodology nationwide.

## Conclusions

The past 15 years have witnessed numerous attempts to use satellite imagery to produce detailed forest vegetation type maps. We have identified four dynamic factors which account for the success of this project and make it possible for image processing to effectively respond to the demand for fast, accurate, and inexpensive GIS data sets:

- Computers today are far more powerful and less expensive than they were even one year ago. Image classifications which once took two weeks can now be run in a few hours. This provides the opportunity to process a classification, assess its accuracy, set aside the portions which are correct, and focus efforts on reclassification of the areas which are incorrect.
- GIS and statistical software can now be fully integrated into image processing, allowing the analysis of the relationships between spectral variation on the image and land-cover variation on the ground.
- The technology has worked its way into the main stream university courses so that personnel using imagery to make maps understand both spectral and vegetative variation. Thus, the people producing the maps are foresters, geographers, or ecologists who not only understand what causes variation in image spectral response, but also understand what causes variation in vegetation.
- The spatial resolution of SPOT imagery and the spectral and spatial resolution of the Landsat TM data are a major improvement over the earlier MSS data. We believe that resolution of the data is so good that it will be several years before image processing methodology is capable of making full use of it.

TABLE 2. THE NUMBER OF FIELD AND PHOTO SITES USED IN THE QUANTITATIVE ACCURACY ASSESSMENT.

| Forest Name | Field | Photo | Total |
|---|---|---|---|
| Olympic | 65 | 196 | 261 |
| Mt. Baker-Snoqualmie | 81 | 423 | 504 |
| Gifford Pinchot | 53 | 312 | 365 |
| Mt. Hood | 39 | 166 | 205 |
| Willamette | 53 | 301 | 354 |
| Siuslaw | 44 | 151 | 195 |
| Umpqua | 40 | 174 | 214 |
| Rogue | 55 | 217 | 272 |
| Siskiyou | 68 | 251 | 319 |
| Total | 498 | 2191 | 2689 |

TABLE 3. THE ERROR MATRIX FOR THE ENTIRE STUDY AREA.

| Map Data | Reference Data: OG | Reference Data: NOG |
|---|---|---|
| OG | 912 | 141 |
| NOG | 337 | 1299 |

Classes

OG = Old Growth

overall accuracy = 2211/2689 = 82%

TABLE 4. THE OVERALL ACCURACY FOR EACH NATIONAL FOREST IN THE STUDY AREA.

| Forest Name | Reference Data both Photointerpretation & Ground Visits | Reference Data Ground Visits Only |
|---|---|---|
| Olympic | 80% | 79% |
| Mt. Baker-Snoqualmie | 87% | 86% |
| Gifford Pinchot | 85% | 89% |
| Mt. Hood | 83% | 84% |
| Willamette | 87% | 91% |
| Siuslaw | 80% | 81% |
| Umpqua | 91% | 100% |
| Rogue | 82% | 85% |
| Siskiyou | 84% | 76% |

The corresponding benefit of all of these factors is to lower the cost per acre of performing such a project by one third while providing 14 layers of GIS data instead of just the one layer that results from traditional aerial techniques. This cost savings is a significant conclusion of this study and is based on previous costs incurred by the U.S. Forest Service, Region 6 for aerial photointerpretation.

Traditional paper and mylar maps were produced for this project. But more importantly, the project resulted in the creation of sophisticated computer databases which can be used to evaluate the effects and impacts of management alternatives. Both regional and site specific analysis are now

possible. The Forest Service will be able to address issues such as fragmentation of old growth and its implications on wildlife habitat. They will also be able to develop initial estimates of the biological diversity of forest vegetation. Resource managers will be able to analyze spatial relationships such as

- What is the spatial distribution of old growth stands?
- What is the average acreage of old growth stands and how continuous or fragmented are these stands?
- How much old growth acreage is presently in National Parks and wilderness areas?
- What is the primary species composition of existing old growth stands? What is the structure and size class of these stands? Which stands are ecologically diverse? Which are homogeneous?
- How does the extent and amount of old growth acreage change under various definitions of old growth?

The total benefits of the GIS system for land management go beyond the initial cost savings and increase in map detail. The Forest Service needs detailed physical vegetative information in a timely, consistent, and accurate form to make critical resource decisions. It is critical to be able to model the effects of different management decisions before they are put into effect.

## Acknowledgments

This project has been a monumental team effort involving numerous subcontractors, Forest Service personnel, and, at one time or another, every one of Pacific Meridian's employees. We would like to acknowledge each of these individuals for their essential involvement and contribution.

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