THE INTERAGENCY VEGETATION MAPPING PROJECT

ESTIMATING CERTAIN FOREST CHARACTERISTICS USING LANDSAT TM DATA AND FOREST INVENTORY PLOT DATA

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Abstract

The Interagency (USDA Forest Service, USDI Bureau of Land Management) Vegetation Mapping Project (IVMP) is producing maps of certain forest characteristics (percent cover of vegetation, conifers and hardwoods, average tree size, and stand structure) across all forested lands in western Oregon and western Washington, to comply with the effectiveness monitoring requirements of the Northwest Forest Plan. Maps are produced using a regression modeling technique combining Landsat 5 imagery, existing forest inventory field data, and photo-interpreted data taken at plot locations. Maps are inclusive of all land ownerships. We provide an overview of methods used to produce the maps, and a summary of lessons learned in the process.

Keywords: remote sensing, vegetation mapping, northwest forest plan, regional scale, forest inventory, regression modeling, IVMP.

Introduction

Listing of the Northern Spotted Owl (*Strix occidentalis caurina*) (Figure 1) as a threatened and endangered species dramatically changed the dynamics of timber economies and timber flow throughout the Pacific Northwest. Forest management plans provided guidance for foresters in dealing with spotted owl habitat, but many resulting timber sales were challenged in court, often successfully. President Clinton and Vice President Gore convened a timber summit in Portland, Oregon, in 1993, meeting with industry, environmental and other interested groups, in an effort to remove forest resource management from the courts. This resulted in the Spotted Owl Recovery Plan, also called the President's Plan, which has since evolved into the Northwest Forest Plan (Tuchmann, et al., 1996).

Figure 1 - Northern Spotted Owl

The Northwest Forest Plan requires surveys of critical species to estimate population, distribution, biology and habitat requirements, as well as development of management plans to ensure long term viability of each species. About 400 species currently require surveys, and some estimates suggest over a thousand species may eventually be involved. These species cover a broad range, including mollusks, mammals, and plant species including bryophytes. The Federal Circuit Court has also mandated that the Northwest Forest Plan be formally monitored for both implementation and effectiveness.

The Interagency Vegetation Mapping Project (IVMP) is chartered to map certain forest characteristics throughout western Oregon and western Washington as part of effectiveness monitoring and other landscape analyses for the Northwest Forest Plan. IVMP products are expected to be particularly useful in monitoring late successional reserves, spotted owl habitat, and marbled murrelet (*Brachyramphus marmoratus*) habitat.

IVMP is a collaborative effort between:

- the Bureau of Land Management (BLM) Oregon State Office,
- Region 6 (R6) of the USDA Forest Service (USFS), including the Regional Ecosystem Office (REO) and the Regional Current Vegetation Survey (CVS) Group,
- USFS Pacific Northwest Research Station (PNW), Portland Forest Sciences Laboratory (PFSL) and Corvallis Forest Sciences Laboratory (CFSL), and
- the USFS Remote Sensing Applications Center (RSAC) in Salt Lake City, Utah.

The concepts behind many of the modeling techniques used in IVMP were developed by Tom Spies and Warren Cohen at the PNW CFSL (Cohen and Spies 1992; Cohen et al. 1995; Cohen et al. in review).

Study area

IVMP is producing "wall-to-wall" coverages of all forested areas in western Oregon and western Washington, across both private and federal lands. The area ranges from sea level to 14,000 feet, and includes dense temperate rain forests, sparse oak woodlands, alpine areas, National Parks and industrial forest lands. Total area mapped is in excess of 50 million acres

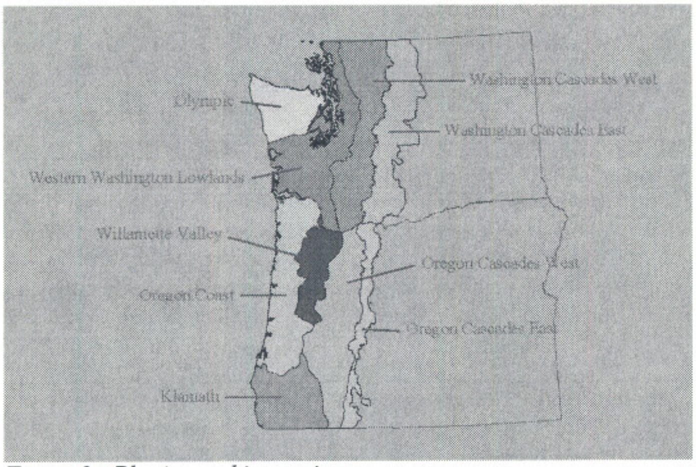


Figure 2 - Physiographic provinces.

The study area is divided into nine physiographic provinces, with each of the provinces being modeled separately (Figure 2).

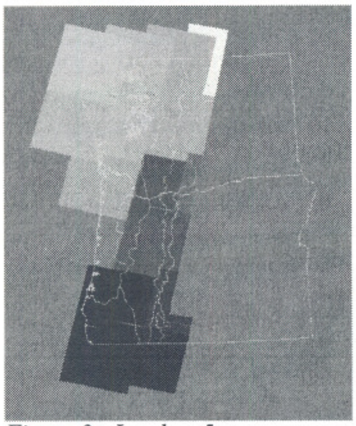


Figure 3 - Landsat 5 scenes.

IVMP uses 18 Landsat 5 Thematic Mapper (TM) scenes (Figure 3), with most scenes acquired in 1996. Finding a cloud-free scene of the Olympic Peninsula required using a scene from 1992. Resolution of TM imagery is 30 meters.

Data from approximately 10,000 existing forest inventory plots are used in addition to the Landsat imagery. Plot data were collected between 1989 and 1998 from existing forest inventories. Private lands are inventoried by the Forest Inventory and Analysis Unit (FIA) of the PNW PFSL (using a 3.4 mile grid spacing), National Forest lands are inventoried by the Region 6 CVS Program (using 3.4 and 1.7 mile grid spacing), and BLM lands are inventoried using both a BLM grid of 5-point plots (using a 3.4 mile grid spacing), as well as CVS plots on BLM lands. Aerial photography for all field plots was acquired, at scales from 1:12,000 to 1:40,000.

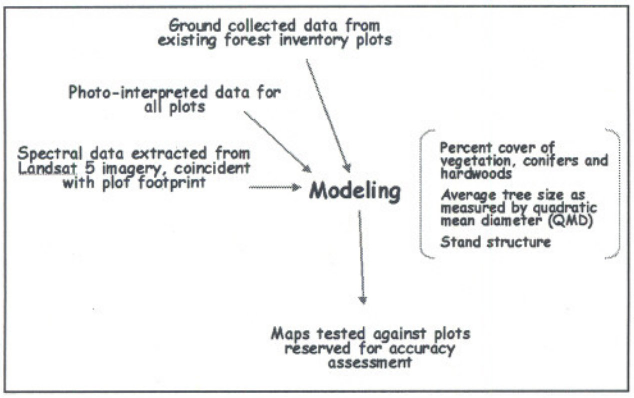


Figure 4 - Procedural diagram of modeling process.

Modeling

IVMP uses a regression modeling technique that combines ground data from existing field plots, photo-interpreted data of the plots, and spectral information extracted from TM images coincident with plot locations (Figure 4). IVMP starts with the random grid of field plots, and extracts spectral information at those points. Several layers of quality control screening identify plots that are reasonably homogeneous. Still, some forest types were not well represented by field plots, and additional homogeneous areas were identified on aerial photography outside the plot locations for use with some aspects of the modeling. These extra points did not have associated ground plots so could only be used for modeling vegetation, conifer, and broadleaf cover (i.e., not for modeling tree size).

Predictive variables were identified by the Vegetation Strike Team of the REO (Askren et al. 1995), and include:

- percent cover of vegetation, conifers and hardwoods,
- average tree size as measured by quadratic mean diameter (qmd), and
- stand structure (whether a stand has a single or multi-layered canopy).

Stand structure is proving to be difficult to model with the regression approach, and is currently not being actively modeled. Furthermore, hardwoods could not be spectrally separated from broadleaf shrub and grasses. Consequently, a broadleaf category was defined as hardwood + shrub + herb, and is being modeled instead of hardwood alone.

Figure 5A

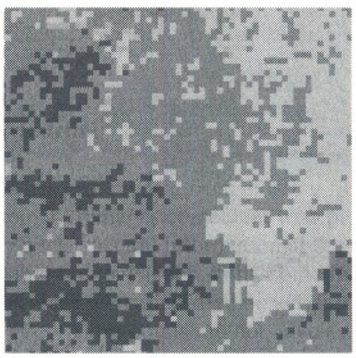


Figure 5B

Figure 5 This figure shows a patch of the Coast Range province (approximately 550 ac), with conifer quadratic mean diameter (QMD) predictions as:

(A) continuous values (1" increments; smaller QMDs are lighter greens) and

(B) three classes, where small = 0 - 9.9" (light green), medium = 10 - 29.9" (medium green), and large >= 30" (dark green).
In both maps, cyan areas represent regions not mapped due to insufficient vegetation (i.e., < 70% areal cover), or < 30% conifer cover.

IVMP models variables with nearly continuous data (tree diameters in one inch classes and percent cover in one percent classes). This allows users to combine data into whatever classes are required (Figure 5).

Image Preparation

TM images are geometrically corrected, if needed, and clipped to a province boundary. TM images are mosaicked for final map production, but each scene is modeled separately in each province. Slope and aspect are derived from 30 meter Digital Elevation Models (DEMs), and a mask is produced to remove non-forest areas (such as urban, agriculture, snow, water and barren).

Figure 6 - Photo-interpretation template.

Photo interpreted variables

Aerial photography is photo-interpreted within the footprint of each inventory plot (Figure 6). Twenty well-distributed points are classified as hardwood, conifer, shrub, dark (shadows), agriculture, grass/herb or non-vegetation. For hardwoods and conifers a stand structure determination is made for hardwoods and conifers (whether the tree under the interpretation point is dominant or is in an understory class). A greenness estimate is made for shrubs, grass and herbs (a subjective measure of relative vegetation density), and a plot-level estimate is made of stand homogeneity (a subjective assessment). Photo-interpretation of plots on federal lands is conducted by trained photo-interpreters at RSAC, but because of the confidentiality rules for FIA plots, photo-interpretation of private lands is done at PNW PFSL.

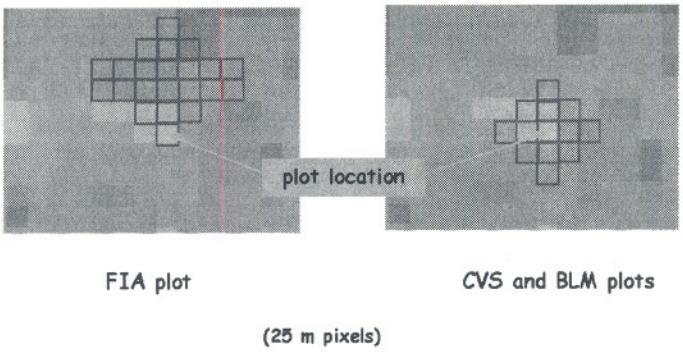


Figure 7 - Plot templates used to extract pixel information.

Plot templates

A computer program extracts spectral information from all 6 TM reflective bands (bands 1, 2, 3, 4, 5, and 7) for each pixel in a template designed to encompass the full plot footprint (22 pixels for FIA plots and 13 pixels for CVS plots and BLM 5-point plots) (Figure 7). Elevation, slope, and aspect and effective solar incidence angle for these pixels are extracted from DEM-derived coverages. Three tasseled cap bands and three ratio bands (4/3, 5/4, and 5/7) are also calculated.

Field-collected tree data are summarized for each plot from the most current available inventory. Finally, one quarter of all field plots are selected for accuracy assessment.

Quality assurance, quality control

Plot locations from pin-pricked aerial photography are compared to TM imagery to check for appropriate image registration. Also, forest conditions are compared in the photography and imagery to determine if any change has occurred from harvesting, blowdown, fire or other disturbance between the time the photographs and imagery were acquired, and photography is checked for reasonableness of the photo-interpreted calls. Imagery is checked for correctness of extracted spectral information (certain pixels are queried for Digital Number (DN), and compared with the DN extracted with the computer program, to determine if the pixel template is properly located). Finally, TM imagery and aerial photos are checked across the plot template for the presence of roads and shadows. A determination is made whether a plot can be used for regression modeling, or will be set aside for testing of candidate models. Regression model building plots are mostly homogeneous, have no roads or shadows, are well registered to the image, and show no change between the field data, photo and image.

Modeling

Extracted TM band data are plotted in scatter plots, and evaluated for trends and relationships that might suggest a suitable model (Figure 8).

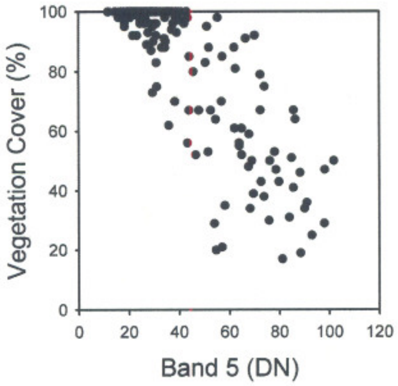


Figure 8A

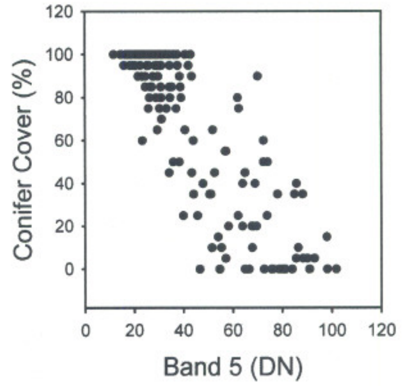


Figure 8B

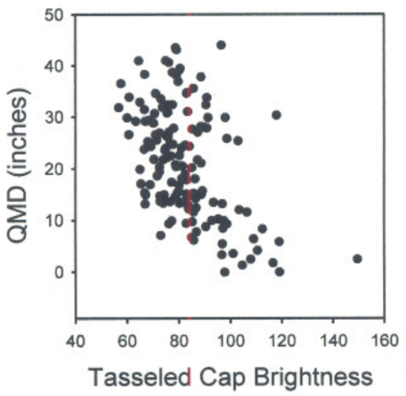


Figure 8C

Figure 8. Typical scatter plots for (A) vegetation cover, (B) conifer cover, and (C) quadratic mean diameter (QMD). Note: transformations may be needed for final modeling, but have not been applied to these examples.

Outliers are identified, checked against the aerial photography and ground data, and resolved if possible. Simple linear regression and multiple regression models are developed, and the candidate models are evaluated against the pool of test plots.

QMD requires a more robust modeling effort, and is performed in three major steps:

Step 1) We remove the variability in the spectral data that can be explained by changes in effective solar incidence angle (if that variability is greater than 15%). To do this, we perform simple linear regressions between effective solar incidence angle and individual bands to provide residuals (i.e., what variability in spectral data is <u>not</u> explained by changes in effective solar incidence angle) that are then used in the next steps.

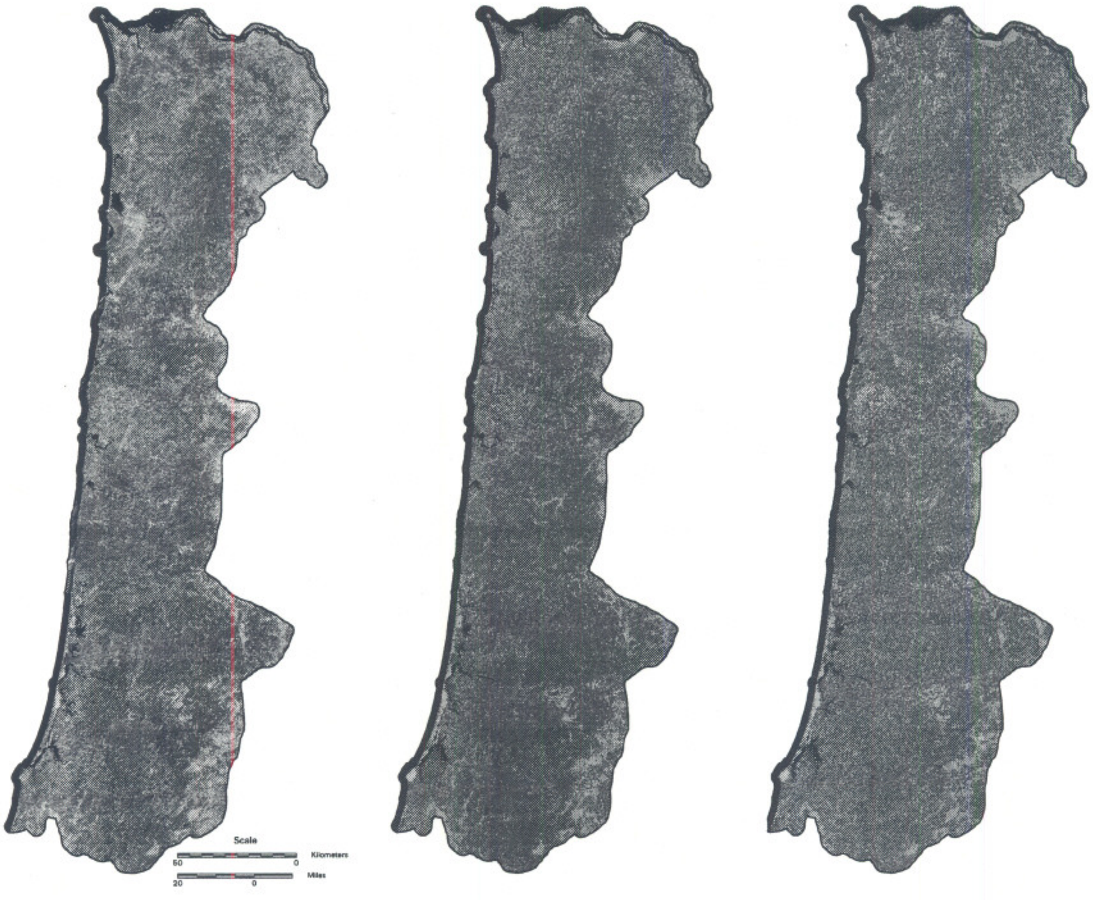
Step 2) A canonical correlation analysis (CCA) is performed on candidate subsets of the spectral residuals and topographic variables along with QMD to reduce the residual and topographic variables to a single index for each candidate set.

Step 3) The candidate CCA indices are regressed against QMD to obtain models which are evaluated against the pool of testing plots.

Results

IVMP has produced draft review maps for the Coast Province of Oregon (Figure 9), with work progressing at some stage on all other provinces.

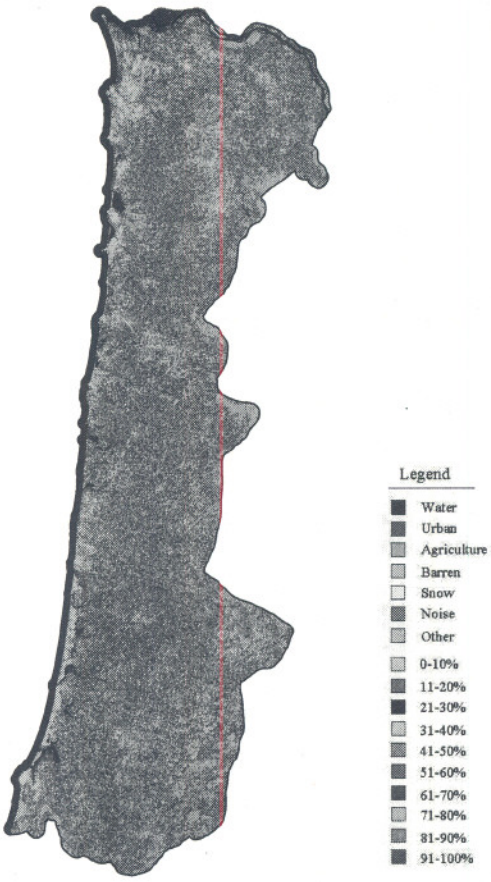
Coast Province Results - Products for the Coast Province include maps of continuous predictions as well as maps re-coded to Vegetation Strike Team standards (Askren et al. 1995). These maps provide end-users with the flexibility to make their own trade-offs between accuracy of class definitions minimum mapping unit size.



Raw data
Figure 9A

Percent vegetation cover
Figure 9B

Percent conifer cover
Figure 9C



Percent broadleaf cover
Figure 9D

QMD
Figure 9E

Figure 9. Draft final results for the Coast Province are shown. Maps include (A) raw band data displayed in near-IR, short mid-IR, and red, (B) percent vegetation cover, (C) percent conifer cover, (D) percent broadleaf cover, and (E) quadratic mean diameter. Maps (B) – (E) are shown using Vegetation Strike Team –defined classes. Shades of blue (other than royal blue) represent smaller values, shades of green intermediate values, and shades of purple larger values for any given variable being mapped. Royal blue is water, red is urban, orange is agriculture, and yellow is other (smoke, clouds, etc.). Note that the first legend applies to Figures 9B - 9D, and the second legend applies to Figure 9E.

Lessons learned

1) Forest roads return a typically very bright spectral signature, or a very dark signature if shadowed (Lillesand and Kiefer 1994; Kauth and Thomas 1976). Because these non-vegetative returns would skew the regression modeling for vegetation if included, all plots intersected by roads were excluded from model building. In some areas of Western OR, it is very difficult to find a road-free two and a half acres (the plot footprint).

Reductions in harvest levels on federal lands have resulted in increased harvest on private lands, resulting in many plots where high levels of vegetation change had occurred between the time inventory data were collected and aerial photography and/or Landsat imagery was acquired. These plots were also were excluded from model building.

Because these exclusions left some forest types with too few plots from which to build a model, we delineated homogenous areas of these types on aerial photography to build models for cover, however, because these areas contained no inventory plots, QMD could not be modeled for these types.

2) Regression equations must be limited in the range of data to which they are applied. For instance, in our typical model, darker areas on TM imagery tend to contain larger trees. This relationship works fine until the model encounters shadows around the edges of clearcuts, which then get predicted as very large trees. Post-classification filters can correct mis-predictions due to shadow, but this reveals the danger of extending regression equations beyond their limits.

Also, the edge lines between TM scenes are evident in the predictions because of variations in the spectral conditions in each image. This can be addressed with feather mosaic techniques, although if model predictions in adjacent images are different enough, even this technique will not help.

3) Complex projects involving several agencies, at several locations, are susceptible to a high degree of human error. For instance, even getting the plot number recorded in a consistent manner can be a problem (some groups use integers, others use character strings). Working on different types of computers, at different locations, with different file formats involves constantly checking the dates of image and program files to make sure everyone is using the same version of the data, and often finding that they are not.

4) The strict confidentiality of FIA plot locations on private lands is mandated by public law (H.R.3423, 1999), so PNW can not release plot locations. This requires that remote sensing contractors visit the PNW facility to extract spectral signatures, and also requires that all photo-interpretation of private lands be done at the PFSL. This results in duplicate versions of the imagery and resultant data files, scheduling conflicts for equipment and facilities, and inefficiencies and errors.

5) Regression models can be evaluated as to how well they explain the variance in the underlying data, and model development strives for the best possible fit of the model to the data. The Vegetation Strike Team did prioritize variables for modeling, although they did not provide any criteria by which models could be judged for acceptability. There is a theoretical upper limit of how much variation can be explained by certain classes of regression models, but time and expense constraints dictate less model refinement to meet production schedules.

6) Key members of IVMP, from all agencies, have moved on to different projects, retired, or have been detailed to other assignments. This disruption of team continuity has led to significant delays.

Future

The long term effectiveness monitoring for the NW Forest Plan suggests that there is a need for an update to IVMP every five years to determine forest change, and that if the methodology proves useful, the project may expand to other forested areas in Region 6. This decision should not be undertaken lightly, however. A project of this scope requires a formal commitment from managers for both budgets and personnel in order to be effective.

Short of a second round of IVMP mapping there are some refinements that might make IVMP more effective.

1) There is something fundamentally different about looking up at a canopy and looking down at a canopy. Typical ground based canopy estimates are varied (measurements can be made of canopy closure, height, layers) and can correlate poorly with imagery. Better ground-based canopy estimating techniques should be developed to correlate directly with image based estimates.

2) Stand structure is an important indicator of forest conditions (Spies and Franklin 1991), and regression based approaches used by IVMP are not suitable. LIDAR or similar canopy-penetrating technology may prove useful for providing these estimates.

Conclusions

IVMP is an ongoing project that will map all forested areas in western Oregon and western Washington. Samples of finished products may be obtained by contacting Lisa Blackburn at the BLM Oregon State Office at (503) 952-6276.

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