

DERIVING DECADAL VEGETATION CHANGE FROM NALC IMAGERY FOR SOUTHERN APPALACHIAN NATIONAL FOREST WATERSHEDS

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ABSTRACT

With the initiation of the Chief's Conservation Agenda, watershed protection and restoration has become a focal point of Forest Service program activity. Watershed analysis is now a requirement for Forest Plan revision. Forest change is a core watershed analysis parameter. This paper describes the utilization of North American Landscape Characterization (NALC) Landsat Multispectral Scanner (MSS) imagery to identify the location and trend in the proportion of vegetated land within the 5th level watersheds associated with the Southern Appalachian Planning Unit National Forests.

The Southern Appalachian Planning Unit extends from Virginia to Alabama encompassing National Forests in 6 states. Landsat scenes acquired during the mid 1980's and early 1990's from 19 path/row scene locations were required to complete the project. To measure vegetation change the Normalized Difference Vegetation Index (NDVI) was calculated for each image. The breakpoint between vegetated and non-vegetated land was determined independently from the NDVI images for each date. Combinations of the vegetated and non-vegetated classes for the 2 dates were used to derive 4 vegetation change classes. Generalization routines were used to delete and recode to the surrounding class, patches smaller than the minimum mapping unit. Supervised classification was used to identify areas of clouds and water on each date of imagery. The cloud and water images from the 2 dates were mosaicked with the vegetation data sets to produce the final vegetation change images. The vegetation change images were exported to the ESRI Grid format and delivered to the planning team for integration into the watershed analysis. A Forest GIS specialist, under the direction of the Regional Remote Sensing Specialist, performed the work. The Forest Service advanced image processing workstation available under the IBM contract was used to conduct the project. The cost to provide the data to the planning team was \$13,000 or approximately \$.62 per thousand acres of watershed area.

INTRODUCTION

The Forest Service is committed to a policy of restoring and maintaining healthy watersheds for current and future generations. This policy is built on the premise that we cannot meet the needs of people without first securing the health of our lands and water. The Agency's vision for healthy watersheds is being implemented through a nine-point strategy. Making watershed restoration and maintenance the highest priority in Forest Plan revision is the first element of this strategy.

Watershed analysis is the basis for incorporating watershed restoration and maintenance into the Forest Plan revision process. The watershed analysis for the Southern Appalachian Planning Unit encompassed the 5th level (25,000 to 40,000 acres) watersheds that are included within or intersected the proclamation boundaries of the 5 National Forests (Figure 1) within the planning unit. Identifying and ranking watershed condition and trend are major components of the analysis process. Watershed trend was based on change in human population and the proportion of vegetated land in the watershed over time. Neither existing Forest Service GIS data nor available land cover classifications provided the vegetation change information required for determining watershed vegetation trend. Agency GIS data represents only a single point in time and covers only the federal land within the National Forest boundary. Land cover classifications from several sources completely encompass the study watersheds but they represent a single point in time and could not be used to identify trends in vegetative cover.

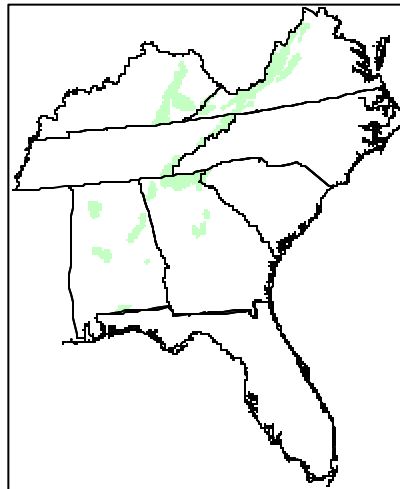


Figure 1 Southern Appalachian Planning Unit National Forests

The Regional Geometronics Services Unit was requested to provide vegetation change data sets to support watershed trend analysis for the Southern Appalachian Planning Unit. Completion of the project within a 4-month period was requested to meet the deadlines of the plan revision schedule. Based on initial cost estimates by an outside vendor, the decision was made to perform the work with Agency systems and personnel. The Forest Service advanced image processing workstation located in the Regional Office Geometronics Services Unit was used to conduct the project. The system consisted of an IBM 266 MHz. Power PC AIX workstation with 18 gigabytes of disk storage and ERDAS Imagine 8.3 image processing software. A Forest GIS specialist (the junior author) without previous image processing experience was available for the approximately 4 months estimated to perform the processing. To meet the time constraints and the limitations of available funding, analysis was limited to watershed vegetation changes between the 1980's and 1990's.

DATA

Forest hydrologists provided boundary files for sub-watershed hydrologic units included in the project. The hydrologic unit files were used to define the extent of the vegetation change images provided to the planning team. Landsat Multispectral Scanner (MSS) imagery was utilized to identify the features required to support the project's change detection requirements. Landsat MSS images are available from the launch of the first earth resources satellite in 1972 until the early 1990's. The MSS and the current Landsat Thematic Mapper (TM) instruments acquire imagery along nominally north/south paths or swaths. The imagery acquired along a path is subdivided into scenes of 185 by 170 kilometers with predefined scene centers or path, row locations. MSS images are composed of a rectangular array of digital values in four spectral bands (green, red, and two near infrared). Each MSS scene element or pixel represents the average reflectance over a 57 by 79 meter ground area. North American Landscape Characterization (NALC) Landsat Multispectral Scanner (MSS) triplicate data sets produced as part of the NASA Landsat Pathfinder Program were utilized for this project. The Forest Service Inter-Regional Ecosystem Management Coordinating Group (IREMCG) purchased the NALC triplicate data sets for Agency applications.

Preparation of the NALC triplicate data sets included scene selection, radiometric correction, systematic correction, and geometric rectification. Landsat MSS scenes were selected from the archives to minimize cloud cover and to the extent possible provide data sets with consistent vegetative state and solar illumination (Lunetta *et al.*, 1998). The NALC data sets were preprocessed and terrain corrected and rectified to the UTM projection. The rectification process was designed to minimize misregistration between the images. The imagery was resampled from an original pixel size of 57 by 79 meters to an output pixel size of 60 by 60 meters. The 60 X 60 meter pixel size was selected for compatibility with the 30 X 30 meter resolution of the currently available TM sensor. A cubic convolution kernel was used to perform the resampling. Cubic convolution is an inverse distance weighted resampling kernel that smooths or generalizes the output image.

VEGETATION CHANGE DETECTION

Landscape change detection techniques utilizing satellite imagery are based on categorizing the difference in scene reflectance between the dates the images were acquired. Difference in the images that are not related to changes in land cover can lead to the identification of change where none exists. The extraneous factors that can influence change detection include misregistration of the images (Townshend *et al.*, 1992), changes in the position and orientation of the sensor, changes in location and orientation of the illumination source, atmospheric conditions and differences in the phenological stage of vegetation at the time the images were acquired. Careful preprocessing can minimize misregistration of the images. The remaining factors can be reduced by acquiring the images under as similar conditions as possible on each date and in the design of the analysis procedure. Change detection procedures fall into two broad classes, 1) direct comparison of the original or transformed image pixel values and 2) post classification change detection. In post classification procedures each image is independently classified into a set of common cover classes and the classification are compared to identify areas of change.

The least sophisticated direct image comparison techniques involve simple image differencing based on the values in a single band, usually the green or near infrared. Vegetation indexes, algebraic combinations of multiple image bands, have proved useful in highlighting vegetation change and in some cases reducing the impact of extraneous factors. A number of these indexes take advantage of the unique relationship between the reflectance in the visible red and near infrared wavelengths to highlight changes in the presence or quantity of green vegetation. Green vegetation has a significantly higher reflectance in the near infrared compared red portion of the spectrum. The MSS Vegetation Ratio Index (VRI) computed by dividing values in the near infrared band (band 4) by the value in the red band (band 2) provides a measure of the amount of vegetation in the pixel. The VRI, however, is affected by a number of extraneous factors including the slope of the terrain. The Normalized Vegetation Difference Index (NDVI) is a widely used variation of VRI. The NDVI is computed by dividing the difference of the infrared and red bands by the sum of the infrared and red bands (near IR-Red/near IR + Red). NDVI produces more useful results when significant topographic relief is present in the project area. Normalization compensates for the extraneous factors providing a robust vegetation index (Lyons *et al.*, 1998).

The objective of most direct vegetation change procedures is to determine the extent of vegetation change between two dates of imagery. These procedures generally provide three classes; vegetation increase, vegetation decrease and no change in the amount of vegetation. To identify these classes the difference in the values of the vegetation measure on two successive occasions is computed ($VM_{D2} - VM_{D1}$) and a difference value representing the change threshold is identified. Pixels whose positive or negative vegetation index difference values exceed this threshold are identified as having increased or decreased vegetation during the time period between the acquisition of the two images. For example if the change threshold is determined to be twenty digital values, differences in pixel values from -20 to +20 would be considered to be in the no change class, while pixels with a difference exceeding +/- 20 would be classified as increased or decreased vegetative cover respectively. Under direct change identification approaches pixels in the “no change” category may be either vegetated or non-vegetated on both dates.

Post classification change detection involved comparing two or more independently generated land cover classifications to identify change. The individual cover classifications may be created by any of a wide range of procedures including clustering and maximum likelihood supervised classification. The number of classes in post classification change detection is the number of permutations of classes in the two classifications being compared. No classification is without error. Post classification change detection may potentially have a higher level of error than direct change detection. Overall accuracies for general land cover classification frequently range from 70 to 90 percent. The accuracy of post classification change detection is a product of the accuracies of the classifications being compared. The accuracy for post classification change detection, for example, would range from 49 to 81 percent, based on the range of accuracies for the input cover classification above. Post classification change detection does not place as strict a requirement on the similarity of the input images for the vegetation phenologic stage and other factors as direct change detection. Direct and post classification change detection each have advantages. One or the other or a combination of the two may be appropriate for a specific situation.

METHODS

The methods utilized in this project were dictated by the time, resources, and data available for the project, as well as the information requirements of watershed analysis. The anniversary dates of the scenes available in the NALC data set differed by as much as 35 days and were acquired in the late fall and early winter when the phenological state of the vegetation and extent of terrain shadowing are rapidly changing (Figure 1). Image calibration, which would have corrected for atmospheric and internal sensor variations between the images, would have been almost mandatory if we had elected to utilize direct comparison change detection procedures (Schott *et al.*, 1988). Calibration, however, would have added significantly to the complexity and cost of the project. In addition it was important for watershed analysis to know the trend in the proportion of vegetated versus non-vegetated land within the watershed and if the “no change” acres represented vegetated or non-vegetated land. To meet these requirements and constraints a hybrid processing strategy was devised that utilized a combination of direct and post classification change detection procedures.

Initial project activities focused on importing the images from CD ROM's, using the Imagine generic binary import option, and subsetting the images to reduce the “no data” portion of the image files (Figure 2.). NDVI images were computed from the 1980's and 1990's MSS images for each path/row location within the project area. The NDVI images were scaled to integer values in a range from 1 to 200. Portions of the NDVI images outside the intersection of the scenes were categorized “no-data”. The steps of computing and scaling the NDVI images and defining the area of intersection were performed utilizing a model written in the ERDAS Spatial Modeler Language (SML).

To identify the breakpoint between vegetated and non-vegetated land the NDVI images were visually compared to a 3-band color infrared display of the input images using the Imagine viewer swipe tool and manipulating the opacity of the NDVI images. NDVI values less than the breakpoint were recoded to a value of 1 (non-vegetated) and those greater than the breakpoint to a value of 2 (vegetated). A second SML model was created to perform a post classification change detection utilizing as input the two class (vegetated, non-vegetated) images from the decades of the 1980's and 1990's. The output vegetation change images included 4 classes (Figure 3). The Imagine clump routine was run on the vegetation change images to identify contiguous groups (8-way connected) of pixels in each cover class. Contiguous pixel groups or patches smaller than three pixels (1.08 hectares) were eliminated and recoded to the adjacent cover class using the Imagine eliminate function.

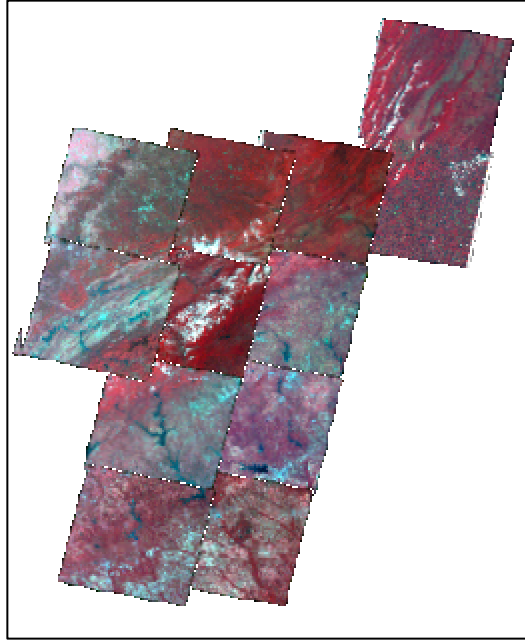


Figure 2. Partial Mosaic of Southern Appalachian National Forest Planning Unit MRLC Scenes

Portions of the scene with cloud cover cannot provide valid NDVI values. The NDVI values of water bodies are unpredictable and not indicative of land cover. A combination of unsupervised clustering and supervised classification was performed on each of the of the MSS images to identify cloud cover and water bodies. Unsupervised clustering was used to generate a set of 25 signatures representing the cover classes within each scene. The signatures served as input to a supervised maximum likelihood classification of each scene. Following classification, the cover classes representing clouds and water were identified visually and recoded to values 5 and 6 respectively. The remaining of the cover classes in each scene were recoded to 0.

Final vegetation trend data sets were produced by mosaicking the vegetation change and cloud/water images for the scenes needed to cover each National Forest and the associated watersheds. An Area of Interest (AOI) vector file previously created based on the extent of the watersheds was used to define the extent of the individual vegetation trend images. The output Imagine files were exported to ESRI Grid format and copied to CD ROM for shipment to the Planning Team hydrologist. The Planning Team was also provided with a document outlining the process by which the vegetation trend data sets were produced and a description of the limitations of the data. No formal accuracy assessment or verification of the vegetation trend data was performed. At the conclusion of the project intermediate and final products were backed up to CD ROM. Approximately 32 CD's were needed to backup the project image, vector, and model files.

1. Non-vegetated in both the 1980's and the 1990's. (Red)
2. Vegetated during the 1980's and non-vegetated during the 1990's (orange)
3. Vegetated during both the 1980's and 1990's (dark green)
4. Non-vegetated during the 1980's and vegetated during the 1990's (chartreuse)
5. Water during the 1980's or 1990's or both decades (blue)
6. Clouds during the 1980's or 1990's or both decades (white)

Figure 3. Change product classes

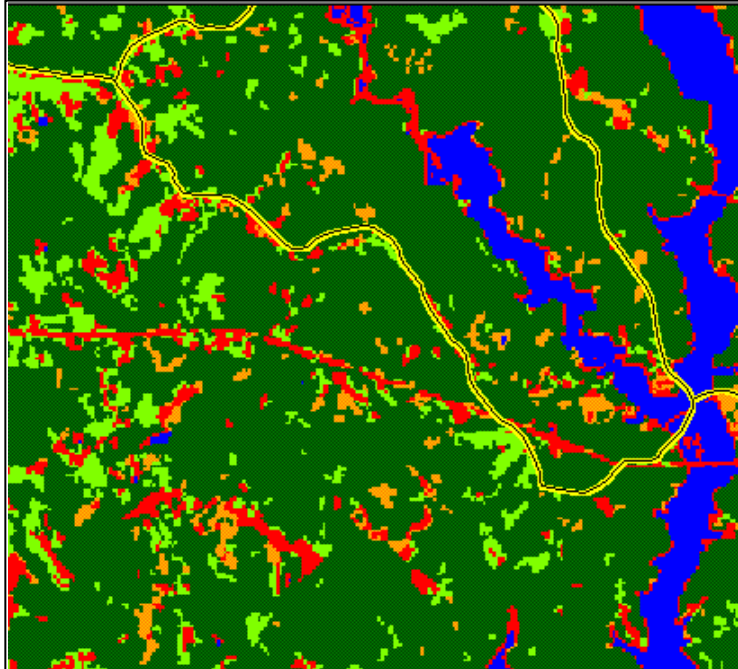


Figure 4. A portion of a watershed change image (with watershed boundaries in yellow and black)

OBSERVATIONS

This project was conducted utilizing Imagine 8.3 software provided through a participating agreement between the Southern Region and ERDAS. Help desk support was provided directly by ERDAS. Problems identified during this project may not be present in the Imagine software delivered under the IBM contract. Some of the problems we encountered were, no doubt, the result of our lack of user experience rather than shortcomings of the software.

The availability of sufficient disk space to process imagery is a significant issue in any project that encompasses multiple scenes. In this project which included 19 path row scene locations space was a continuing problem even on a workstation. A number of steps were taken to minimize the disk space requirements. NALC data sets include 7 bands, 4 MSS spectral bands, a pixel identity band, an elevation band and a spectral cluster band. Only the 4 spectral bands were imported for processing in this project. Approximately 51% of the NALC scene image raster values are no data or background data, substantially more than generic geocoded Landsat MSS imagery. The Imagine import function provides an option for lossless (run length encoding) compression of the imported Imagine file. Utilizing this option in importing the MRLC images reduced the file size by approximately 60%. After importing, the NALC images were subset to the minimum bounding rectangle of the image data to facilitate display, reduce file size and to preclude classifying the image identifier burned into the background. The Imagine subset function does not provide the option of compressing the output file. As a result, our subsetted images were 60% larger than the input images. This was true even though the subsetted images had 361 fewer columns and 543 fewer rows than the input images. We later learned that it is possible to maintain image compression during subsetting and in subsequent processing step by setting the spatial modeler preference setting for compression to "run length".

In our initial discussions of the project with the Forest Service Remote Sensing Applications Center (RSAC) it was suggested that we run a noise (low pass smoothing) filter on the images prior to calculating the NDVI (see also USDA Forest Service, 1999 p26-27). Based on examination of the data the application of a smoothing filter did not seem warranted. The data were already generalized or smoothed through the application of cubic convolution resampling kernel during image rectification. RSAC also suggested that we recode the NDVI images from the initially computed range of real numbers in a range from -1 to $+1$ to a consistent integer range of 0 to 200. Scaled integer values are easier to work with in subsequent processing and require less storage space. Including the value of

0 in the range of recoded values created a problem that was not detected until the initial products were delivered to the planners. Imagine use a single value, usually 0, to represent no data cells outside the image. Recoding the image to a range of values that included 0 resulted in a relatively few isolated cells within the image being coded to 0. These were basically holes in the image. An intermediate step was added to our NDVI model to recode these cells to a value of 1. It would have been more appropriate to initially recode the NDVI values to a range of 1 to 200.

Determination of the NDVI vegetated/non-vegetated breakpoint is a subjective decision on the part of the analyst involving detailed evaluation of the MSS imagery, NDVI images and ancillary data. The quality of the decision may be significantly affected by the analyst's image processing experience and familiarity with the area, as well as the ancillary data available to the analyst and the time available to reach a decision. Because of the variability in spectral response of vegetation some misclassification will occur even when a diligent effort has been made in the selection of the breakpoint. If this technique is used in the future, it would be desirable to determine the sensitivity of the classification results to small changes in the value of the vegetation change breakpoint. Non-vegetated areas may represent a number of cover classes including; land cleared for development, fallow agriculture, sparse pasture, forest harvest, early forest regeneration, and transportation features. Because of seasonal differences areas planted in annual agricultural crops may show up as either vegetated or non-vegetated depending on the timing of the image acquisition.

A combination of unsupervised and supervised image classification was used to identify water and cloud areas in the input MSS scenes. A maximum likelihood classification was performed on the input MSS images using the signatures created during a 25 class unsupervised clustering classification of each scene. Water and cloud classes were identified by inspection of the source imagery and review of the signature histograms. The use of supervised classification in the identification of water and clouds is the only portion of the change detection process described in this paper that cannot be performed using the basic Forest Service image processing software configuration. The additional step of running a supervised classification generally seemed to improve the classification of water bodies. If only the Forest Service basic image processing software is available, water and clouds can probably be adequately identified from the image derived from the unsupervised classification alone. Bodies of water free from sediment are generally represented in 1 or 2 distinct classes in the unsupervised classification. With the bands available in MSS imagery, sediment-laden water bodies will generally require significant additional effort to classify correctly. Areas of terrain shadow may be classified as water in MSS imagery. Additional signatures were not collected and evaluated to improve the accuracy of the water classification in this project because of time constraints. Stream networks were not consistently identified in the water classification. The delineation of water bodies and associated acreage information should be treated with caution. While larger water bodies are correctly classified streams and sediment-laden water bodies may not be consistently identified from MSS imagery. Cloud shadows, which can affect NDVI values, were not identified in the vegetation change classification.

CONCLUSIONS

Detection, classification and monitoring of major changes in landscape patterns are crucial to understanding the cumulative large-scale effects of past, present and future forest management decisions on watershed health. Analysis including private and public lands is crucial to evaluating the health of the watersheds, that Forest Service management activities effect. The use of satellite imagery makes this both monetarily feasible and timely in today's environment of shrinking budgets and advancing technologies. All processing for this project was performed by the junior author, a GIS specialist on the Chattahoochee and Oconee National Forests. While the work was performed under the direction of the Regional Remote Sensing Specialist, other sites should be able to implement the procedure with appropriate technology transfer materials and basic Imagine training. The Forest Service advanced image processing workstation, available under the Forest Service IBM contract, was used to conduct the project. The cost to provide the vegetation change data to the planning team was \$13,000 or approximately \$.62 per thousand acres of watershed area. The cost included salary for the GIS specialist performing the work and the prorated cost of the workstation. The change detection procedure described in this presentation provides a robust technique for identifying change in the proportion of vegetated area within watersheds to support watershed trend analysis.

LITERATURE CITED

Lunetta, Ross S, J. G. Lyon, B. Guidon, C. D. Elvidge. North American Landscape Characterization Dataset Development and Data fusion Issues. (1998). *Photogrammetric Engineering & Remote Sensing*, 65(8) 821-828

Lyon, John G., Ding Yuan, Ross Lunetta, Chris elvidge. A Change Detection Experiment Using Vegetation Indices. (1998). *Photogrammetric Engineering & Remote Sensing* 64(2) 143-150

Schott, John R., Carl Salvaggio, and William J. Volchok. 1988. Radiometric scene Normalization Using Pseudoinvariant Features. *Remote Sensing of Environment*. 26 1-16

Townshend, John G. R., Christopher O. Justice, Charlotte Gurney, and James McManus. (1992). The Impact of Misregistration on Change Detection. 1992. *IEEE Transactions on Geoscience and Remote Sensing*. 30(5) 1054-1060

USDA Forest Service. Implementation of Remote Sensing for Ecosystem Management. (1999). USDA Forest Service Remote Sensing Applications Center, Salt Lake City UT. 48pp.