MONITORING FOREST REGROWTH USING A MULTI-PLATFORM TIME SERIES

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1. INTRODUCTION

Over the past 50 years, the forests of western Washington and Oregon have been extensively harvested for timber. This has resulted in a heterogeneous mosaic of remaining mature forests, clear-cuts, new plantations, and second-growth stands that now occurs in areas that formerly were dominated by extensive old-growth forests and younger forests resulting from fire disturbance (Spies and Franklin, 1988). Traditionally, determination of seral stage and stand condition have been made using aerial photography and spot field observations, a methodology that is not only time- and resource-intensive, but falls short of providing current information on a regional scale. These limitations may be solved, in part, through the use of multispectral images which can cover large areas at spatial resolutions in the order of tens of meters. The use of multiple images comprising a time series potentially can be used to monitor land use (e.g. cutting and replanting), and to observe natural processes such as regeneration, maturation and phenologic change. These processes are more likely to be spectrally observed in a time series composed of images taken during different seasons over a long period of time. Therefore, for many areas, it may be necessary to use a variety of images taken with different imaging systems. A common framework for interpretation is needed that reduces topographic, atmospheric, instrumental, effects as well as differences in lighting geometry between images. The present state of remote-sensing technology in general use does not realize the full potential of the multispectral data in areas of high topographic relief. For example, the primary method for analyzing images of forested landscapes in the Northwest has been with statistical classifiers (e.g. parallelepiped, nearest-neighbor, maximum likelihood, etc.), often applied to uncalibrated multispectral data. Although this approach has produced useful information from individual images in some areas, land-cover classes defined by these techniques typically are not consistent for the same scene imaged under different illumination conditions, especially in the mountainous regions. In addition, it is difficult to correct for atmospheric and instrumental differences between multiple scenes in a time series. In this paper, we present an approach for monitoring forest cutting/regrowth in a semi-mountainous portion of the southern Gifford Pinchot National Forest using a multisensor-time series composed of MSS, TM, and AVIRIS images.

2. METHODS

The time series was composed of five spatially co-registered images: two MSS images (26 June and 30 September 1987, two TM images (7 July 1991 and 31 July 1994), and one AVIRIS image (30 September 1994.). Bands in the 1.4-µm and 1.9-µm water absorption features were not used in analysis of the AVIRIS data, leaving 180 of the original 224 bands. An extension of spectral mixture analysis called Foreground-Background Analysis (FBA) (Smith et al., 1994, 1995) was subsequently applied to these data. Like simple mixing models, the objective of FBA is to obtain quantitative abundance estimates (fractions) of spectral endmembers. However, unlike simple mixing models which typically use three to five endmembers, in FBA a rotation of the spectral data space is found that minimizes the spectral variability within the set of spectra that represent a sought-after "foreground" material (e.g. green vegetation in this study), and at the same time maximizes the contrast between the foreground set and other materials or shade which are treated as "background." In this study, background included spectral variability from multiple sources, such as subtle atmospheric variations, endmember variability, calibration differences, photometric effects from varying viewing and illumination angles, and multiple scattering. The general set of equations for FBA is:

$$\text{Foreground: } 1 = \sum_{b=1}^{Nb} w_b DN_b + c$$

$$\text{Background: } 0 = \sum_{b=1}^{Nb} w_b DN_b + c$$

where a vector w is defined as a projection in hyperspace of all foreground DNs as 1 and all background DNs as 0. Nb is the number of bands and c is a constant. The vector w and constant c are simultaneously calculated from the above equations using singular-value decomposition. When applied to each of the five data sets, a total of five images, each representing the relative fraction of foreground (green vegetation in this study) in each scene, were produced. From these data the change in the fractions over time for each forest stand was evaluated and compared to U.S. Forest Service cutting/replanting records.

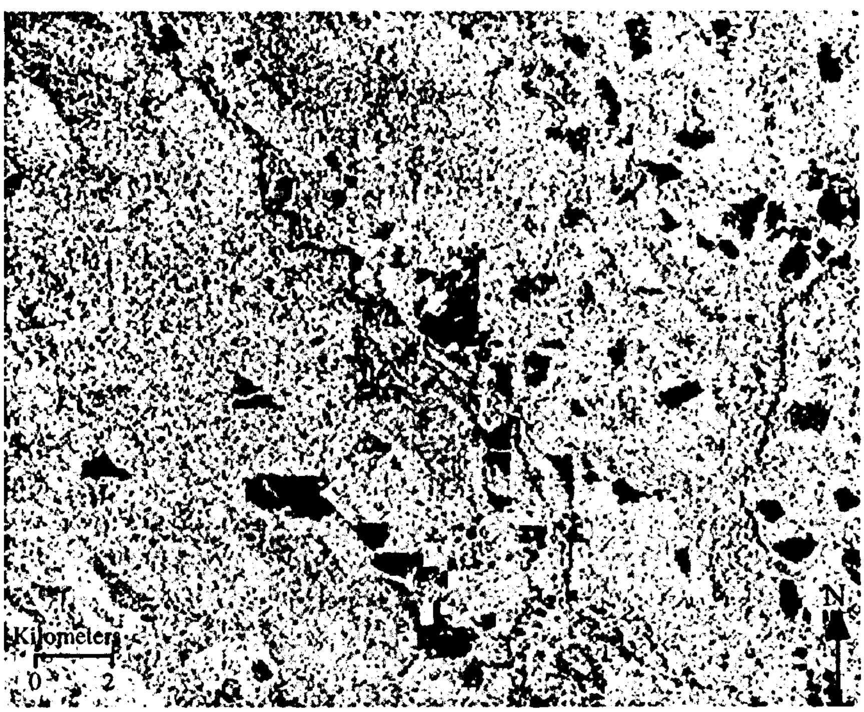
2. RESULTS / DISCUSSION

FBA suppressed topographic effects, and minimized the effects of atmosphere and clouds. An example from the 1994 AVIRIS image is shown in Figure 1. Here, the effectiveness of topographic "removal" can be seen by comparing the 846-µm band, which contains topographic information, to the scaled FBA vegetation fraction image, calculated using 180 of the AVIRIS bands, in which shade has been removed. This removal was effective because in FBA shade can be treated more realistically than in simple mixture models as a range of spectra (Roberts et al., 1991). Shading, shadow, sky-illuminated shadow, bounce-illuminated shadow, and various expressions of vegetation shade all were be grouped as background and "removed" from the image. Because detection of green vegetation was optimized in this application of FBA, the fraction of green vegetation was determined even in areas that were poorly illuminated (e.g. shaded slopes).

Figure 2 shows the change in the fraction of green vegetation over seven years for four representative forest stands. The date of cutting was obtained from U.S. Forest Service records. Forests have a high index (~100) prior to cutting, after which the index drops close to zero. As the cut areas regrow, the index of green vegetation generally increases, although it varies in response to management practices in the area (e.g. burning, thinning, clearing of underbrush).

The distinctive temporal signatures of regrowth and phenologic changes are difficult to determine in this series due to the low temporal resolution. For example, annual images in the series would greatly improve evaluation of regrowth, while determination of phenologic changes would be enhanced with monthly images. However, cutting and general regrowth history can clearly be determined using these images, even in stands that are poorly illuminated due to topography. Our FBA approach shows a vast improvement over our earlier results on a single image where reconstruction of cutting history was reliable only in areas of low relief (Sabol et al., 1995).

AVIRIS Band Image (848 μm)



FBA Scaled Vegetation Index Image

Figure 1 - FBA results for an area in the southern Gifford Pinchot National Forest, Washington using AVIRIS (9/30/94) data. Note that the topography is flattened in the scaled vegetation index image (lighter tones indicate a higher abundance of green vegetation).

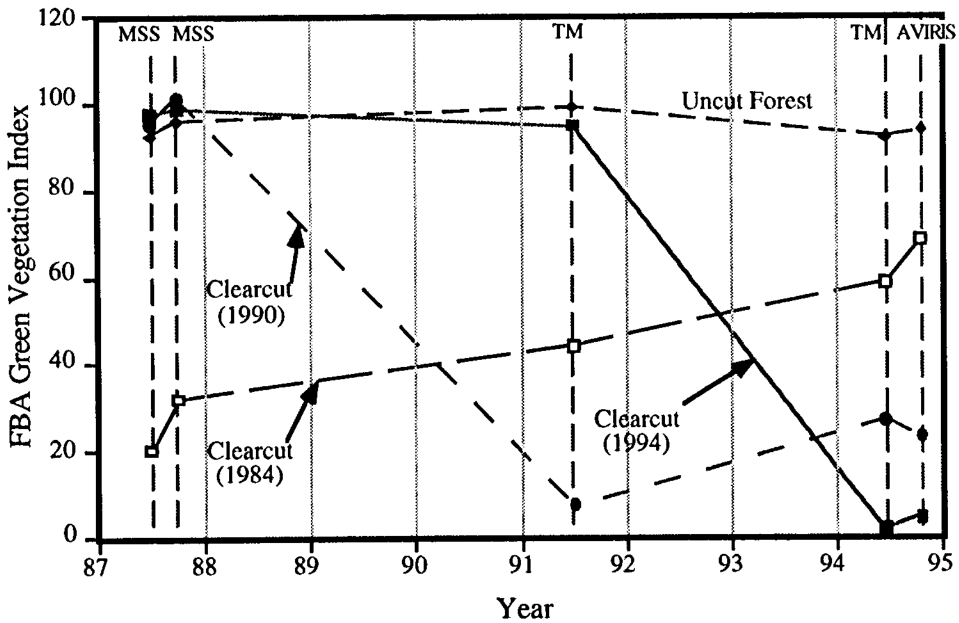


Figure 2 - Change in the FBA vegetation index over time for three clearcuts in the Gifford Pinchot National Forest, Washington. The temporal signature for clearcuts is a rapid decline of vegetation followed by a gradual increase during regrowth.

Because of the low spectral resolution of MSS and TM in the time series and because we have only a single AVIRIS image, we concentrated on optimizing green vegetation for evaluating seral stage instead of a full evaluation of forest endmembers. However, the high spectral resolution of AVIRIS allows estimation of non-photosynthetic vegetation (i.e. bark, stems) (NPV) as an additional parameter for monitoring seral stage and stand health. Sabol et al. (1995) found that detectable fractions of NPV are present in young forests (< 10 years) and may be present in old-growth forests (> 250 years), which may aid in distinguishing old growth stands from other mature forests (100-200 years old). Calibrated AVIRIS spectra from stands of different ages are shown in Figure 3. Downed trees, bark, and branches typically cover the surface of recent cuts. As a result, these sites have a strong NPV component, characterized by absorption features at 2.09 μm (xylan and cellulose) and at 2.13 μm (lignin) (Elvidge, 1987). Within two years, the spectral signature is dominated by invading deciduous bushes and ferns which have a high green vegetation index. In time, replanted coniferous trees become spectrally dominant. The increase of shade/shadow associated with the canopy structure of coniferous forests reduces the overall reflectance of the stand.

3. CONCLUSION

FBA was used to establish a stable framework for evaluation of regrowth history, even when using images taken at different times (different lighting and atmospheric conditions) in mountainous terrain. The stability of this framework in optimizing the detectability of green vegetation allows incorporation of images with low spectral resolution (i.e. Landsat) as well as newer, higher resolution systems (i.e. AVIRIS) into as time series for monitoring forest regrowth.

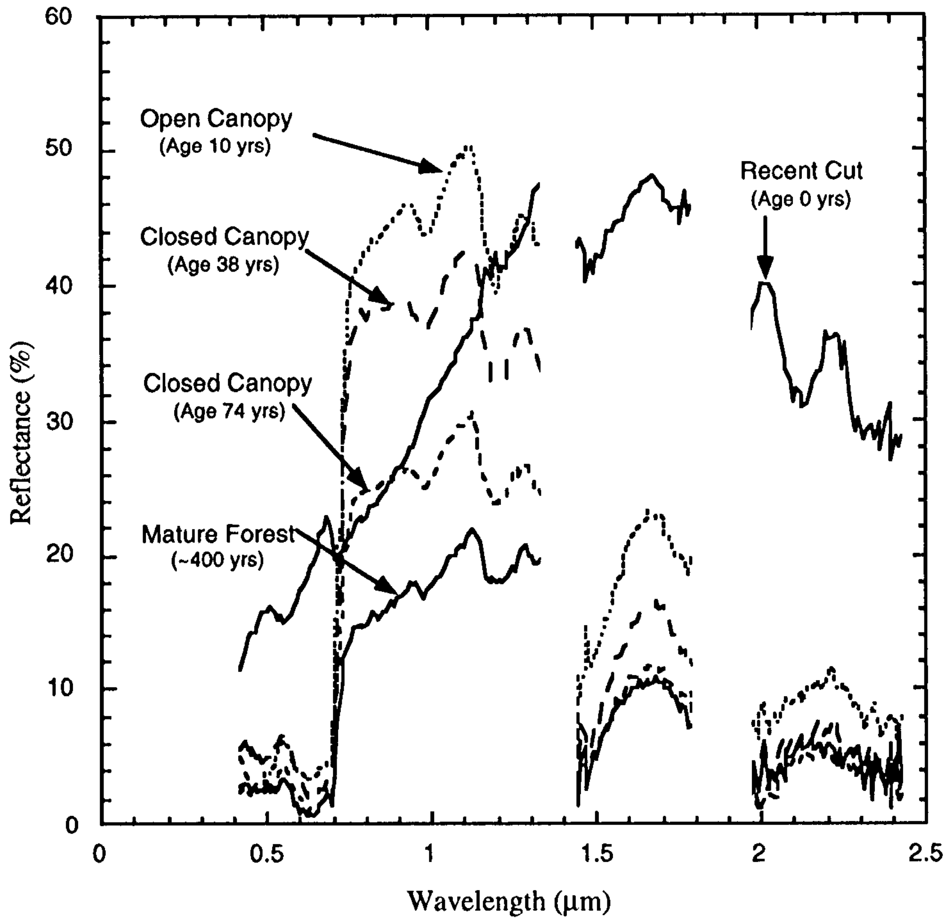


Figure 3 - AVIRIS spectra of different age stands. The surface of the recent cuts are covered with bark, branches and wood scraps resulting in a strong NPV signature (cellulose and lignin absorptions between 2.0-μm and 2.2-μm). Within two years of cutting, brush and ferns invade the area and result in a bright green vegetation signature. As the stand ages, replanted coniferous trees (and the shadows cast by them) gradually dominate.

The low resolution of MSS and TM make spectral separation of NPV and many soils unreliable. Hence, we limited the determination of cutting and replanting history to the changes in the abundance of green vegetation in the scene over time. However, the distinctive absorption features of NPV (cellulose and lignin between 2.0-μm and 2.2-μm) are more detectable using the high resolution of AVIRIS. With the addition of future AVIRIS data of this area to the time series, NPV as well as green vegetation may be used further improve monitoring of cutting, regrowth, and phenology.

4. REFERENCES

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