AVIRIS SPECTRAL TRAJECTORIES FOR FORESTED AREAS OF THE GIFFORD PINCHOT NATIONAL FOREST

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1. INTRODUCTION

In the Pacific Northwest, the practice of clear-cutting and replanting of "old-growth" (250+ year old) forest over the past 40 years has resulted in large areas of replanted trees in various stages of regrowth. How quickly a clear-cut area regrows is a function of many factors (e.g. soil condition, sun exposure, moisture availability, replanting history, elevation, etc.). Monitoring regrowth status is important for management decisions. Clearcutting has greatly decreased the amount of "old-growth" forests. For example, it was estimated that less than 28% of the major national forests of western Washington, Oregon, and northern California was old growth in 1990 (Morrison et al., 1991), raising questions of species diversity and overall forest "health." This estimate is very rough and hotly debated as it is difficult to separate mature forest from old-growth forest using remote sensing. Therefore, it is still uncertain how much "old growth" exists and where all of it is located.

In this study, we applied spectral mixture analysis to an AVIRIS image of a portion of the Gifford Pinchot National Forest, Washington to: 1) estimate forest regrowth stage and to provide a framework for monitoring the regrowth over time, and 2) present initial work on mapping old-growth forest as separate from other mature forest.

A simple mixing model using reference endmembers of green vegetation (GV), non-photosynthetic vegetation (NPV), soil, and shade was applied to a September 22, 1994 AVIRIS image of a portion of the Gifford Pinchot National Forest. Noisy bands were excluded leaving 180 of the 224 bands. The image data were calibrated to reflectance using spectral mixture analysis (Gillespie et. al, 1990). Results from the AVIRIS image were compared with a similar analysis of a 1992 Landsat TM image of the same area.

Fractions of endmembers were computed for each AVIRIS pixel and displayed as images. The shade-fraction image included the effects of topographic shading and shadow, as well as shade contributed by textural elements, such as forest canopy at the subpixel scale. In our analysis of the TM image topographic shade was "removed" by a digital elevation model (DEM), thereby enhancing the component of shade contributed by canopies. Registration of the DEM to the AVIRIS image is not completed: therefore, this report considers only a portion of the image that has moderate to low relief.

Means of fractions in the AVIRIS image were measured for variable sized blocks of pixels (3 by 7 and greater, depending on the size and shape of each site) at 90 sites known from field surveys (Fig.1). The sites included clearcuts of different ages, mature forest and old-growth forest. Field data were obtained from the US Forest Service and gathered by the authors in July and August of 1994. In the context of the field data, the simple mixing model provided a framework for understanding the main differences in surface cover: however, it was not expected that four endmembers would model the full spectral complexity of the scene.

2. RESULTS

2.1 Forest Regrowth

Recent clearcuts were characterized by high fractions of NPV and low fractions of GV and shade. Burned clearcuts had enhanced fractions of apparent shade, caused by charcoal and dark ash mimicking the spectrum of shade. Clearcut areas with partial cover of ferns, grasses, forbs, and shrubs had low to moderate fractions of GV, without a significant component of shade.

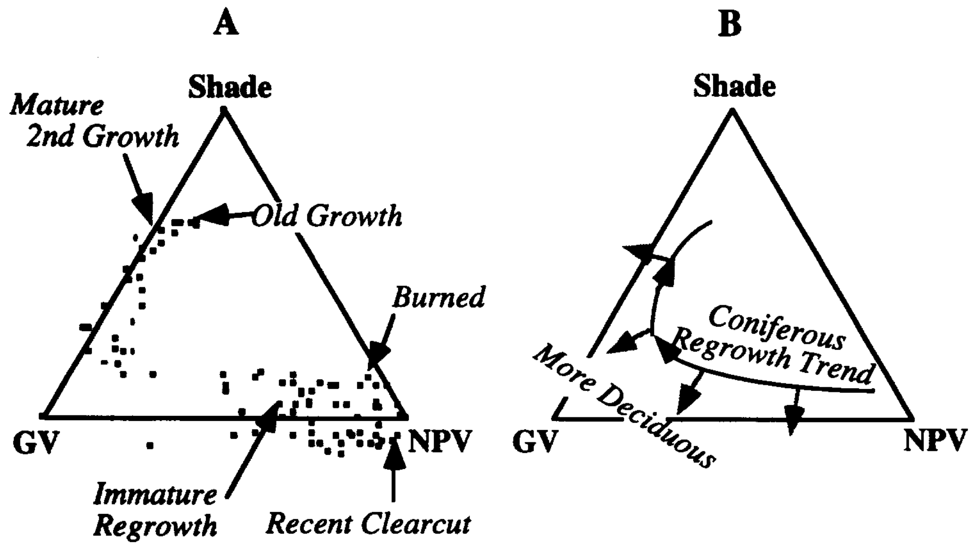

Figure 1. A) Ternary scatterplot of mean fractions for 90 sites (clearcuts of different ages, mature forest and old-growth forest). B) Generalized regrowth trends observed in the image data.

Typically, clearcuts were replanted with conifers within 1 to 3 years, most commonly with *Pseudotsuga menziesii* (Common Douglas Fir). With increasing cover, stands had correspondingly higher fractions of GV and shade, along with a decrease in the fraction of NPV. Closed-canopy stands had low (<0.1) fractions of NPV (contributed by exposed branches) and intermediate values of shade (Fig.1A). Older stands with increasingly complex canopies had higher fractions of shade. Pure stands of conifers of various ages defined a trajectory in the ternary fraction diagram (Fig 1B).

Although trees replanted in this part of Washington are exclusively coniferous, deciduous species such as *Alnus rubra* (Red Alder), *Acer circinatum* (Vine Maple), and various species of ferns occurred within many of the cut areas. Clearcuts containing deciduous species had higher fractions of GV than those with just conifers. Areas dominated by deciduous regrowth had the highest GV fractions, plotting farthest from the trend line (Fig. 1B) for pure coniferous regrowth.

For each of the 90 test areas on the AVIRIS image, ages of stands were determined from Forest Service records of date of planting. Stand age was compared with endmember fractions. The coniferous regrowth trend defined a general increase in age for the test areas on the image (Fig. 2). Fractions changed rapidly during the first decade as regrowth obscured the substrate. With further maturation of the stands, the rate of change of the fractions slowed, and the main effect was an increase in shade.

There was considerable scatter of ages along the coniferous regrowth trend. Although the general trend was clear, it was not possible to invert the AVIRIS spectral data to arrive at an unambiguous stand age for each test area. Various factors influenced rate of regrowth, including altitude, slope, aspect, soil conditions, disease, and management history. These factors would have to be known to use the spectral data to infer stand age; however, obvious departures from the main regrowth trend might be used to identify stands with retarded growth rates.

2.2 Old Growth

Mature forest and old-growth forest are spectrally similar in both TM and AVIRIS data. Both forests types have similar fractions of GV and relatively high fractions of shade. Separation can be complicated by the presence of topographic shade and shadow. It was possible to identify old growth in a TM image by high mean fractions of "textural shade" and high pixel-to-pixel variability in shade, after isolation of the main topographic effects with a cosine correction based on DEM data. No clear change in NPV was measurable in the TM data above the system noise, although field observations indicated exposure of woody material in the crowns of old-growth forests.

The AVIRIS image was used to test whether it was possible to detect a higher fraction of NPV in old growth relative to mature forest. Based on field observations we predicted that when the coniferous regrowth trend reached old growth it would hook back toward NPV (Fig. 2). The AVIRIS data showed the old growth to be higher in NPV than mature forest by 0.03 to 0.05. A 3 to 5% increase in NPV is detectable by AVIRIS, based on our experience with other test areas (Sabol et al., 1992). If this result is

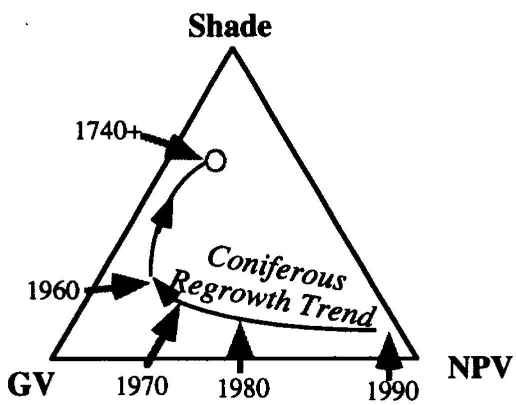

Figure 2. Mean date of replanting for 90 sites (clearcuts of different ages, mature forest, and old-growth forest).

confirmed by further analysis it provides a second spectral parameter by which to characterize old growth (the other being shade and shade variability). A more sensitive measure of NPV can be made using the new method of foreground-background analysis (Smith et al., 1994). This work is in progress.

The simple mixing model was used to locate old growth throughout the image. Within the image 13.6 % of the area was mapped as old growth. This result is in good agreement with the 11.2 % mapped by the Wilderness Society (Morrison et al., 1991). The comparison will be repeated after further analysis of the AVIRIS data to remove topographic shade and to increase the reliability of the NPV estimate.

3. CONCLUSION

A simple mixing model employing reference endmembers (green vegetation, non-photosynthetic vegetation, soil and shade), and using 180 AVIRIS bands, was used to established an interpretive framework for a forested area in the Pacific Northwest. A regrowth trend, based on changes in the endmember proportions, was defined for conifers that extends from clearcuts to mature forest, and by implication to old growth. Deciduous species within replanted forest plots caused the fractions to be displaced from the main coniferous regrowth trend and to move toward the green vegetation fraction. The results indicate that the spectral information in AVIRIS can be inverted to estimate approximate stand age and relative proportion of deciduous species in the context of the area studied.

Using AVIRIS we measured a 3 to 5% increase in woody material in old-growth forest, as distinct from other mature forest. This result is consistent with a predicted increase in NPV in old-growth forests, based on field observations. Previous application of the mixing analysis to a TM image of the same area separated old growth based solely on the shade fraction; however the approach required successful removal of shade introduced by topography. Our new results suggest that with the high spectral resolution and high signal-to-noise of AVIRIS images it may be possible to characterize and map old-growth forests in the Northwest using both the NPV fraction and shade.

4. REFERENCES

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