

Monitoring Post-Fire Vegetation Regeneration in a Madrean Ecosystem

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Abstract—Fire suppression over the past century has contributed to the conversion of grasslands to shrublands in Sky Island communities. Two prescribed fires were ignited in the Peloncillo Mountains: Baker Canyon in 1995 and Maverick Spring in 1997. Remote sensing data were used to examine prescribed fire effectiveness in reducing shrub cover and to monitor post-fire regeneration. Landcover maps identified an initial decrease in shrubcover due to foliage loss and top-killing, with shrubcover increasing in following years where low burn severity did not kill shrubs completely. Results indicate the need for a regular schedule of prescribed fire to achieve permanent shrubcover reduction.

Introduction

Sonoran and Chihuahuan Desert ecosystems have been identified as major biodiversity “hot spots” because they contain an abundance of unique flora and fauna concentrated within a relatively small geographic area (Mittermeier et al. 2003). In particular, the Madrean Archipelago is the only sky island complex extending from subtropical to temperate latitudes and contains an exceptionally diverse pattern of flora and fauna. The conservation status of this area has been declared “vulnerable,” with recent research indicating deterioration due to climate change, wildfire, grazing, suburbanization, and invasive species. Monitoring land cover modifications is crucial to understanding the role and effects of disturbances, and quantitative research is needed to understand what changes are occurring, the rate of occurrence, and how to minimize impacts of change through land management methods.

Fire suppression over the past century has caused significant change in Madrean ecosystems. The semi-arid grasslands located throughout the Madrean complex require frequent, low intensity fires to keep shrub encroachment in check. Local ranchers decided, with the help of the Forest Service, to reintroduce fire in these deteriorating grasslands. Two prescribed fires were ignited in the Peloncillo Mountains: Baker Canyon in 1995 and Maverick Spring in 1997. The purpose of this research was to examine the effectiveness of prescribed fire in reducing shrub cover and to monitor post-fire regeneration patterns using remote sensing.

Study Area

The Peloncillo Mountains extend north and south along the Arizona-New Mexico border near the United States-Mexico border. Baker Canyon and Maverick Spring are located in

the southwestern portion of the Peloncillo Mountains with elevations ranging from 900 to 2,000 meters. Vegetation communities found in both areas include semi-arid grasslands, shrublands, and some Madrean woodlands. Baker Canyon covers an area of 41 sq km and Maverick Spring covers an area of 76 sq km. While a substantial percentage of the Baker Canyon site burned in 1995, only a small percentage of the Maverick Spring site burned in 1997.

Data

This study used eighteen Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper-plus (ETM+) images, broken into two seasonal sets of annual images from 1994 to 2002, with anniversary dates in February and August of each year. Station-collected precipitation data from the National Climatic Data Center (NCDC) were used in conjunction with Landsat TM and ETM+ data to provide evidence of vegetation phenological state. Ancillary data included 1 m spatial resolution color infrared digital orthophotoquarterquadangles (DOQQ) from 1997 and 1998, field plot measurements of percent bare, grass, and shrub cover in each study area acquired in June and July 2003, and digital photographs of plot sites and other parts of the study areas acquired in June, July, and August 2003. Other ancillary data incorporated in this research were vegetation maps generated during prior research in this area (Muldavin et al. 1998).

Methods

Field Observations

Post-fire field observations in Baker Canyon revealed large expanses of grassland in areas that were once occupied by shrubs such as tarbush, acacia, and mormonia. This confirms

the assertions made by Rogan and Yool (2001) because the most severe damage caused by the prescribed burn occurred in shrub-dominated areas. Some regeneration was seen in areas dominated by *Juniperus monosperma* and *Prosopis glandulosa*; however, many shrubs were killed completely with only snags remaining. Observations in Maverick Spring revealed only a few patchy areas of shrub mortality and resulting new grassland where high burn severity was experienced. Most of the area experienced low burn severity, and *Juniperus monosperma* and *Prosopis glandulosa* regenerated robustly. The magnitude of change in Maverick Spring was nearly negligible in terms of the spatial resolution used in this research.

Image Processing

Landsat TM and ETM+ data were projected to UTM WGS 84, and images were coregistered to each other to within less than 0.5 pixels (15 meters). Atmospheric correction was performed using a dark object subtraction technique to remove atmospheric path radiance. Standard orthorectification was omitted from this research intentionally in order to take full advantage of the built in topographic shade reduction technique in the unmixing algorithm.

The entire Landsat TM and ETM+ dataset was transformed using spectral mixture analysis (SMA), a linear unmixing algorithm that calculates a least-squares best fit for each pixel along a mixing line extending between the endmembers for each image band. Fraction images of each endmember were produced, each representing the per-pixel fractional amount of the given endmember. Prior to performing SMA on the two datasets, the image spectra were evaluated to derive candidate pure image endmembers for green vegetation (GV), non-photosynthetic vegetation (NPV), soil and photometric shade. Four image endmembers were chosen to represent the fractional land cover for the study area. In this case, GV was green grass, NPV was a mix of non-photosynthetic grasses, Soil was bright-bare soil, and shade was deep water.

Accuracy Assessment

Validation was performed using the root-mean square error (RMSE) image to calculate the fit of the model to the given endmembers and measure the spectral residual not explained by the model. In addition, DOQQs and field-collected data were used to quantify the accuracy of the fraction images. Boundaries of the test sites (chosen via stratified random sampling) were selected and identified on the DOQQs, and areas of the polygons were calculated to represent the reference data. For each polygon, the percentage of corresponding endmember fractions in the pixels was summed to indicate the area of the polygon estimated by SMA. This amount was compared to automated canopy cover measurements calculated on the DOQQs. Endmember fraction accuracy was identified as the mean of the percentage absolute difference between actual (DOQQ and field data) and modeled (TM/ETM+ fraction images) cover estimates.

Results

Spectral Mixture Analysis

An average percentage was computed for each endmember in each area for February and August to track change over time. In the February imagery, the endmember fractions did not exhibit much variability. Low precipitation amounts and resulting lack of vigor are responsible for diminished signal. In the August imagery, GV and NPV were influenced strongly by precipitation variability and associated vegetation phenological state. Soil and Shade remained relatively constant, indicating both were well modeled. Results of the comparison between August and February image sets indicated August is the best time period for this work, since the regeneration signal is peaked during the monsoonal greenup. The shade fraction was influenced significantly by topographic effects from mountainous terrain, indicating it worked well in removing topographic shade from the image. This demonstrates the suitability of the shade fraction as a substitute for standard topographic normalization procedures (O'Neal 2004). Average RMSE values fell below 0.025 ρ , with the exception of areas with dark, rhyolitic soils.

The endmember fraction trends from August in Baker Canyon exhibited a strong regeneration signal. The pattern produced by the signal displayed a divergence between post-fire GV and NPV and indicated an inverse relationship between these endmembers. The signal was lost in 1999 when an above average amount of precipitation fell in the study area, which caused a sudden, dramatic increase in the GV fraction and in turn reduced the amount of NPV.

The endmember fraction trends from August in Maverick Spring did not appear to contain a clear regeneration signal. There was a decrease in GV and an increase in NPV; however, the trends did not appear to be correlated completely since the decrease in GV was gradual and the increase in NPV was sudden; this signal was also lost in 1999. The control area endmember fraction trends in August looked very similar to those from Maverick Spring and supported observations from fieldwork in Maverick Spring of a small area experiencing significant burn. Results indicated better spatial and/or spectral resolution is needed to examine lower intensity fires with less visible damage.

Accuracy Assessment

Endmember validation was performed on the August 1997 and the February 1998 SMA fraction images, since they were closest in date to the DOQQs acquired in late 1997 and early 1998. Accuracy rates were extremely high for NPV in both dates, and within an acceptable range for GV and Soil, indicating fractional estimates for these endmembers were generally accurate. Lower accuracy for GV was attributed to different vegetation phenological states between reference data and imagery. Accuracy rates for Soil were expected to be low, due to the extreme spectral differences between the dark and bright soils. Fraction validation was not performed on the

Shade endmember due to illumination differences between reference data and imagery.

Conclusions

From an operational standpoint, this work combines a reasonable dataset and method for evaluating the effectiveness of prescribed burns and assessing regeneration pace and magnitude over time. Landsat TM and ETM+ data provide a cost effective view of the area and SMA offers a method for viewing biophysical differences due to fire. This research presents an excellent foundation for future post-fire regeneration monitoring and offers encouraging contributions to Madrean ecosystems research.

References

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