Monitoring Resources in the Fremont-Winema National Forest and Yosemite National Park Using Satellite Imagery

Galli Basson, ARC DEVELOP, Mail Stop 242-4, Earth Science Division, Biospheric Science Branch, NASA Ames Research Center, Moffett Field, CA 94035; gbasson@mail.arc.nasa.gov

Cindy Schmidt, ARC DEVELOP, Mail Stop 242-4, Earth Science Division, Biospheric Science Branch, NASA Ames Research Center, Moffett Field, CA 94035; cschmidt@mail.arc.nasa.gov

J. W. Skiles, ARC DEVELOP, Mail Stop 239-4, Earth Science Division, Biospheric Science Branch, NASA Ames Research Center, Moffett Field, CA 94035; Joseph.W.Skiles@nasa.gov

Introduction

The DEVELOP program is a student run and led internship program that creates pilot demonstration projects, with supervision from NASA scientists, under the Earth Science Division at NASA Ames Research Center. During an intensive 10-week program DEVELOP students use NASA facilities, techniques, computers, and technology for research primarily directed toward environmental issues, community development, management, and/or local policy.

The objective of this paper is to illustrate to resource managers how NASA Earth science data and imagery can be used as decision support tools for forest management. The use of NASA Earth science data and technology in environmental management applications is demonstrated by three projects completed by students in the NASA Ames DEVELOP program over the last three years. Each of the three following projects incorporated NASA Earth science data and technology, computer analysis, and field work. The U.S. Forest Service or the National Park Service were collaborators for these studies.

Fire behavior modeling and carbon budget in the Fremont-Winema National Forest, Oregon

The state of Oregon is a significant area to study carbon sequestration in forests because it is the leading provider of lumber in the United States. Within the 2.3 million acres of the Fremont-Winema National Forest (Figure 1), approximately 12 million cubic feet of timber is harvested annually for sale and to reduce fuel loads (N. Michaels, pers. comm.). Forest managers were interested in how timber harvesting and forest fires affect the carbon budget within the forest. In order to address these issues, the project contained two main components: fire behavior characteristic modeling and carbon simulation modeling. Both of these components used a combination of satellite imagery and field data.

Fire modeling

Due to the selective timber cutting that occurs throughout the Fremont-Winema forest, re-plantings of tree species such as mono-aged, thin-bark lodgepole pine (*Pinus contortus*) have replaced diverse-aged and more fire resistant communities of ponderosa pine (*Pinus* *ponderosa*) and Douglas fir (*Pseudotsuga* sp.) which has resulted in increased fire risk. Fremont-Winema forest managers were interested in fire behavior modeling to identify locations in the forest that might require prescribed burns or selective cutting due to accumulated fuel load.

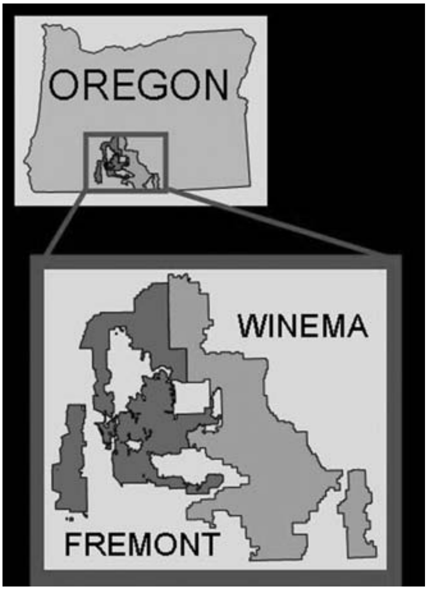


Figure 1. Location of Fremont-Winema National Forest.

The fire model used for this project is a software program entitled FlamMap, produced by the Fire Sciences Lab in Missoula, Montana, which computes potential fire behavior characteristics for constant weather and fuel moisture conditions. The inputs used for FlamMap included geographic data layers such as elevation, slope and aspect, remotely sensed data, and weather data. The outputs of the fire behavior model are rate-of-spread, which indicates how quickly a fire moves across a landscape, and flame length, which is an indication of fire intensity. Combined, these two maps can be used as a decision support tool to estimate fire risk and identify target areas for fuel-load reduction treatments. Fuel-load reduction treatments such as clearing slash and fallen trees to prevent large fires could also act as management tools to preserve the forest's carbon budget.

Carbon budget modeling

The forest's carbon budget was analyzed using the NASA Carnegie-Ames-Stanford-Approach (CASA) model. The NASA-CASA model is an internationally recognized carbon simulation model that estimates Net Primary Productivity (NPP) and soil heterotrophic respiration at regional to global scales. The model was set to simulate Net Ecosystem Productivity (NEP) over a 100-year re-growth period for two different harvest scenarios consisting of high and low slash values, in three climate regions throughout the forest. Other inputs to the model include vegetation, elevation, Fraction of Photosynthetically Active Radiation (FPAR), and soil texture.

According to results of the CASA model, wood harvest scenarios deplete the forest of several years of non-recoverable NPP carbon inputs. The results show that NPP will begin to decrease after 50-years of re-growth. Even after 100 years, drier climate areas still retain negative NEP flux. Ecosystems of this type do not contain enough productivity to recover completely from harvest losses of carbon and the slash and natural soil pool decompositions that follow.

An important and unanticipated finding of this project is based on our inputs to the NASA-CASA model, NEP will continue to decrease every time timber is harvested regardless of how long a forest is left to regenerate after selective-cuts. This finding should alert forest managers to the carbon sequestration effects of excessive timber harvesting. All of the data, maps and findings were turned over the Fremont-Winema National Forest for possible use in their 2005 management plan as decision support tools (Cleve et al. 2005).

Vegetation recovery in fire scars in Yosemite National Park, California

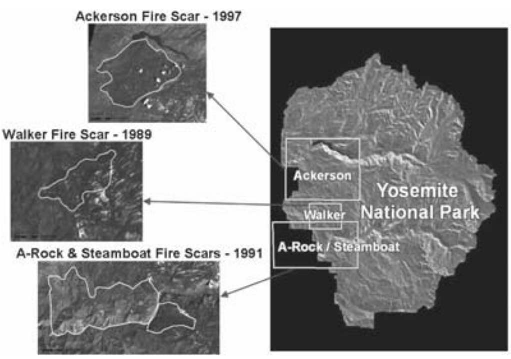
Remotely sensed data utilized for projects addressing landcover changes traditionally concentrate on detecting deforestation; however, studies have also successfully detected forest regeneration and succession with remotely sensed data (Foody et al. 1996; Fiorella and Ripple 1993). A thorough fire management plan includes long-term considerations such as assessing forest regeneration, which creates important, but not always obvious, forest changes. The objective of this project was to study subtle long-term post-fire regeneration changes in order to aid natural resource managers in long-term fire management decisions.

A total of four fire sites were assessed for this project within Yosemite National Park: A-Rock, which burned in 1990; Steamboat, 1990; Walker, 1988; and Ackerson, 1996. The sites were selected based on the criterion of resource management interest, accessibility, and availability of cloud free imagery. All four fires were naturally started by lightening and burned various vegetation zones.

Landsat imagery from the Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) sensors were analyzed for the years between 1988 and 2004 and vegetation indices were selected to enhance interpretability of change patterns (Figure 2). Specifically, the normalized differenced vegetation index (NDVI) and normalized difference moisture index (NDMI) were computed for each Landsat image from 1989 to 2004. NDVI is used extensively to monitor vegetation (Jenson 1996), but NDMI has been proven useful for detecting forest changes (Jin and Sader 2005; Wilson and Sader 2002).

The older-date NDVI and NDMI images were subtracted from the newer date images on a pixel-by-pixel basis from the first year of the fire scar through 2004, in two-year intervals, in order to display a time-series of change patterns. This method is a means to broadly quantify the amount of moisture and vegetation change. In order to validate the imagery analysis, field data were collected in 65 plots for dominant species, percent cover, diameter at breast height, and tree height.

Figure 2. Landsat TM false color composites of study sites in Yosemite National Park, CA (grayscaled here). The outlines of the fire scars from the imagery are one year after the fire.



All of the fire scars were dominated by shrubs such as ceanothus (*Ceanothus* sp.) and manzanita (*Arctostaphylos* sp.). Trees had not re-colonized the fire scars and these areas were still in the shrub-seedling-sapling stage of the second defined stage of successional recovery (Allen 2003). The analysis showed that all four sites consistently had the greatest change occur within the first six years of recovery and remained steady throughout the second stage of succession. The vegetation growth patterns identified in this project are useful to NPS resource managers in understanding long term effects of fires on regeneration (Syfert et al. 2006).

Identifying vegetative anomalies in Yosemite National Park

Monitoring ecological disturbances such as fire and insect infestation within Yosemite National Park's 1,158 square miles is a challenging endeavor for the National Park Service. Lightning fires consume approximately 16,000 acres of Yosemite National Park per year, destroying an average of 2.4 percent of the park's combustible vegetation annually. The National Park Service could effectively augment their use of remote sensing technology to rapidly identify potential regions of concern, as well as monitor the recovery of already disturbed areas.

The purpose of this project was to demonstrate the effectiveness of the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument to park resource managers. Located on two of NASA's Earth Observing satellites, Terra and Aqua, MODIS sensors provide repeat coverage at 250-m, 500-m, and 1,000-m spatial resolutions every one to two days. Such high temporal resolution enables resource managers to monitor rapid changes on the earth's surface at both regional and global scales. By utilizing MODIS data, Yosemite Park resource managers could be more cost and time efficient in detecting and identifying threats to the park.

Methods

The leaf area index (LAI) is the ratio of total leaf area to ground area. LAI data for this project were processed by NASA's Terrestrial Observation and Prediction System (TOPS). TOPS is a data and modeling software system designed to seamlessly integrate data from satellite, aircraft, ground sensors, and weather/climate models to quickly and reliably produce operational nowcasts (descriptions of current conditions) and forecasts of ecological conditions. The use of TOPS outputs is advantageous for ecological monitoring as they are rapidly processed and made available to the user (Nemani et al. 2007).

LAI data for Yosemite National Park from 2000 through 2005 were averaged for the month of July on a pixel by pixel basis. This average was then contrasted with the average LAI for July 2005. Low, average and high LAI ranges were classified for the July 2005 average relative to the five year average, resulting in an LAI-anomaly map. Landsat data and field data were collected and analyzed during the summer of 2006 to verify the accuracy of the MODIS instrument to detect vegetative anomalies in Yosemite National Park's coniferous forests. Analysis of vegetation maps, Landsat imagery, fire data, and insect infestation data revealed the likely causes for these anomalies.

Four sites were chosen for field investigation: one site was identified as having an *unknown* cause for a low LAI anomaly, one site was identified as having a *known* cause for a low LAI anomaly, and two sites represented the highest LAI value and average LAI value. Three utilities were used to verify MODIS LAI values: the LAI-2000 handheld instrument, allometric measurements (diameter at breast height, total tree height, and height above first branch), and Landsat 7 images. LAI was computed for the allometric data and the Landsat 7 images and these values were compared to MODIS LAI values using statistical analysis.

Results

The LAI-2000 data were found to be poorly correlated to the MODIS LAI values. This could be due to the fact that all trees studied were coniferous and the LAI-2000 is known to underestimate LAI values for conifers by as much as 52% (Malone et al. 2002; Jonckheere et al. 2005). Because of the inconsistency of the LAI-2000 in collecting leaf area indices for coniferous trees, the LAI-2000 data were found to be inconclusive in verifying MODIS.

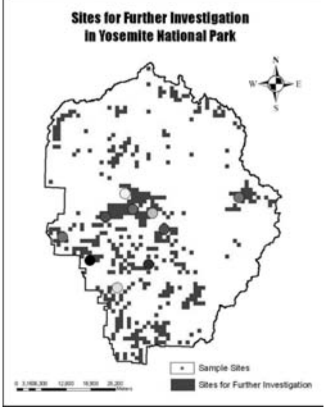
There was a strong correlation between the allometric data-derived LAI values and the MODIS-derived LAI values. The strong correlation supports the accuracy of MODIS LAI, and also allows for MODIS to be used to calculate allometric data. There was also a strong correlation found between the Landsat LAI image and the MODIS LAI image, which further supports the accuracy of MODIS LAI.

Low LAI anomalies composed 48.1 percent of the entire park. Of that 48.1 percent, 10.4 percent was attributable to 2001-2005 fires; 2.2 percent to 2001 and 2002 beetle infestations; 3.6 percent to late snow fall; and 10.2 percent to rock. The remaining 73.6 percent of the low LAI anomalies need further investigation to determine the reasons for the vegetation disturbance. A map with the coordinates of these areas was given to park resource managers as a decision support tool (Figure 3).

Discussion

This project has laid out the method by which Yosemite National Park's resource managers can monitor vegetative disturbances and identify sites to investigate further. Due to strong correlations between allometric data and MODIS LAI, as well as Landsat LAI and MODIS LAI, an automated change detection model which will not only output the coordinates of sites for further investigation, but also reveal the cause and severity of future disturbances, could act as a powerful tool for forest management. Officials could use this information to preview sites before beginning control burns, monitor the shifts in the tree line, and have access to a historic record of MODIS LAI data. By observing changes in LAI values at higher elevations, Yosemite National Park resource managers could study how vegetation responds to the corresponding fluctuations in temperature and snowfall. If such trends in anomalous LAI persist, the LAI data have the potential to aid NPS resource managers in identifying the possibility that plant communities and ecosystems are shifting elevations. The accumulation of MODIS LAI will create a database of additional information that could act as an important point of reference for future studies (Voss et al. 2007).

Figure 3. Sites for further investigation in Yosemite National Park, CA.



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