UTILIZING MODIS LAI TO IDENTIFY VEGETATIVE ANOMALIES IN YOSEMITE NATIONAL PARK

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ABSTRACT

During the summer of 2006, students from Ames Research Center's NASA DEVELOP program examined vegetation disturbances in Yosemite National Park. This project used Moderate Resolution Spectroradiometer (MODIS) Leaf Area Index (LAI) data processed by the Terrestrial Observation and Prediction System (TOPS). Monthly LAI was averaged over a four-year period from 2001 – 2005 and then compared with the monthly averages for summer, 2005 to produce a map of LAI anomalies. This map was then overlaid with known areas of insect infestations, snow cover, and recent wild fires to identify possible causes of low LAI. Field work was conducted to confirm the explained causes and ascertain the causes of unexplained anomalies. Thus far, the ecological disturbances for over a quarter of anomalous area have been identified and verified, and further fieldwork is currently underway to investigate the remaining unexplained regions. Continuation of the project will result in the creation of an automated change detection model, which will not only output the coordinates of sites for further investigation, but also help reveal the cause and severity of future disturbances. This methodology is of interest to managers of national parks and forests due to the accessibility of MODIS data, its high temporal resolution, and the speed with which large areas of land can be analyzed.

INTRODUCTION

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, destroying an average of 2.4 percent of the park's burnable vegetation annually (National Park Service, 2004). Bark beetles are associated with the annual destruction of an estimated 24.8 percent of Yosemite's coniferous forest (D Rizzo et al., 2000). 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.

By utilizing Moderate Resolution Imaging Spectroradiometer (MODIS) data, Yosemite Park forest managers could be more cost and time efficient in detecting and identifying threats to the park. Located on two of NASA's Earth Observing satellites, Terra and Aqua, MODIS sensors provide repeat coverage at 250m, 500m, and 1,000m 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. Gathering 36 bands of data over the visible and infrared portion of the spectrums, MODIS allows researchers to derive information about the landscape such as Leaf Area Index (LAI). LAI is a ratio of the total leaf area to ground area, influenced by a plant's gas exchange and light reflectance. This value is a factor in determining primary production and in creating global climate models (Myneni, et al., 1997).

Researchers have conducted MODIS LAI validation studies in various biomes with mixed results. Privette et al. (2002) studied LAI at five sites in the South African Kalahari in 2000, and obtained accurate results with first-year MODIS data. Myneni et al. (2002) studied the LAI and FPAR products at a global scale and found that MODIS LAI data are valid in six different biomes. Cohen et al. (2003) studied four sites in North America, comparing Landsat ETM+ with MODIS discovering strong correlations between MODIS reflectance data and LAI at three of their study sites. Comparing land classifications obtained from Landsat and MODIS data, Price (2003) found that although classifications were generally similar, some ambiguity occurred when one pixel contained two or more land cover types. Chen et al. (2005) studied four post-fire sites in Krasnoyarsk, Siberia. Results were poor with MODIS over-estimating LAI in sparse canopy areas and underestimating LAI in dense canopy areas. In 2006, Turner et al. attempted to validate the MODIS estimate of daily gross primary production and annual net primary production products using nine sites varying in biome type and land usage. MODIS products tended to be underestimated in high productivity sties. Given these results, one goal of this study is to continue verification of the MODIS products.

In the summer of 2006, student interns from NASA's DEVELOP Program conducted a 10-week research project using MODIS and LANDSAT data as well as *in situ* data to detect anomalies in LAI values of Yosemite National Park's coniferous forests. With these values, the interns verified the accuracy of the MODIS instrument. This project reduces the need for Yosemite National Park resource managers to physically investigate all causes of low vegetative health. The high temporal resolution of the MODIS sensor makes it possible for the Park Service to monitor changes in vegetation health each day.

STUDY AREA AND DATA

The study area for this project is defined by the perimeter of Yosemite National Park. The park is located in the Sierra Nevada Mountains and covers 1,189 mi² (3,081 km²) of Mariposa and Tuolumne Counties in east central California. Five major vegetation zones are found within the park: chaparral/oak woodland, lower montane, upper montane, subalpine, and alpine (National Park Service, 2004). Elevations range from 2,000 to 13,123 ft. (610 to 4000m).

The 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, and ground sensors, and weather/climate models with application models to quickly and reliably produce operational nowcasts and forecasts of ecological conditions. Among other outputs, TOPS produces LAI and FPAR data at 1000m spatial resolution. Use of these outputs is advantageous for ecological monitoring as they are rapidly processed and made available to the user (Nemani 2006).

Ancillary data sets provided by the National Park Service included shapefiles of fires from 1930 to 2004 as well as a 2005 fire shapefile. Areas of bark beetle infestation and snow cover shapefiles were also incorporated. Shapefiles of the Yosemite National Park boundary, roads and rivers were also made available for this study.

METHODOLOGY

Field Site Selection

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. Analysis of vegetation maps, Landsat imagery, fire data, and insect infestation data revealed the likely causes for these anomalies. Locations for field investigation were then selected based on the criteria below.

Each site must be:

distributed over at least two types of land cover; accessible, that is located near roads at relatively low elevation and slope. In addition, one site was identified as having an *unknown* cause for a low LAI anomaly,

one site was identified as having an *known* cause for a low LAI anomaly, and

two sites represented the highest LAI value and average LAI value.

To determine site accessibility, a one-kilometer buffer was created for all roads. Anomaly sites within this buffer were acceptable for field study. Slope was calculated from a 10-meter digital elevation model (DEM).

Anomaly sites where slope was below 18 degrees and elevation was less than 2,500m were also considered candidates for investigation.

From within the remaining anomalous regions, four sites were selected. 1) For the low - LAI site with a known disturbance, five layers were compiled: low LAI, one-kilometer road buffer, the slope file, 2001 to 2005 fire boundaries, and elevation. One site was selected from this file. 2) For low- LAI with an unknown disturbance, six layers were added: low LAI, one-kilometer road buffer, the slope file, 2001 to 2005 fire boundaries, low LAI anomalies, and elevation. 3) The average LAI site with no disturbance was determined by summing the following bands: average LAI, one-kilometer buffer, the slope file, and elevation. 4) For high LAI with no disturbance, four files were used: high LAI, one-kilometer buffer, the slope file, and elevation. Vegetation data were obtained from the Mariposa, Tuolumne, and Madera counties. These were merged and clipped to the Yosemite National Park boundary, rasterized, and overlaid with the four potential site layers. The vegetation data were used to pinpoint eight potential sites one square kilometer in area. The final four sites were selected by visual inspection of USGS 7.5 minute topographic maps.

Fieldwork Procedure

GPS devices and compasses assisted in locating the four sites' centroids. Two perpendicular transects were laid in the north-south and east-west directions. The transects varied from 250 to 1000m depending on site conditions (Figure 1).

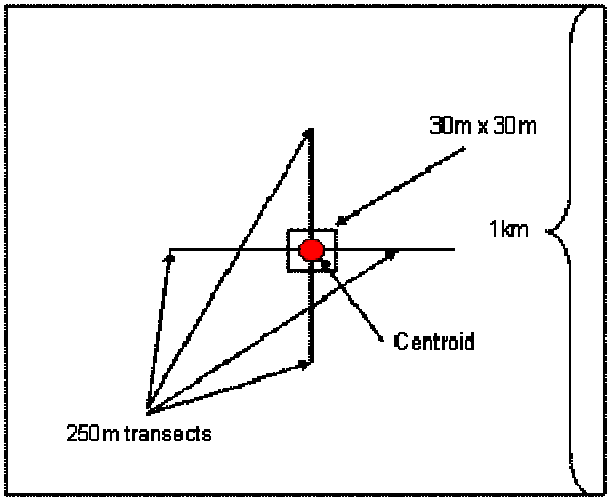

Figure 1. Diagram illustrating transect selection.

The first *in situ* measurements were circumferences and angles of elevation to the base of the tree, first branch, and top. These were taken every 20m along the transects and within a 30m by 30m square surrounding the centroid (Figure 2).

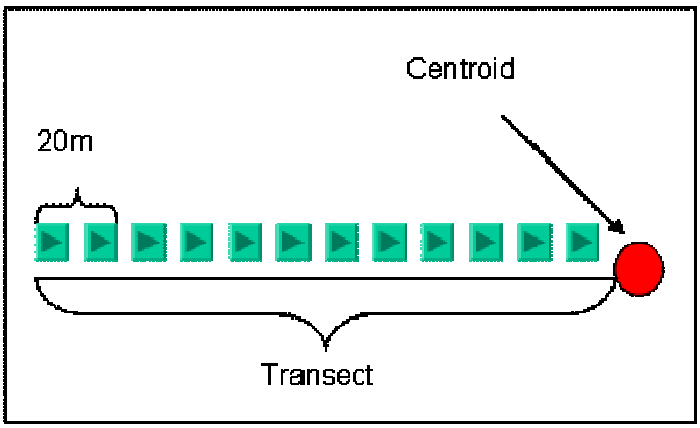

Figure 2. Diagram illustrating *in situ* measurement scheme.

The second measurement directly recorded LAI values with the LAI-2000 every 40m along the transects by comparing the amount of vegetation light reflectance to ambient light.

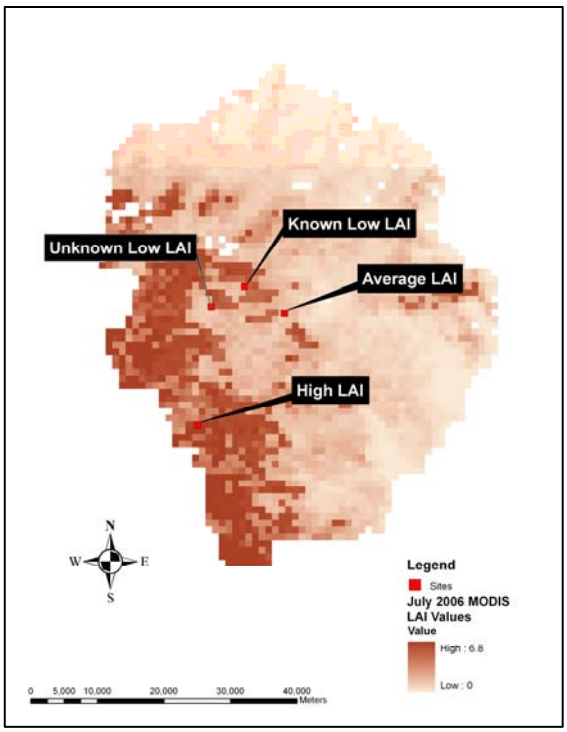

Figure 3 Sites selected in Yosemite National Park Overlaid with July 2005 LAI Anomalies.

RESULTS

Three utilities were used to verify MODIS: the LAI-2000 handheld instrument, allometric measurements collected in Yosemite, and Landsat 7 images.

LAI-2000 Data Analysis

After the LAI 2000 data were uploaded to a computer, they were organized and averaged giving nine leaf area index values: two for the high, average, and known low LAI sites each, and three for the unknown low. After

statistical analysis, LAI-2000 data were found to be poorly correlated to the MODIS LAI values, with a coefficient of determination of 0.0073 (Figure 4).

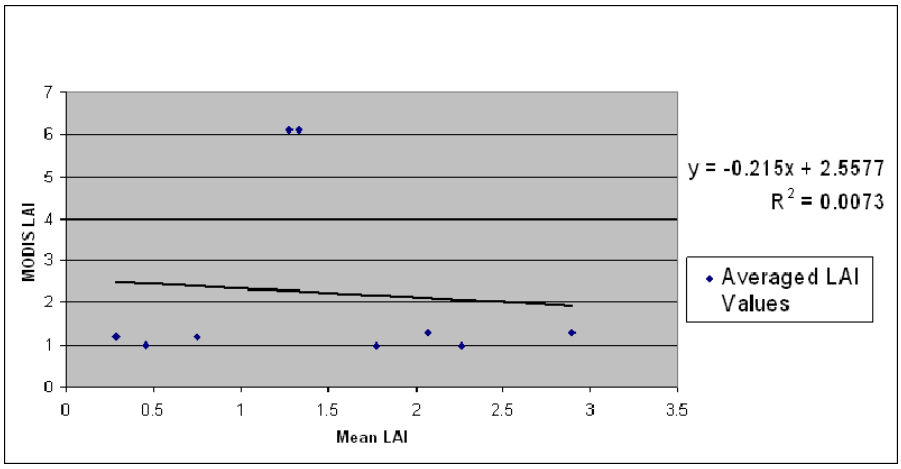

Figure 3. Mean LAI vs. MODIS LAI.

The two outliers caused by the high LAI site are negligible for two main reasons. First, the LAI-2000 must take an ambient reading for several under-canopy readings in order to properly determine the light reflectance of trees and calculate the leaf area index. Because of the density of trees, few proper clearings were found, perhaps skewing the data. Second, the dense understory rendered it nearly impossible to access the centroid and lay out a suitable transect. As such, the transect could only be laid out in a section of the site less dense than, but not representative of, the surrounding area. The r-squared correlation strength became nearly ten times stronger upon exclusion of the high LAI values (Figure 5).

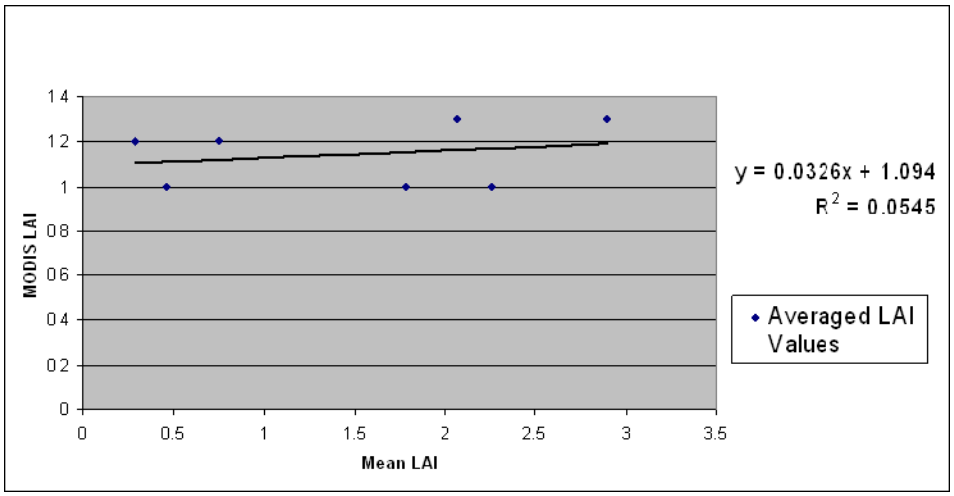

Figure 4. Mean LAI vs. MODIS LAI (excluding high LAI values).

Even when averaged high LAI values were eliminated, the R-squared of 0.0545 is still remarkably low. 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% (Jonckheere et al., 2005; Malone et al., 2002). 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.

Allometric Data Analysis

The second method employed to verify MODIS data was to collect tree measurements, convert measurements into more useable data, enter the data into an allometric equation to calculate LAI, and compare outputted LAI and MODIS LAI values. From the circumferences and various angle measurements, the diameter at breast height (DBH), total tree height, and height above first branch were calculated. The next step of inputting these data into a formula regrettably could not be completed as an allometric equation specific to Yosemite does not currently exist. The creation of an original allometric equation is a lengthy procedure requiring destructive sampling, unauthorized by our field work permit. However, allometric data were utilized by comparing the DBH, total height, and height above first branch to MODIS LAI values (Figures 6, 7, and 8). The strong correlations support the accuracy of MODIS and allows for MODIS to be used to calculate allometric data.

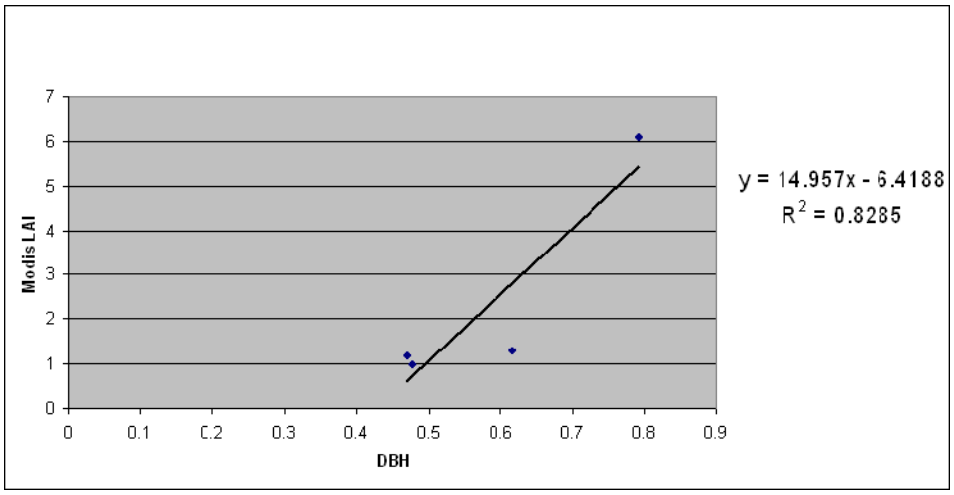

Figure 5. Diameter at Breast Height (DBH) vs. MODIS LAI.

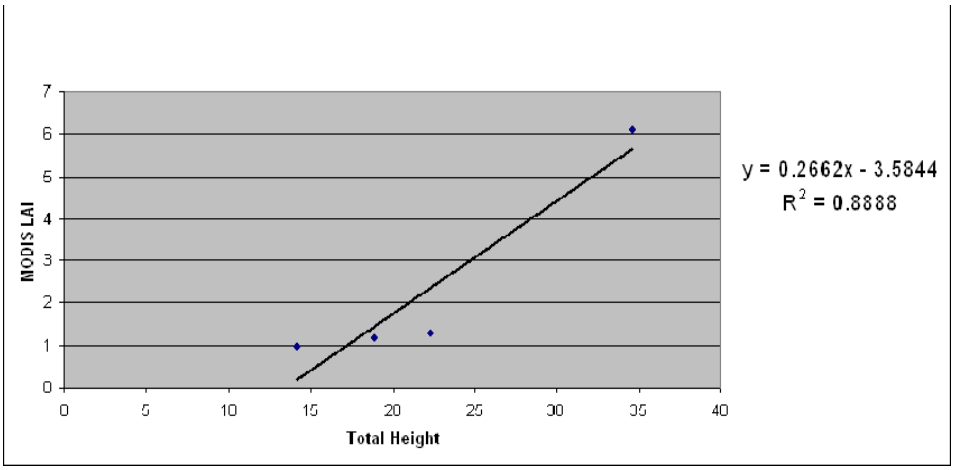

Figure 6. Total height vs. MODIS LAI.

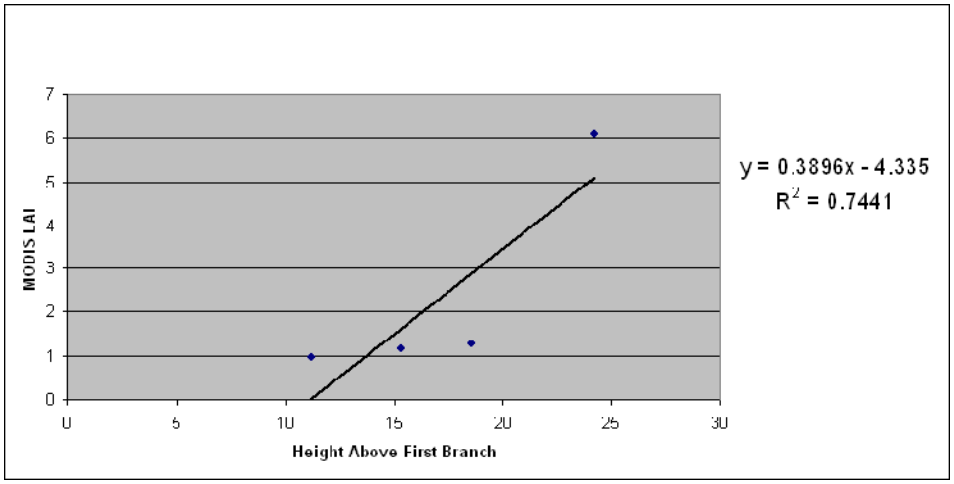

Figure 7. Height above first tree branch vs. MODIS LAI.

Landsat Data Analysis

A July 2006 MODIS LAI image was compared to a Landsat LAI image. To create the Landsat LAI file, the NDVI was derived from a 11 July 2006 Landsat scene, and then entered into this equation: $LAI = 0.2273e^{4.9721(NDVI)}$ (White et al., 1997), using ERDAS IMAGINE Model Maker. The pixels were averaged within ten randomly selected one-kilometer squares in the Landsat LAI image and then compared to the corresponding pixels in the MODIS LAI image. Figure 9 illustrates the relatively high correlation between the two files.

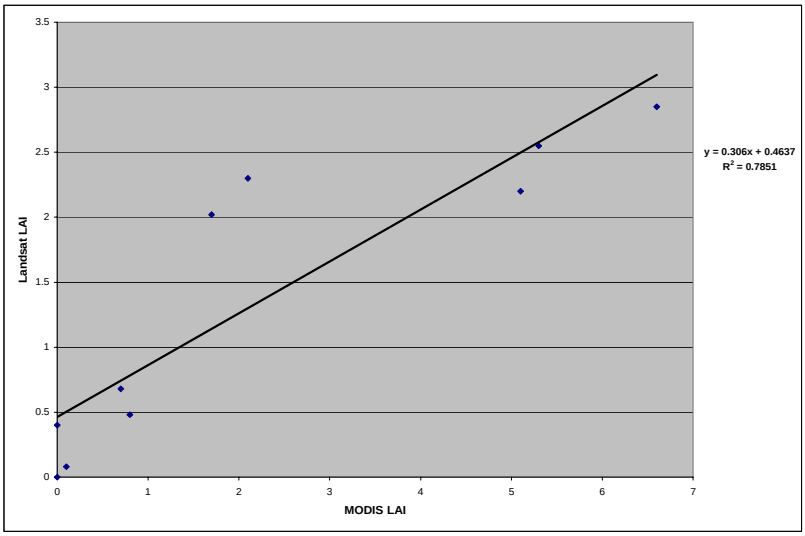

Figure 9. Landsat LAI vs. MODIS LAI.

The percentage of sites within the July 2005 low LAI anomaly file for which no known disturbance was found was determined through raster overlay (cross-tabulation) with the four disturbance datasets. 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 was deemed as being area for further investigation. The park service can investigate these sites by calculating the centroids and locating their coordinates with a GPS unit (Figure 10).

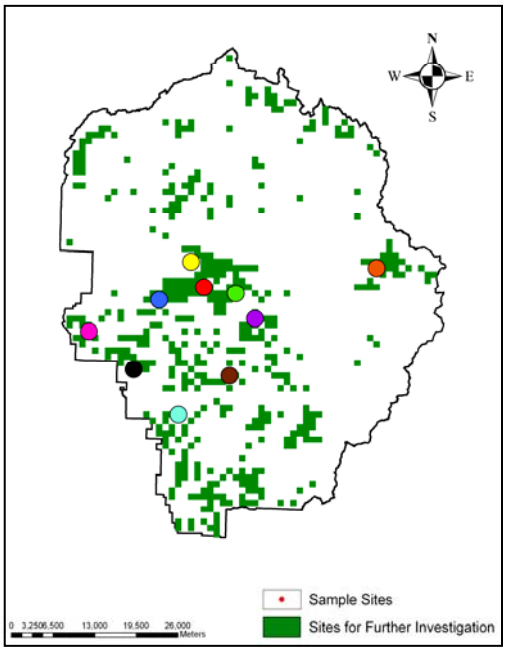

Figure 10. Sites for further investigation.

CONCLUSION

This project has laid out the method by which Yosemite National Park's forest management may choose sites to investigate or for others to use in their own studies. Due to strong correlations between allometric data and MODIS LAI as well as Landsat LAI and MODIS LAI, an automated change detection model 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. Fires, droughts, or beetle infestations could have weakened trees, potentially creating low LAI sites. By observing changes in LAI values at higher elevations, the Yosemite National Park Service 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 national park forest 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.

This study is part of a larger, on-going NASA project that focuses on ecological forecasting and intends to supply the Yosemite forest management with landcover-change model outputs. This monitoring system will eventually extend to management in other national parks.

Perhaps the next project conducted with such an ecology model would be the prediction of forest fires. Fires could be forecasted using past MODIS LAI data and fire/beetle relationships in Yosemite National Park. These data could be complemented by the climate predictions in TOPS, NASA's Terrestrial Observation and Prediction System, to increase the scope of an automated change-detection model.

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