Progress Report Year 2, NAG5-6003:
The Dynamics of a Semi-Arid Region in Response to Climate and Water-Use Policy

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Introduction

The objectives of this project are to determine the response of semi-arid ecosystems to the combined forcings of climate variability and anthropogenic stress. Arid and semi-arid systems encompass close to 40% of the worlds land surface. The ecology of these regions are principally limited by water, and as the water resources wax and wane, so should the health and vigor of the ecosystems. Water, however, is a necessary and critical resource for humans living in these same regions. Thus for many arid and semi-arid regions the natural systems and human systems are in direct competition for a limited resource. Increasing competition through development of arid and semi-arid regions, export of water resources, as well as potential persistent changes in weather patterns are likely to lead to fundamental changes in carrying capacity, resilience, and ecology of these regions. A detailed understanding of these systems respond to forcing on a regional and local scale is required in order to better prepare for and manage future changes in the availability of water.

In the Owens Valley CA, decadal changes in rainfall and increased use of groundwater resources by Los Angles (which derives 60-70% of its water from this region) have resulted in a large-scale experiment on the impacts of these changes in semi-arid ecosystems. This project works directly with the Inyo County Water Department (local water authority) and the Los Angles Department of Water and Power (regional demand on water resources) to understand changes, their causes, and impacts. Very detailed records have been kept for a number of selected sites in the valley which provide essential ground truth. These results are then scaled up through remote sensed data to regions scale to assess large scale patterns and link them to the fundamental decisions regarding the water resources of this region. A fundamental goal is to understand how resilient the native ecosystems are to large changes in water resources. Are they are on a spring (remove and return resources, do the systems return to the original state) or a vector (when water returns have the systems fundamentally changed).

Reduction and Analysis of Remote Sensed Data

Collection of Field Data

Field observations of vegetation abundance have been acquired since 1987 for 33 sites across the valley. These permanent monitoring sites include areas assumed to be affected by groundwater pumping and control sites not affected. Each of the monitoring sites which show distinct change characteristics during the drought and exhibits a pronounced, and unique response after the drought. It is these effects which we are interested in quantifying and classifying using remotely sensed data.

Remotely Sensed Data

Fifteen yearly Landsat TM scenes, between 1984 and 1998, were chosen from those acquired during September of each year. September is after summer growth has stabilized and annuals have passed into senescence, but before the winter rains occur. These images were coregistered, georeferenced, and then calibrated to a common spectral response using ground invariant points. The coregistration of the data sets was given high importance since detection of change at the high level of precision we demand relies heavily on well registered data.

Spectral Mixture Analysis

The spectral mixture model was run on all 14 Landsat TM to extract the vegetation abundance. Mixing models treat each pixel as the weighted sum of endmember spectra, which are de-mixed by the algorithm, resulting in a separate image of the surface abundance of each endmember. The surface abundance is, in essence, the aerial % of each pixel covered by a particular endmember. For the valley floor and bajada surfaces, we used four endmembers to describe the scene: vegetation, tan soils, gray soils, and shade (to account for illumination effects). Standard ratio methods of extracting vegetation information from remotely sensed data, such as NDVI, are limited in that they use only two spectral channels and do not quantitatively measure a physical abundance in the image. The results from mixture models can immediately be used as a measurement of percent vegetation abundance. A first look at these vegetation abundance images showed extreme variability across the 14 years, particularly in areas where heavy pumping occurred. The images presented are from the area around the town of Independence and were acquired in(left to right) 1984, 1989, and 1995. These images show high, pre drought, vegetation abundance in 1984, decline in 1989 and partial recovery in 1995. We have produced similar images for every year from 1984 to 1996.

Validation

The mixture model vegetation endmember images were compared to the field results by finding each field site in the image and extracting the vegetation abundance information. Due to the 30 by 30 meter pixel size and field site location uncertainties great care was taken to correctly locate each field site in the dataset. In each case, GPS locations, air photos, correlation statistics, and a general knowledge of the field site were used to select the best four (2 by 2) pixels to represent the field site. It was recognized that a near by road or different vegetation community could change the response of the selected pixels, thus GIS layers of roads and other geographical features were used to eliminate this problem.

There are 6 dates between 1990 and 1996 (one each year) which we have both image measurements and field measurements for each of the 33 field sites. We have compared these field data with the SMA vegetation fraction images at all 33 sites and have found that the remote measurements are accurate to within +/- 4.0%. NDVI, perhaps a more accepted approach, does not demonstrate this high of a correlation. However, SMA results are directly comparable to the field measurements while NDVI would need to be regressed to the field measurements to obtain a measured of %lc.

In comparisons between specific data of the field sites and remote estimates, we note that for some sites the correspondence is close to 1:1 while at other sites a consistent offset or bias is observed. This offset is attributed to differences in the vegetation structure (leaf orientation and woodyness) and therefore, is site dependent. At sites that exhibit a bias, the absolute abundance of vegetation measured using SMA is offset from field measurements. The year to year changes in abundance are, however, represented well by the SMA results. Thus we can remove the bias an recalculate the degree of correspondence for the remote estimates as a quantitative measure of change in %lc. These results show a strong linear correlation from which an uncertainty of +/- 3.8% live cover can be calculated. The same results for NDVI do not show nearly the same linear relationship. Furthermore, SMA predicts the correct sense of change (increase or decrease) 86% of the time while NDVI is accurate only 68% of the time.

These results indicate that SMA can be used as a reliable indicator of vegetation abundance in semi-arid regions. We have calculated an uncertainty of +/- 4.0%lc on measurements of absolute live cover and +/- 3.8%lc on measurements of change in live cover. Not only is NDVI not a quantitative measure of vegetation abundance, but our work shows that it does not even correctly estimate the direction of change from year to year in over 30% of our field sites. The reasons for the discrepancy for NDVI is related to the effects of soil brightness.

Response Analysis and Change Classification

Change images were produced by subtracting the 1984 vegetation image from the vegetation image of each year. These quantitative change data were then used to classify the valley according to common response classes. The classification has been validated through field work in the summer of 1998. Hundreds of sites were investigated to record the dominate species, field characteristics, and relationship to prior measurements. This has provided a robust validation of the change classification that provides a high degree of confidence to then use the results to investigate response.

Response of communities to the coupled climatic and anthropogenic forcing functions is the focus of current research. As expected, areas that show the largest decrease in vegetation abundance are those affected by groundwater pumping. The tremendous variety of responses seen on the valley floor are coupled to groundwater recharge, community drought tolerance, and other factors that we are investigating. By combining the vegetation change class data with the existing GIS layers of vegetation communities, our change classes will be linked to physical parameters and processes in the valley.

In support of these investigations, we are using ground penetrating radar (GPR). These data will be used for characterization of subsurface soil stratigraphy, pedogenic horizons, and depth to groundwater. This has been done in areas with well characterized subsurface stratigraphy, as well as a number of sites representative of major surface types. Subsequent analyses of the GPR data verifies the ability of this technique to discriminate important sedimentological properties, pedogenic profiles, and the definition of the groundwater table. This allows us to characterize these properties over vertical scales of several meters, and horizontal scales of 10's to 100's of meters. Additional critical sites have been collected in 1998 and will be incorporated into the response analysis.

Land Use History

A component of the response analysis will include considerations of land-use history. Here we consider the implications of prior use on potential responses observed. Three sites in the valley have been investigated in detail for their land-use history. These histories were compiled from land surveys in the early 1900's, a very detailed survey in 1926, and air photos from 1944, 1966, the mid-1970's and 1980's. Agriculture was prevalent in the northern valley during the early part of the century and has left its mark in places. Grazing and pasture irrigation have largely left no effect on response. Row agriculture, however, appears in some regions to have left a legacy to continues to today. In these areas, the vegetation is very low and dominated by weeds. During years with abundant water, there is high growth that covers much of the ground. In subsequent years there is little to no growth. The reasons for these persistent impacts on ecosystem function 60-70 years after abandonment are not yet clear but are the subject of continued investigations.

Relationships of Pattern to Process and Impacts

At this stage in our analysis, we have identified fundamental patterns of change that are correlated to available water. Nevertheless, there is considerable variability in the magnitude of responses to inferred forcings, recovery from impact, and assemblages of species. We are in the process of developing a more detailed and quantitative understanding of the factors that affect response. Ultimately, this will be tied back to the fundamental decisions that have been made to manage water resources in this region and to then link decisions with impacts on the land use and land cover in this important region.

Outreach

One important outreach aspect of this project is the close relationship we have with the scientists and managers at the Inyo County Water Department. As unfunded co-investigators of this project, they have made valuable contributions to the research. However, they have also benefited greatly from the results and the vegetation change data sets created from the remotely sensed data are now part of the Inyo County GIS. These data are now used on a routine basis to guide resource planning, mitigation efforts, and are a new data set used in the management of water and ecological resources of the Owens Valley. We have kept close communications with the Los Angeles Department of

Water and Power as well. They have provided valuable feedback on the utility of the approach and will be considering this technology in future monitoring programs.

Ongoing developments in this project can be found at the following web site:

http://www.planetary.brown.edu/planetary/LCLUC_Owens

Publications

Elmore, A. J., J. F. Mustard, S. Manning, and D. Lobell, Quantifying percent live cover in multitemporal data of a semi-arid region: Comparison between spectral mixture analysis and NDVI, *Remote Sensing of Environment* (*in revision*), 1999.

Elmore, A. J. F. Mustard, S. J. Manning, A. Steinwand, and D. Lobel, Use of Spectral Mixture Modeling to quantify the percent live cover of vegetation from remotely sensed data of arid and semi-arid regions, Ecological Society of American Annual Meeting, 1999.

Elmore, A. and J. F. Mustard, Vegetation response to climatic and anthropogenic forcing functions in a semi-arid ecosystem, American Association of Geographers Annual Meeting, 1998.