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Quantifying Grassland-to-Woodland Transitions and the Implications for Carbon and Nitrogen Dynamics in the Southwest United States

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Statement of Proposed Research

Replacement of grasslands and savannas by shrublands and woodlands has been widely reported in tropical, temperate and high-latitude rangelands worldwide (Archer 1994). These changes in vegetation structure may reflect historical shifts in climate and land use; and are likely to influence biodiversity, productivity, above- and belowground carbon and nitrogen sequestration and biophysical aspects of land surface-atmosphere interactions. The goal of our proposed research is to investigate how changes in the relative abundance of herbaceous and woody vegetation affect carbon and nitrogen dynamics across heterogeneous savannas and shrub/woodlands. By linking actual land-cover composition (derived through spectral mixture analysis of AVIRIS, TM, and AVHRR imagery) with a process-based ecosystem model, we will generate explicit predictions of the C and N storage in plants and soils resulting from changes in vegetation structure. Our specific objectives will be to (1) continue development and test applications of spectral mixture analysis across grassland-to-woodland transitions; (2) quantify temporal changes in plant and soil C and N storage and turnover for remote sensing and process model parameterization and verification; and (3) couple landscape fraction maps to an ecosystem simulation model to observe biogeochemical dynamics under changing landscape structure and climatological forcings.

Functional Interpretation of Structural Change

Our current and planned field analyses include collection of field spectral and biophysical data concomitant with AVIRIS, TM, and MODIS data collections, as well as collection of data on biogeochemical, phenological and population dynamics. Field spectra are collected using an ASD Full-range (400-2500 nm) spectroradiometer. Field biophysical data include fraction of intercepted photosynthetically active radiation (fIPAR), leaf area index (LAI), live/dead fractions, and cover estimates. A wide range of ecological measurements are described in context below.

Our first field season (1997) involved trips to our pre-established north Texas site, and to the New Mexico LTER Sevilleta and Jornada sites. Our northernmost area, a Texan *Prosopis glandulosa* savanna, serves as a primary site due to its large spatial extent, low species diversity, and history in grazing. The Jornada site is at the northern end of the Chihuahuan desert, representing the dry extreme of our project area. The Jornada trip was in coordination with NASA's Jornada Field Experiment, a remote sensing campaign to quantify rangeland vegetation change and plant community/atmosphere interactions. Encroachment of creosotebush and mesquite into black grama grassland has occurred in large areas of the Jornada over the last 100 years, appearing to be driven by both natural and human-induced environmental changes. The Sevilleta is structurally very interesting as it occurs at the intersection of Great Plains grassland, Great Basin shrub-steppe, Chihuahuan Desert, interior chaparral, and montane coniferous forest biomes; the Sevilleta was released from grazing in late 1972. Our measurements at the Sevilleta and Jornada were coincident with an AVIRIS overflight.

Measurements of fIPAR and LAI were made at all permanent plots at the Texas site. fIPAR, LAI, leaf optics and spectral endmembers were acquired at both New Mexico sites.

Measurements at the Sevilleta were located along line transects established by the LTER to evaluate temporal and spatial dynamics in vegetation transition zones. These included 4 transects: a grama-dominated grassland site (Deep Well), a grassland/creosote transition (Five Points), a mixed grassland site (Bronco Well), and an interface of creosote-bush and burrograss/black grama grassland (Rio Salado). Jornada measurements were made in grama grassland, a *Prosopis* dune region, and a mixed shrub/grass area.

To increase our understanding of factors regulating the balance between grasses and woody vegetation and the strength of their interactions, selective removal and reciprocal transplant experiments were installed in fall/winter of 1997/98 at the north Texas site. These experiments will be followed for the duration of the project to determine: (A) Grass effects on tree growth and reproduction. Does the herb layer compete with adult *Prosopis* for resources? To what extent does disturbance on the herb layer affect *Prosopis* growth? How are these interactions affected by soil properties? (B) Tree effects on grasses. How does the presence of *Prosopis* affect grass biomass and composition? How does grazing alter overstory-understory interactions? What is the relative importance of light, soil nutrients and root competition in determining *Prosopis* effects on grasses under and away from its canopy? (C) Tree effects on neighboring trees. Does *Prosopis* exhibit intraspecific competition (i.e. self thinning)? Nutrient flux changes associated with the experimental manipulation of grass vs. woody plant abundance will be quantified and will provide a database from which to evaluate the output of dynamic simulations incorporating disturbances which cause shifts in the relative abundance of grasses (i.e. grazing) and woody plants (i.e. fire).

The 1998 field season will focus on analyses of critical functional properties of the north Texas savanna, including:

(1) The spatial and temporal variability in nitrogen fixation by *Prosopis* plants using acetylene reduction and ^{15}N isotope analyses.
(2) Turnover of soil carbon in plots of differing grazing intensity using fractionation, ^{13}C and ^{14}C methods.
(3) Links between nitrogen mineralization and NO/NO_2 gas fluxes across land-use gradients.
(4) Land-use effects on standing biomass, soil CO_2 efflux, NPP, and NEP.
(5) Soil textural effects on N, P, and base cation availability.

Developments in Image Analysis

Change Analysis using Aerial Photography

Aerial photographs from 1937 and 1994 were analyzed for vegetation cover change in an approximately 2000 hectare region of our north Texas site. Woody, grass, and bare soil classes were quantified and compared for each of 8 areas (ranging in size from 171 ha to 430 ha) for the two dates. Cover change trajectories varied among sites; no one directional change dominated, although the area experiencing the greatest shift had a significant increase in woody cover. A similar, more extensive analysis needs to be completed for the entire region to determine relationships between land-use history and directional cover change. Since much of the land-use history for this area is anecdotal, areas for which management has been better documented will be used to track landscape response.

Spectral Mixture Analysis and Radiative Transfer Modeling

Five endmembers (tree, senescent grass, soil, water and shade) were derived with the Manual Endmember Selection Tool (MEST) of Bateson and Curtiss (1996) from Landsat TM data acquired over the north Texas site in September 1992. Tree cover fractions computed from a spectral mixture analysis of the TM data with the derived endmembers were within 1 standard deviation of tree cover estimates from the aerial photography. The mean error between the fractions computed with both methods was 4%.

A new method has been developed to automatically derive endmembers by a simulated annealing minimization of the volume they determine. Time spent manually selecting the five endmembers for the north Texas TM image was greatly reduced by applying this method to produce an initial set of endmembers to be refined by the MEST. The need to refine the endmembers most certainly is due to endmember variability resulting from natural variation in components.

Work continued on fine tuning and testing a method of spectral mixture analysis that acknowledges endmember variability. In this method, a landscape component is represented by a set or bundle of spectra rather than one endmember spectrum and unmixing with endmember bundles yields maximum and minimum fractions images that ideally bound the true fraction values. Bundle unmixing was performed on an AVIRIS image simulated with our photon transport model (see below). The results of this unmixing were reported at the Seventh Annual JPL AVIRIS workshop and will appear in the proceedings of the workshop.

In an effort to further evaluate the unmixing tools under controlled conditions, we have designed and implemented a 3-dimensional landscape photon transport model to test the impact of vegetation, soil, and shade endmember variability on the unmixing results. The model can simulate a variety of sensors including AVIRIS, MODIS, TM, and AVHRR with varying degrees of random and systematic noise. Vegetation endmembers are created from field-based analyses of tissue (leaf, wood, litter) and soil optical properties, and whole canopies and landscapes are created using a mechanistic radiative transfer model. This approach is useful for systematic analysis of different landscape components, atmospheric conditions, and sensor spectral resolutions. Once the testing on simulated data is complete, we will exercise the unmixing approach on highly available TM, AVHRR, and soon, MODIS data. These initial tests will be compared with those made using AVIRIS (from which the methods were initially derived and tested) when the opportunity arises.

Biogeochemical Modeling Development

To enhance our ability to predict the response of these arid and semi-arid ecosystems to woody encroachment, we are developing a biogeochemistry model that draws from the best tested aspects of existing models (CENTURY, CASA, BGC), and which adds significant improvements that are unavailable in existing models. A major area of effort is focused on an ability to ingest remote sensing data into the model structure when it is available, but to return to a non-remote sensing driven mode when observational data access is limited. This incorporates aspects of radiative transfer, biophysics, and growth and phenological modeling, and it relies upon a gained understanding of timeseries data and lagged biogeochemical effects. We are also improving our water sub-model to include a more mechanistic approach based on Darcy hydrology and field measurements of organic matter transport. All of our current and planned field research focuses upon aspects of carbon, nitrogen and water cycling needed to link processes of woody encroachment to biogeochemical fluxes. For example, we have planned experiments to improve our understanding of carbon turnover, nitrogen fixation, NO_x fluxes, and NEP which we think has changed with woody encroachment in the region (noted above).

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Involvement of Undergraduate, Graduate and Post-Doctoral Researchers

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Graduate Students	Mark Simmons, Ph.D. (Texas A&M)
	Nancy Golubiewski, Ph.D. (Univ. Colo.)
Post-Doctoral Researcher	Dr. R. Flint Hughes (Univ. Colo.)

Presentations and Publications

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