Progress Report for NASA Grant NAG5-11238

Regional NPP and Carbon Stocks in Southwestern USA Rangelands: Land-use Impacts on the Grassland-Woodland Balance

9/01/02 – 8/31/03

Principal Investigator Carol A. Wessman
Cooperative Institute for Research in Environmental Sciences &
Department of Ecology and Evolutionary Biology
University of Colorado
Boulder, Colorado 80309-0216

Ofc: 303-492-1139
Fax: 303-492-5070
email: Carol.Wessman@Colorado.edu

Co-Investigators:

Steven R. Archer	University of Arizona	sarcher@ag.arizona.edu	520-626-8791
Gregory P. Asner	Carnegie Inst., Stanford	gpa@stanford.edu	650-325-1521
C. Ann Bateson	University of Colorado	ann@cses.colorado.edu	303-492-5289
Thomas Boutton	Texas A&M University	boutton@neo.tamu.edu	979-845-8027

Proposal Abstract

Tree/grass ratios profoundly impact the biogeochemistry of grasslands and savannas by affecting: (i) decomposition of above- and belowground biomass, (ii) vertical distribution, mass, and size of roots in the soil, and (iii) microclimatic influences on soil microbial biomass and rates of organic matter turnover. Because dryland ecosystems comprise half the terrestrial surface, changes in tree/grass ratios likely influence global biogeochemical cycles and climate. In our past work, we have focused on quantifying how changes in tree/grass ratios affect storage of carbon (C) and nitrogen (N) across topoedaphically diverse landscapes. In this project, we expand our LCLUC work to the greater Southwest, and initiate new objectives addressing the Carbon Cycle Science Initiative. We will extrapolate our high-resolution, validated studies to assess land-use impacts on NPP and C-storage in rangeland ecosystems throughout the Southwest. We will integrate aircraft, Landsat, and MODIS data to retrieve, with increasing spatial coarseness, biogeophysical information relevant to biogeochemistry, vegetation dynamics, and land management. Sequenced validation of land cover fractions from plot-to-Landsat-to-MODIS scales using spectral mixture analysis will enable us to determine scaling properties of key biophysical variables (e.g. live vs. dead vegetation) from landscapes to regions in contrasting bioclimatic zones. These variables will constrain an ecosystem process model and thereby estimate regional productivity and C-storage in vegetation and soil. $\delta^{13}C$ of soil organic carbon (SOC), a biogeochemical tracer of woody-herbaceous inputs, have been obtained for our temperate savanna site (N. Texas) and will be used to test model performance and, hence, the adequacy of the remote sensing inputs. $\delta^{13}C$ of SOC will also enable us to document long-term vegetation history, estimate SOC turnover, and the relative contribution of grasses vs. woody plants to ecosystem productivity and C-storage. This $\delta^{13}C$ database will be comparable to that completed at our subtropical savanna site; therefore, we will compare and contrast effects of woody plant encroachment on ecosystem C-storage in contrasting bioclimatic regions.

We will develop a spatially explicit land-use history within our Arizona study region to distinguish among land-use practices influencing tree/grass ratios (e.g., grazing, fire, brush clearing, cropland abandonment) Because human management plays a dominant role in this region, we will test scenarios encompassing the range of impacts that might result from contrasting land-use policies. We cannot predict what state/federal policies might be enacted to affect range management practices. Nor can we predict what economic incentives pertaining to 'carbon credits' might arise. However, we can use our linked remote sensing-modeling approach to predict regional C budgets in response to potential policies or incentives that may emerge. Land-use scenarios that define different policy environments (e.g., government subsidies to support woody plant control, or carbon credit incentives that promote woody plant proliferation) will be developed and played out through a simple GIS approach. Consequent prescribed changes in vegetation structure, when coupled with a carbon simulation model, will enable us to estimate the influence that policy changes might have on trajectories in C-sequestration and liberation at the scale of the Southwest region.

Keywords:

1) Research Fields: Carbon Cycling, Rangeland Management, Biogeochemical Cycling, Anthropogenic Effects, Land Use Modeling
2) Geographic Area/Biome: North America, Semi-Arid, Grassland, Savanna, Woodland
3) Remote Sensing: Landsat, MODIS, hyperspectral
4) Methods/scales: In-situ Data, Mixture Modeling, Regional Scale

Questions

Our project focuses on the third NASA ESE question (ESE Q3) concerning the consequences of LCLUC. We are interested in land management impacts on grassland-woodland transitions within Southwestern rangelands. We are involved in mapping activities, but will not systematically assess historic change in land cover and land use (ESE Q1). Much of our past work has concentrated on the causes of land-cover/land-use change, namely mechanisms involved in the shift of grassland to woodland ((ESE Q2).

Proportion of Research Themes:

Social Science: 0-25%

We will look at the results of human management on vegetation structure through a series of GIS scenarios defining different policy environments. We are not looking at the social drivers themselves, but rather their impact on landscape structure and function.

Carbon: 50%

Our past and current work focuses on the sequestration and cycling of carbon through field studies of primary productivity and soil processes, and extrapolation via remote sensing and biogeochemical modeling.

Remote Sensing 25-50%

We use spectral mixture analysis at landscape (Landsat) and regional (MODIS) scales to determine fractional woody and grass cover. These data will be integrated into biogeochemical modeling and GIS analysis to assess NPP and carbon stocks under current and projected land management scenarios.

Project Goals: Our goal(s) for this period were to: (1) shift our land use history focus of the project from the N. Texas site to the Santa Rita Experimental Range (SRER) in southern Arizona (see below); (2) continue soil analyses and interpretation in N. Texas site; (3) continue remote sensing analyses of management practices in S. Texas site; (4) continue studies of Chihuahuan desert encroached by creosote bush; (5) initiate ecosystem model validation and interpretation based on SOC $\partial^{13}C$ measurements from N. Texas, and (6) initiate synthesis of our data across the Southwest to develop insights on key processes or constraints driving the woody encroachment phenomenon.

Gaps & Issues

Two of our PIs changed institutions in 2002. Asner and Archer moved to the Carnegie Institute-Stanford, CA, and University of Arizona, respectively. Subcontracts for both institutions were delayed significantly: Jul'02 for Carnegie and May'03 for UA. This delay disrupted work and the hiring of a new graduate student for Archer, and will undoubtedly result in a request for a no-cost extension of the project at its scheduled completion date of 8/31/04.

With Archer's move to UA, we deemed it practical to shift the land use history focus of the project from the Waggoner Ranch site in northern Texas to the Santa Rita Experimental Range (SRER) in southern Arizona. SRER is preferred to the Texas site because: (a) it has a much longer history of documented land use (dating back to 1903); (b) documentation of land use is much better; (c) it has a much richer scientific database, having been the focus of formal research activities by the USDA-ARS, USDA-FS, and the UA (see bibliography at http://ag.arizona.edu/SRER/). This database includes permanent transect data on vegetation cover dating back 50+ years, and repeat ground photography dating back to 1903; (d) the SRER spans a much broader elevational range and hence encompasses a much greater land-cover diversity than the Texas site. Whereas the Waggoner Ranch is a mesquite-grassland, the SRER ranges from creosote bush desert scrub to mesquite savanna to oak savanna to oak woodlands to pine forest. Thus, at one site, our work can efficiently address the same questions for an array of vegetation types representative of the Southwestern US; (e) the SRER is presently the focus of numerous research activities relevant to our project; and several of these are supported by NASA (e.g., Alfredo Huete and colleagues, Chuck Hutchinson and colleagues). Our work will compliment that of these researchers and the information from these other projects will enrich our image interpretation and modeling efforts.

Progress

Arizona The Santa Rita Experimental Range's diverse and well-documented history of livestock grazing and brush management histories enables large-scale testing of hypotheses regarding patterns of woody cover change, influence of livestock grazing on rates of woody plant cover change, rates and patterns of change following brush management, and changes in aerial photographs compared to changes in long-term ground transects. Progress on studies at the SRER has been made during this funding period in the following areas: (1) Hiring of graduate student Dawn Browning (Archer at UA); (2) search for and acquisition of historical aerial photographs; (3) GIS compilation of soil, elevation, boundaries, built features, and rain stations; (4) geostatistical and time-series analysis of precipitation; (5) analyses Landsat TM (NDVI) and DOQQ (1996 woody fractional cover) for change detection; (6) analysis of AVHRR NDVI time-series and construction of a monitoring survey (Figs. 1 and 2); and (7) identification of a soil carbon study vegetation transect.

<u>*Next steps*</u>*:* Aerial photographs and Landsat TM will be analyzed for fractional cover of woody plants and converted to biomass and carbon density measures as described by Asner et al. (2003). Fieldwork will be initiated in winter 2003/04 to quantify relationships between woody plant canopy cover and biomass on sites with contrasting soil types and land management histories. We will seek opportunities to examine interactive effects (e.g. grazing x soil; brush management x soil; grazing x fire) in order to ascertain how these might differ from main effects of disturbances (fire alone, grazing alone, brush management alone). We will aggressively seek opportunities to relate rates and patterns of woody cover change to climatic variables that might be influencing them (e.g. amount and seasonality of annual rainfall) and to determine the extent to which land use impacts are accentuated or dampened by climatic variation.

New Mexico: The Sevilleta LTER site experienced intense livestock grazing until the former cattle ranch was designated as a National Wildlife Refuge in 1973. Creosote bush (*Larrea tridentata*) expanded in the *Bouteloua eriopoda* (black grama)-dominated Chihuahuan Desert biome of the Sevilleta during this period of intense grazing. We have completed the first draft (pending validation) of a vegetation map of the region based on spectral mixture analysis of 3.2-m AVIRIS imagery (Figure 3). The transition zone between the Chihuahuan Desert and the Shortgrass Steppe (*B. gracilis* (blue grama) dominant), and the gradient of creosote bush ingress into the grasslands are delineated in fractional cover images.

Next steps: We will characterize the fractal structure of the creosote patches and the grass/shrub mosaic through percolation and multifractal analyses. PhD student Bryan Brandel (Wessman at CU) was recently awarded a NASA Earth System Science fellowship (July 2003) to complete field and modeling studies of biogeochemical implications of the transition from grassland to creosote bush shrubland. This will fully complement the LCLUC project and expand our understanding of Southwestern woody plant encroachment from mesquite to the second-most dominant shrub, creosote bush.

Texas: Soil samples were taken under mesquite (*Prosopis glandulosa*) tree/shrub canopies and in adjacent grassland areas from sites representing untreated controls and two different land use practices: (a) livestock grazing, and (b) woody plant management by root plowing. A total of 84 soil cores were taken to a depth of 1.5 m and 240 cores were taken to 20 cm. Bulk density, pH, elemental (%C and %N) and isotopic (∂13C) analyses are being performed on all soil cores at 10 cm depth increments (total of 1740 samples). All samples have been prepared for analysis and bulk density, a value critical to converting soil C concentrations (g C kg^{-1} soil) to carbon densities (g C m^{-2}), has been completed; no consistent differences occur between land uses or between grass vs. woody plant cover. Soil pH measurements are currently in progress. A full-time research associate with expertise in soil isotope chemistry, Dr. Million Hailemichael, was hired to participate in the soil analyses at Texas A&M.

Next steps: Elemental (%C and %N) and isotopic ($\delta^{13}C$) analyses will be initiated by 9/1/03, and should be completed by 12/03. Dr. Hailemichael plans to expand the scope of this work by quantifying soil inorganic carbon. His preliminary studies indicate that inorganic carbon represents a significant proportion of soil carbon stores in the Texas study area. In addition, a new PhD student, Emily Hollister, will work with Boutton. She is supported by a NASA Earth System Science Graduate Fellowship (awarded July 2003) and will quantify net primary production in mixed grass savanna near our primary study site in north-central Texas. Her dissertation work should complement and enhance ongoing efforts with this project.

In our efforts to track land management practices in woody encroached areas, we are analyzing the sensitivity of Landsat TM imagery to the impact of herbicide treatments at La Copita, our S. Texas site. Aerial herbicide treatments applied in May of '86, '87 and '90 to select areas destroyed only the overstory in some areas and in others only the understory. Shade and green vegetation cover fractions from spectral mixture analysis of TM imagery acquired in 10/5/85 (baseline) and 9/25/87 (when grasses were senesced) are interpreted as surrogates scaling with tree canopy plus understory for a mandatory finer discrimination of herbicide effects (Figure 4). Changes on the order of 10-15% in canopy cover from pre-treatment (1985) to 16- and 4-month post-1986 & 1987 treatments, respectively are detectable. Change in cover in untreated areas from 1985 to 1987 generally show increases on the order of 5-10% cover, with notable decreases in areas where building or other manipulations took place. Variable response of understory to herbicides is likely muting the response to defoliation of overstory (*Prosopis*).

Next steps: Additional images (1990s and 2000) will be analyzed and results published.

Southwest: Our studies of grasslands in the Southwest currently point to three factors of importance. First, the encroachment phenomenon is of sufficient magnitude and extent that synoptic monitoring via remote sensing of the spatial distribution and temporal dynamics of woody plant abundance is imperative. The ecosystem impacts of grassland to woodland transitions cannot be captured by ground measurements alone. However, and second in our list, studies of the biogeochemical consequences of these transitions must recognize the importance of understanding local and landscape mechanisms in order to achieve accurate and prognostic regional assessments. This requires well-designed field studies, documentation and monitoring of land use practices, and the implementation of ecosystem simulation models to test our knowledge and build scenarios of change trajectories. We emphasize the importance of integrating fieldwork into the analysis and interpretation of remote sensing data and model development to achieve sufficient understanding of these complex landscapes.

Conclusions

Our work is developing in three directions: (1) focused study in Arizona on impacts of land management history on woody plant encroachment; (2) extension to grassland/shrubland sites that represent more arid areas in the Southwest (NM); and (3) MODIS-based studies of the Southwest regional productivity and carbon stocks. Activities this year were significantly hindered by delays in funding transfers to the Carnegie Institute and Univ. of Arizona. However, we have made progress in developing a research plan for the SRER and acquiring a time series of historical aerial photography for the site. We have prepared baseline products for grassland/shrubland analyses in New Mexico, and are nearing completion of N. Texas soil analyses and remote sensing studies of land management impacts and their detection in S. Texas.

The third funding period will include: refinement of land-use and vegetation histories within the SRER, Arizona site; development of land-use scenarios defining different policy environments; analysis of Sevilleta landscape configuration and its influence on biogeochemical processes; and initiation of NPP and C stock estimates for focus areas (Arizona, Texas and New Mexico sites.

Publications

Archer, S., T.W. Boutton, and K.A. Hibbard. 2001. Trees in grasslands: biogeochemical consequences of woody plant expansion, pp. 115-137. *In*: Global Biogeochemical Cycles in the Climate System (E-D Schulze, SP Harrison, M Heimann, EA Holland, J Lloyd, IC Prentice, D Schimel, eds.). Academic Press, San Diego. http://www.apcatalog.com/cgi-bin/AP?ISBN=0126312605&LOCATION=US&FORM=FORM2

Archer, S. and A. Bowman. 2002. Understanding and managing rangeland plant communities, pp. 63-80. *In:* Global rangelands: progress and prospects (A. Grice and K. Hodgkinson, eds.). CAB International, Wallingford, Oxon, United Kingdom.

Asner, G., S.R. Archer, T.W. Boutton, H.B. Johnson. 2003. Soil carbon and woody plant proliferation. ***Eos, Transactions American Geophysical Union*** (submitted).

Asner, G.P., S.A. Archer, R.F. Hughes, J.N. Ansley, and C.A. Wessman. 2003. Net changes in regional woody vegetation cover and carbon storage in North Texas rangelands, 1937-1999. ***Global Change Biology*** 9(3):316-335.

Dale, V., S.R. Archer, M. Chang, D. Ojima. 2003. Understanding of Ecological Processes Facilitates Land Management. ***Ecological Applications*** (submitted)

House, J., S. Archer, D. Breshears, and R.J. Scholes. 2003. Conundrums in mixed woody-herbaceous plant systems. ***Journal of Biogeography*** 30:1-15.

Jurena, P.N. and S. Archer. 2003. Woody plant establishment and spatial heterogeneity in grasslands. **Ecology** 84: (In Press)

Wu, X.B. and S.R. Archer. 2003. Scale-dependent influence of surface hydrologic features on vegetation patterns in savanna landscapes. ***Journal of Ecology*** (submitted).

Wessman, CA, S. Archer, L.C. Johnson, and G.P. Asner. 2003. Woodland expansion in US grasslands: assessing land-cover change and biogeochemical impacts. *In:* Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface (G. Guttman, et al. eds.). Kluwer Academic Publishers (In Press)

Wessman, C.A. and C.A. Bateson. Building up with a top-down approach: The role of remote sensing in deciphering functional and structural diversity. *In:* Scaling and Uncertainty Analysis in Ecology: Methods and Applications (Wu, J., B. Jones, H. Li, and O. Loucks, eds.). Columbia University Press (in review).

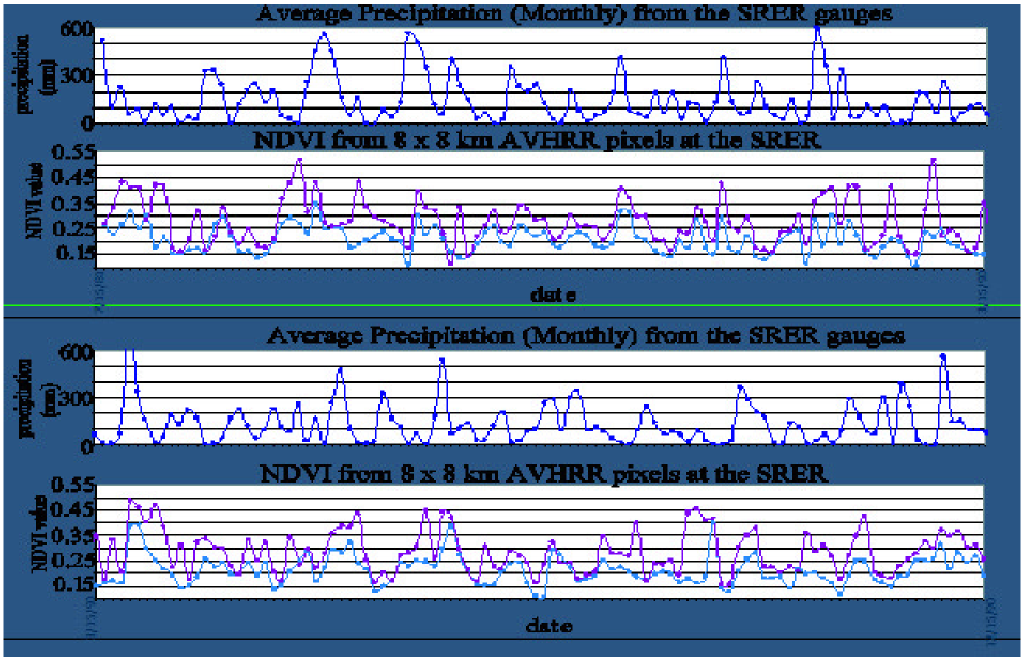

Figure 1. AVHRR time series and average precipitation

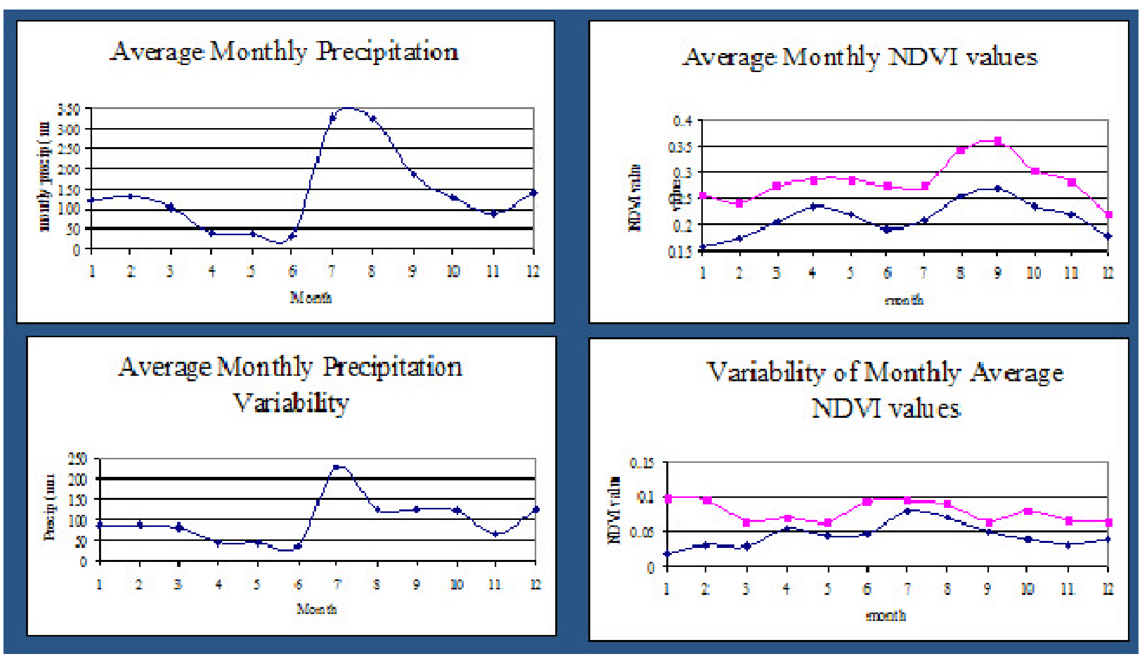

Figure 2. Seasonality of precipitation and NDVI at the SRER.

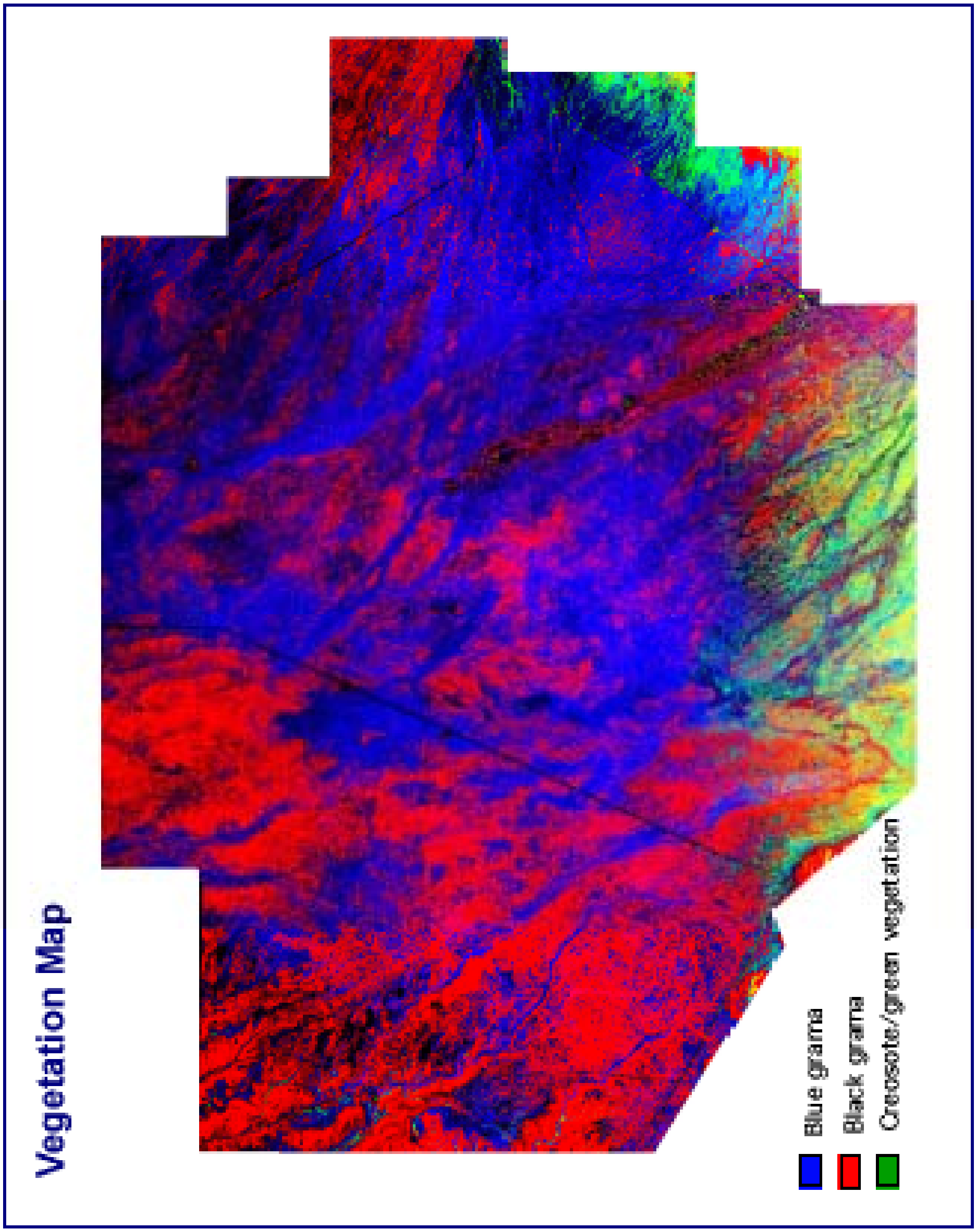

Figure 3. Vegetation map of the New Mexico Sevilleta National Wildlife Refuge and LTER site derived from 44 AVIRIS images (3.2-m resolution) acquired on 20-21 October 1999.

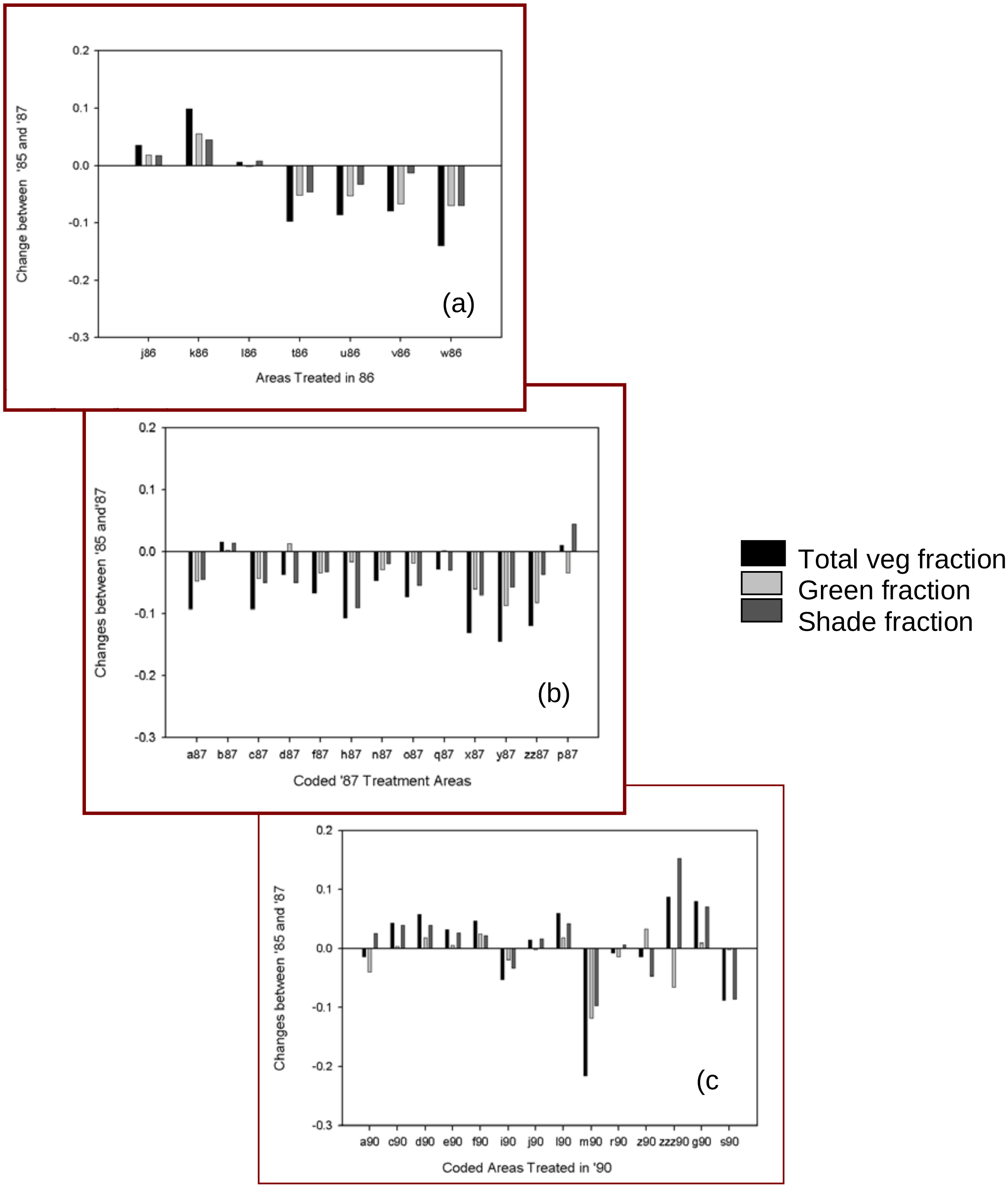

Figure 4. Changes in fractional cover at La Copita, TX, between 1985 and 1987: (a) 16-months post-1986 treatments, (b) 4-months post-1987 treatments, and (c) untreated areas.