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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: Ecosystem and Biogeochemical Impacts

Extensive databases on productivity, decomposition and nutrient cycling processes exist for grassland, shrubland and woodland ecosystems. However, we cannot necessarily take what we know of patterns and processes in these systems and apply them to systems undergoing shifts from herbaceous to woody plant domination. Furthermore, although many concepts and principles developed for grassland, shrubland and forest systems are potentially relevant, the novel, complex, non-linear behavior of communities undergoing lifeform transformations cannot be accounted for by simply studying or modeling woody and herbaceous components independently (House et al. 2003). The appropriate representation of mixed woody-herbaceous systems is fundamental to the performance of global vegetation models (e.g., Neilson 1995, Daly et al. 2000). Models explicitly incorporating woody-herbaceous interactions and dynamics vary widely with respect to their approach, their complexity and their data requirements. They span a continuum of detail, from highly validated empirical formulations to mechanistic, spatially-explicit treatment of individual plants and vary with respect to (a) the extent to which they incorporate plant physiological and population processes; (b) their fundamental assumptions of how and to what extent woody and herbaceous plants access, utilize, and redistribute resources; (c) their spatial and temporal resolution; (d) the extent to which they incorporate effects of climate, soils and disturbance; and (e) their treatment of competition or facilitation interactions. Linking remote sensing of changes in woody plant cover/biomass/leaf area with ecosystem process models is one approach for making large scale assessments and predictions of changes in ecosystem function resulting from changes in the relative abundance of woody plants in dryland systems.

Table 1 summarizes the findings from our work at our focus sites in Texas and New Mexico. Our work, along with other studies, lends insights into what occurs when woody plants invade and establish in grasslands. What is remarkable from these studies is the speed at which some changes have occurred. Changes in soil properties for example have traditionally been viewed as occurring on the scale of centuries. However, as several of the studies in Table 1 indicate, significant changes in soil organic carbon (SOC) and nitrogen pools can occur at decadal time scales subsequent to the establishment of woody plants in grasslands. Indeed, carbon inputs from woody plants appear to be dominating the SOC pool in upper horizons within 50 years of their establishment (See 'Surficial Soil C from Woody Vegetation' in Table 1). SOC mass reflects the balance between organic matter inputs from plants and losses from the decay of organic matter. In the context of woody plant proliferation, SOC could increase if woody plants were more productive than herbaceous plants, and/or if woody-plant tissues decayed more slowly than herbaceous plant inputs. Precipitation and temperature mediate this trade-off by exerting control over both plant growth (inputs) and decomposition (outputs).

The broad range of responses in Table 1 likely results from several factors. First, changes in SOC may be species dependent based on plant productivity, allocation patterns, and/or tissue chemistry. For example, at the Jornada site (MAP = 230 mm) SOC increases ~230% under tarbush, but decreases under creosote bush (-9%) and mesquite (-15%) (Schlesinger and Pilmanis 1998). In Texas (Vernon and La Copita) (MAP = 660-715 mm), SOC increases following woody plant proliferation in former grasslands range from 9% in temperate mesquite stands (Hughes et al. 2000) to 27-103% in more diverse subtropical woodlands (Boutton et al. 1998). Woody plant effects on microclimate which affect decomposition rates (notably soil moisture and temperature) also vary among growth forms in that evergreen and deciduous canopies differ in their magnitude and seasonality of rainfall and radiant energy interception, potentially affecting decomposition processes and hence C and N pools and fluxes.

Differences in woody plant effects on soil properties listed in Table 1 might also reflect differences in the ways microbial communities respond to changes in vegetation structure. For example, shifts from bacterial to fungal populations may accompany shifts from herbaceous to woody domination (Purohit et al. 2002), thus enabling decomposers to more effectively deal with lower litter quality (i.e. increasing C:N), and hence maintain or increase soil respiration and mineralization. Changes in root biomass distribution accompanying shifts from grass to woody plant domination may also change the nature and depth of microbial activity, but available information available is scanty and conflicting. Jackson et al. (2002) inventoried nematodes dependent on plant roots as indicators of changes in microbial activity accompanying shifts from grass to woody plant dominance. They found substantial decreases in maximum depth on some sites (Jornada), substantial increases in maximum depth on some sites (Sevilleta) and no changes on another site (Vernon).

The potential for ecosystem C-sequestration associated with the conversion of grass to woody plant domination will also reflect that balance between biotic processes promoting carbon accumulation (plant modification of soils and microclimate) and geophysical processes promoting nutrient losses (wind/water erosion). The magnitude of geophysical-induced losses and extent to which woody plants can compensate for these likely varies with soils and climate. For example, disturbances such as grazing, which promote woody plant encroachment, may also accelerate the loss of SOC via increased oxidation and erosion. At the Jornada site, shifts from grass to shrub domination have caused major changes in soil nutrient distributions (nutrient pools in shrub-affected soils >> nutrient pools of non-shrub soils), but no net change in total carbon stocks at the landscape scale, as C gains associated with woody plant proliferation are relatively small and have been offset by losses from inter-shrub zones (Connin et al. 1997, Schlesinger and Pilmanis 1998). In contrast, at the La Copita site, losses of SOC associated with livestock grazing in the late 1800s-early 1900s appear to have been fully compensated for by invading woody plants by the 1950s; and by the 1990s, landscapes had ca. 30% more carbon than would occur had the pristine grasslands, present at the time of settlement, been maintained (Hibbard et al. 2003).

It is interesting to note that plant and soil C and N stocks increase at some sites despite significant increases in soil respiration, non-methane hydrocarbon emissions, N-mineralization and NO emissions (e.g. La Copita). In contrast, *Juniperus* encroachment in Konza appears to have caused little change in the SOC pool, despite suppression of soil respiration and high inputs of low litter quality by this evergreen arborescent (Figure 1) (Smith and Johnson 2003). Explanations for this behavior are elusive. At the Vernon site, some studies have shown significant declines in SOC with woody plant encroachment (Jackson et al. 2002) while others have shown significant increases (Hughes et al. 2000). Reasons for this discrepancy may be indicative of the importance of local differences in soil types and land management histories (e.g. Teague et al. 1999, Asner et al. 2003). Indeed, topo-edaphic features do exert substantial control over the direction and rate of change in plant and soil nutrient pools and fluxes. For example, SOC increases in subtropical woodland communities developing on former grasslands vary from 27-37% on upland sandy loam soils to 103% on lowland clay loam soils (Boutton et al. 1998).

These contrasting scenarios point to the need to account for both loss and gain vectors and to the potential dangers of extrapolating from plant or patch scale measurements to ecosystem/landscape scales.

Studies documenting effects of woody plant encroachment on ecosystem processes are accumulating. However, an overlooked aspect of the woody plant encroachment phenomenon is the fact that land managers have been and will continue to implement management practices to reduce woody plant cover. Currently we know little of the extent of such clearing practices, rates of woody community recovery following treatments, or how the treatments affect soil nutrient pools and fluxes.

The challenge for the remote sensing community is to provide tools for tracking structural and biophysical changes accompanying shifts in woody versus herbaceous plant abundance. The challenge for ecosystem modelers is to develop approaches for representing and predicting, in a spatially explicit fashion over large areas, the ecosystem specific changes (Table 1) that occur when land cover transitions from grass to woody plant domination. The linkage of remote sensing and ecosystem process models appears to be a viable strategy for tracking the functional consequences of changes in the relative abundance of herbaceous and woody vegetation in transitional grasslands.

Developments in Image Analysis

Here we summarize the challenges and successes in developing airborne and space-based optical remote sensing methods for quantifying vegetation cover in heterogeneous landscapes. We emphasize our studies that address the issue of quantifying woody and herbaceous plant canopy properties, as this information is central to any analysis of woody encroachment and cover change.

Spatial Observations

Vegetation cover is arguably the most important remote sensing measurement needed to extend a field-level understanding of ecological, hydrological, and biogeochemical processes to broader spatial and temporal scales. It is critical for regional-scale monitoring of land management practices (e.g., Pickup and Chewings 1994, Pickup et al. 1994); and it serves as an important indicator of ecological and biogeochemical processes (Table 1, Schlesinger et al. 1990, 1996, Archer et al. 2001). Furthermore, cover information is needed to constrain ecosystem and land-surface biophysical models to actual abundance and distribution of cover types (e.g., Running et al. 1994, Sellers et al. 1997, Neilson 1995, Daly et al. 2000).

There is a significant demand for high spatial resolution data such as from aerial photography and spaceborne sensors. Schlesinger and Gramenopoulos (1996) used declassified high spatial resolution (~4m) monochromatic reconnaissance satellite photographs to estimate changes in woody vegetation cover between 1943 and 1994 along the Sahel-Sahara Desert ecotone in west Sudan. Their findings showed no change in woody plant canopy cover following widespread drought in mid- to late twentieth century. Asner and Heidebrecht (2002) used IKONOS imagery at the Jornada Experimental Range in New Mexico to quantify woody vegetation cover. IKONOS-based results agreed well with both field and low-altitude aerial photography estimates of woody canopy cover. However, the ~1 m IKONOS data were valuable for quantifying woody cover only when the canopies were ≥3 m in diameter.

Landscape or image texture refers to the local variation of land surface components such as shrubs and bare soils, both in terms of percentage cover and spatial distribution. Image texture (mean, variance, and range of values within a specified pixel window) provides a means to understand land cover heterogeneity and the changes that occur at a spatial scale commensurate with human activities (Haralick et al. 1973, Franklin and Peddle 1990). This approach also provides a means to analyze historical aerial photographs by minimizing the effects of systematic errors associated with background brightness variation and vignetting. Hudak and Wessman (1998, 2001) used textural filtering of digitized aerial photographs and geostatistical analyses to estimate shrub density and temporal variability in South African savanna landscapes over a 30-year period.

Spectral Observations

Although the NDVI is sensitive to pixel-level changes in greenness and fAPAR, it is not differentially sensitive to changes in vegetation cover versus condition (Carlson and Ripley 1997). When an NDVI change occurs, whether or not it was caused by altered vegetation cover or condition of the cover cannot be readily determined. Moreover, the NDVI has had limited success in providing accurate estimates of shrubland cover in arid regions (e.g., Duncan et al.

1993), owing to the variability of background materials such as soils and surface litter (Huete and Jackson 1988, van Leeuwen and Huete 1996). We conclude that the NDVI alone is not sufficient for quantifying woody canopy cover in drylands.

Multi-spectral, non-NDVI measurements have been developed to estimate vegetation cover in drylands. Pickup et al. (1994) used a multi-temporal vegetation index derived from visible wavelength channels to successfully estimate semi-arid rangeland vegetation cover. One of the most common methods for woody and herbaceous cover analysis of grasslands involves decomposing image pixels into their constituent surface cover classes. Known as spectral mixture analysis (SMA), this method allows for the estimation of biophysically distinct cover types at the sub-pixel level. A wide range of SMA efforts have now been applied in analyses of grasslands using airborne and spaceborne multi-spectral scanners (e.g., Graetz and Gentle 1982, Smith et al. 1990, Wessman et al. 1997, Asner et al. 1998a, Elmore et al. 2000).

A major assumption in linear mixture modeling is that the spectral variability of the major landscape components is accommodated by the reflectance signatures employed in the models. Some SMA approaches utilize spectral endmembers derived from the image (e.g., Wessman et al. 1997, Elmore et al. 2000), while others employ libraries of endmember spectra (e.g., Smith et al. 1990, Roberts et al. 1998). In heterogeneous landscapes, it is exceedingly difficult to locate image pixels containing 100% cover of each pertinent endmember, which is usually required when using image-derived endmembers in a spectral mixture model. Thus, library spectra have been widely employed with the recognition that libraries cannot easily capture the full range of endmember variability as is found in nature. Bateson and Curtiss (1996) and Bateson et al. (2000) developed a unique SMA model that allows for the exploration of image data in multiple dimensions via principal components analysis. The technique allows the user to select endmember spectra based on the inherent spectral variability of the image data without requiring homogeneous pixels of each endmember.

Independent of the endmember selection technique, Landsat-type instruments tend to provide sufficient spectral information to broadly discriminate between green vegetation and non-photosynthetic materials such as litter and soil (Smith et al. 1990, Asner et al. 1998a). However, they do not typically provide the spectral resolution necessary to delineate species, functional groups, or greenness conditions within the "green vegetation" class using spectral mixture models unless seasonality enables such separations. Furthermore, multi-spectral sensors such as Landsat TM and MODIS may not provide sufficient information to spectrally separate soils from non-photosynthetic vegetation (Asner et al. 2000). The performance of linear spectral mixture analysis has been compared to vegetation indices in drylands using multi-spectral satellite data. Elmore et al. (2000) compared the performance of a spectral mixture model against the NDVI in mapping green canopy cover from Landsat data. Although the NDVI was generally correlated with green cover, a marked increase in performance was obtained when utilizing the full multi-spectral data from Landsat with spectral mixture analysis. Similarly, McGuire et al. (2000) demonstrated that SMA was more accurate than the NDVI (and other indices) for quantifying green canopy cover in a California desert.

The additional information provided by hyperspectral imagers over that of multi-spectral sensors has advanced many analyses of drylands. For example, using spectral unmixing techniques, Wessman et al. (1997) related subtle differences in hyperspectral reflectance endmembers to biophysical conditions related to rangeland management in a Kansas grassland. In particular, high spectral resolution allowed separation of litter from soil based on plant lignin-cellulose absorption features. Several other efforts have combined hyperspectral reflectance data with spectral mixture models to estimate sub-pixel cover of vegetation in drylands. Roberts et al. (1998) used a multiple endmember spectral mixture model to map major plant functional groups and species in a California chaparral ecosystem. Asner and Lobell (2000) used shortwave-IR (2000-2500 nm) hyperspectral data from AVIRIS to accurately estimate green vegetation, non-photosynthetic vegetation and bare soil extent in arid shrublands and grasslands of the Chihuahuan Desert, New Mexico. In addition, Asner et al. (1998b) used imaging spectrometer data with spectral mixture analysis and radiative transfer inverse modeling to estimate both the horizontal extent and vertical density of live and senescent vegetation and fire fuel load in subtropical savanna ecosystems in southern Texas.

Historical Woody Cover Change Analysis

There are numerous trade-offs between using aerial photography or satellite imagery to track changes in woody plant cover in grassland to woodland transitions. Aerial photos, which may date back many decades, are relatively inexpensive and can provide a deeper historical baseline from which to document change than satellite imagery, which dates back only to the 1970s. In addition, the spatial resolution of aerial photos is often more commensurate with the ground area occupied by the vegetation of interest (e.g., individual trees or shrubs), thus requiring little in the way of image manipulation. In contrast, satellite data require sophisticated calibration efforts, and the greater disparity between satellite spatial resolution and vegetation patch characteristics requires analytical techniques such as spectral mixture analysis. There is also a trade-off in ascertaining large-scale changes in woody plant cover in grasslands: the labor-intensive process of developing mosaics of very high resolution aerial photos versus using lower spatial resolution satellite imagery covering a much larger geographic area but requiring more complicated signal processing and ground validation efforts.

As a compromise, Asner et al. (2003) opted to use a mosaic of high-resolution aerial photos to establish an historical baseline for woody vegetation cover and satellite imagery to quantify contemporary cover. They used this combination to quantify woody cover and aboveground carbon changes for a 63-year period in a north Texas rangeland. Mosaics of high spatial resolution aerial photography were analyzed for woody cover in 1937 using textural filtering and classification techniques. Areal estimates of woody cover in 1999 were then quantified using Landsat 7 data with spectral mixture analysis.

Comparison of the 1937 and 1999 imagery revealed major changes in woody plant cover and aboveground carbon. There were numerous landscapes throughout the region where woody cover increased from < 15% in 1937 to > 40% in 1999. There were also substantial areas where woody plant cover decreased from > 80% in 1937 to < 50% in 1999. The result was a net increase in woody cover and homogenization of woody cover over the 63-year period..

Challenges and Caveats

Scale-Dependence of Observations

Grassland landscapes undergoing woody encroachment are heterogeneous in both space and time. Detection of shrubs and trees within a grass matrix require image resolutions commensurate with the scale of the woody plants or sub-pixel analyses such as spectral mixture analysis. Similarly, frequency of data acquisition, remote and field-based, will have significant influence on analyses and interpretation of cover dynamics and their biogeochemical consequences. The shrub encroachment process under "natural" conditions progresses on a decadal scale. However, management practices introduce a temporal complexity to the landscape as different areas or management units experience different land uses at different times. For example, pastures or portions of pastures with high woody cover may be targeted for 'brush management' and those with low woody cover excluded from treatment. Brush may be cleared via mechanical means in some pastures and via herbicides or prescribed fire in others.

A conceptual model illustrating the challenges to assessing regional woody plant cover and dynamics in the context of brush management is presented in Figure 1. Line I represents woody stand development that might occur in the absence of disturbance (e.g. elimination of fire due to grazing or active suppression) or management intervention. Line II represents a stand whose development is interrupted by natural (e.g. drought Archer et al. 1988, Allen and Breshears 1998), wildfire (Kurz and Apps 1999), pathogenic (McArthur et al. 1990, Ewing and Dobrowolski 1992)) or anthropogenic (e.g. brush management (Scifres 1980, Bovey 2001)) events that 'reset' the carbon accumulation process. The magnitude of these setbacks and rates of recovery vary depending upon the type, intensity and spatial extent of disturbance, soil type, environmental conditions immediately preceding and following the disturbance, and the growth form (evergreen vs. deciduous) and regenerative traits involved. Some stands regenerating from these setbacks might receive follow-up brush management treatments (Line III), but others may not due to financial constraints, availability of subsidies, and many other factors. Thus, remote sensing observations over large areas and limited temporal resolution show net changes (A), whereby increases in woody cover on some landscapes or management units (B and C) are offset by decreases in others (D).

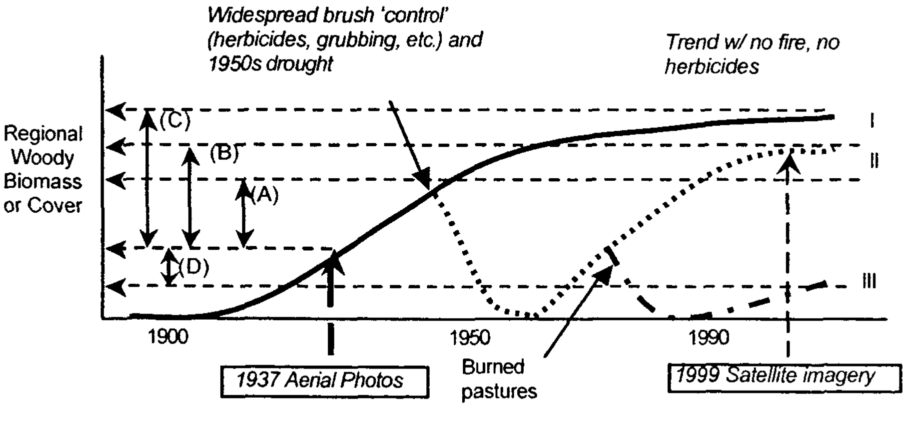

Figure 1. Conceptual model illustrating limitations in tracking regional carbon stock assessments in managed rangelands using remotely sensed imagery. See text for discussion. (Asner et al. 2003)

In sum, remote sensing analyses of woodland expansion must be compatible with the spatial scale of the landscape components and the temporal resolution of the dynamics driving cover changes. Frequency of data acquisition must keep pace with disturbance dynamics and/or land use change in order to capture the important transitional stages associated with management and recovery processes. For example, measurements with poor temporal resolution of net changes in woody plant cover across long time periods may insufficiently estimate rates of carbon cycling and consequently the source/sink potential of an area under transformation.

Remote Sensing-Modeling Links

New generations of ecosystem process models that incorporate remote sensing products as a basis for spatially explicit calculations at large scales are at various stages of development. Approaches linking dynamic simulations of function and process to remote sensing of structure and pattern hold promise for assessments of the functional consequences of changes in land-use/land-cover at unprecedented spatial and temporal scales. (e.g. Field et al. 1995, Schimel et al. 1997, Wylie et al. 2003). For example, in models such as the Carnegie-Stanford Approach (CASA), calculations of NPP are based on remote sensing-estimates of APAR rather than mechanistic details of NPP (Field et al. 1995). This constrains the calculations to observed heterogeneity and reduces errors resulting from unrealistic assumptions based on optimum or potential conditions. This point is particularly important under conditions of woody plant encroachment, in which fundamental shifts in vegetation form result in profound functional differences and transitional properties that cannot be easily estimated based on a steady-state modeling approach. Even a simple modeling exercise exploring diurnal PAR absorption and carbon uptake in the La Copita, Texas savanna found that LAI, vegetation structure, and intercanopy shading (all estimated remotely) are important controls on carbon fluxes which may scale to affect regional carbon estimates (Asner et al. 1998a).

In spatially heterogeneous environments, integration of remotely sensed data with ecosystem models enables us to establish a fundamental connection between the spatial structure and the manifestation of functional processes at landscape scales, an association that is difficult to achieve based solely on field measurements under the best of conditions (Wessman and Asner 1998). Even if we were able to use field-based approaches, the sheer vastness and remoteness of the world's drylands would make it impossible to make such assessments at the frequency and degree of spatial coverage that would be needed to adequately assess and track land use-land cover changes. Remote sensing not only provides access to the spatial distribution of vegetation structure, but also provides some means to bypass our present-day inability to mechanistically connect principles of allocation to biogeochemistry and ecosystem function (Wessman and Asner 1998). Through the integration of remote sensing and modeling, we can, to some degree of accuracy, calculate and track NPP and both above- and belowground (e.g. Gill et al. 2002) carbon storage and dynamics under contrasting land use practices at landscape and regional scales.

Conclusions

Although shifts from grass to woody plant domination have been widely reported in the world's grasslands (Archer et al. 2001), there has been no effort to systematically quantify the rate or extent of change nor to evaluate its biogeochemical consequences at large scales. Two recently emerging factors add urgency to this particular land cover change issue: (a) the latest USA carbon budget assessments which implicate "thickening" of woody vegetation in grasslands as a major (Houghton 2003) or perhaps even the single largest sink term (Schimel et al. 2000); and (b) the possibility of industry or government-sponsored "carbon credit" or "carbon offset" programs. Jackson et al. (2002) stress that current uncertainties around the net change in the carbon cycle due to woody encroachment are large, as are the uncertainties in regional extrapolations of the biogeochemical consequences. Indeed, the complexity in such broad functional shifts in grassland to woodland transitions coupled to socioeconomic drivers of change are profound and in need of further study.

Our studies of grasslands in the Southwest emphasize the importance of three factors. 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.

A third important factor is the fact that, traditionally, there have been strong policy, subsidy and economic incentives for brush clearing on rangelands. Indeed, brush management is often the greatest single expense in commercial ranching enterprises (Scifres 1980, Scifres & Hamilton 1993, Bovey 2001). However, with the prospect of carbon credit/offset programs, 'brush' may become an income-generating commodity because of its potential to sequester more carbon above- and belowground relative to the grasslands it replaced (e.g., Archer et al. 2001). It is easy to envision scenarios in the near future, whereby land owners/managers may be paid *NOT* to clear existing woody vegetation. Furthermore, there could be strong economic incentives to engage in land management practices that promote woody plant encroachment and the displacement of grasslands. From a carbon sequestration perspective this may be desirable. However, perverse outcomes with respect to livestock production, wildlife habitat, grassland biodiversity, aquifer/stream recharge, and NOx and non-methane hydrocarbon emissions may also result (Archer et al. 2001). The scientific community will be uniquely challenged to address the ramifications of these looming issues in land use. We believe that linked remote sensing-modeling approaches will be a critical underpinning for the types of landscape and regional monitoring and assessments that will be required by policy makers seeking to make informed decisions.

Table 1. Changes in ecosystem properties accompanying woody plant encroachment into grasslands (--, -, 0, +, ++ represent substantial decrease, slight decrease, no change, slight increase, and major increase, respectively; "?" denotes expected but unsubstantiated changes). Numerical superscripts point to studies reporting these changes; letter superscripts refer to explanations (see footnotes). For additional information on sites, visit the following URLs: *Vernon*: http://juniper.tamu.edu/IRM/brush/P01JAprojecthome.htm; *La Copita*: http://www.geocities.com/lacopita_research_area/; *Jornada*: http://usda-ars.nmsu.edu/; *Sevellita*: http://sevilleta.unm.edu/.

Metric	**Vernon**	**La Copita**	**Jornada**	**Sevilleta**
Lat/Long	34.5° N; 99.2° W	27.4° N; 98.1° W	32.5° N;106.8°W	34.5°N;106.9°W
City State	Vernon Texas	Alice Texas	Las Cruces New Mexico	Albuquerque New Mexico
Annual PPT (mm)	655 mm	680 mm	230 mm	255 mm
Annual Mean Temp (°C)	17 °C	22 °C	16 °C	14 °C
Characteristics of Dominant Woody Plants				
Stature	Arborescent	Arborescent	Shrub	Shrub
Evergreen (E) or Deciduous (D)	Deciduous	Deciduous	D & E	Evergreen
Potential N_2-fixation?	Yes	Yes	Yes & No	No
Genera	***Prosopis***	***Prosopis***	***Prosopis/Larre***	***Larrea***
Fractional Cover Δ (%/y)	+0.2-2.2%/yr[a, 1 2]	+0.7%/y [3]	+0.4-0.5[a,4]	
Soil Temp Δ		-- [5 6]		
Surfical[e] Soil Moisture Δ	0, + [7]	+ [6 8]	+ [27]	
ANPP Δ	++ ?	++ [9]	- [10]	- [28]
Plant C Pool Δ Aboveground	++ [11 1]	++ [9]	-, 0 [12]	- [13]
Plant C Pool Δ Belowground		++ [8 14]	-, + [12]	
Soil Organic Carbon	-, + [b, 11 15]	++[6 8 14 26]	+ [15]	+ [16 15]
Surfical[e] Soil C from Woody Vegetation (%)		45-88%[c, 17]	53-72% [d, 18]	+ [26]
Soil Respiration Δ		++ [6]		- [16]
Nmin Δ		++ [8]		- [16]
NO/$N_2$0Flux Δ	+ [19]	++ [20]	0 [25]	
NMHC Flux Δ		++ [21]		
Microbial Biomass Δ		++ [6]	+ [22]	- [16]
Potentially Mineralizable Soil C		++ [6]		
Net C exchange (source, sink)	Sink [23]	Sink [9]		
Litter Decomposition		-- [14]		
Δ Maximum depth of nematodes (m)	0 [15]		-- [15]	++ [15]
Plant Species Diversity (richness)	0, + (?)[24]	0, + (?)[24]		

[a] Range reflects different land use/management histories. [b] Range may reflect local differences in soil type and land use history. [c] Range for different community types and age-states. [d] Values for different soil particle size fractions. [e] Upper 7 to 20 cm

1= Asner et al. 2003; 2= Ansley et al. 2001; 3=Archer et al 1988; 4=Buffington et al. 1965; 5=Archer 1995; 6=McCulley 1998; 7=Simmons 2003; 8=Hibbard, et al. 2001; 9=Hibbard et al. 2003; 10=Huenneke et al. 2002; 11=Hughes et al. 2000; 12=Schlesinger & Pilmanis 1998; 13=Cross & Schlesinger 2001; 14=Archer et al. 2001; 19=Smith & Johnson 2003; 15=Jackson et al. 2002; 16=Kieft et al. 1998; 17=Boutton et al. 1998; 18=Connin et al. 1997; 19=Martin 2003; 20=Cole 1996; 21=Guenther 1999; 22=Gallardo & Schlesinger 1992; 23=Ansley et al. 2002; 24=Pers.Obs.; 25=Hartley & Schlesinger 2000; 26=Gill & Burke 1999; 27=Nash et al. 1991; 28=Cross & Schlesinger 1999.

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Project Involvement of Undergraduate, Graduate and Post-Doctoral Researchers

Undergraduate Students	Kevin Cody (Univ. Colo.)
	James Hurley (Univ. Colo.)
	Jeremy Klass (Univ. Colo.)
	Seth Zunker (Univ. Colo.)
Graduate Students	Dawn Browning (Univ. Arizona)
	Nancy Golubiewski (Univ. Colo.)
	Andrew Hudak (Univ. Colo.)
	David Lobell (Stanford)
	Robin Martin (Univ. Colo.)
	Mohammad Noor (Jordan, Texas A&M)
	Mark Simmons (Texas A&M)
	Winston Wheeler (Carnegie)
Post-Doctoral Researcher	Sharon Hall (Univ. Colo.)
	Jeff Hicke (Univ. Colo.)
	R. Flint Hughes (Univ. Colo.)

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