Stability of Tree-Grass Ratios: A Top-Down Perspective

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Introduction and Problem Statement

- Ecological stability is generally defined as a system staying unchanged through time (Holling 1973). This term is often used to assess the response of ecosystems to stress, disturbance or environmental change.
- One of the most significant directional changes in dryland regions has been woody plant encroachment. However, the stability of new plant communities resulting from tree/shrub proliferation over the past 100+ years is unknown.
- Assessing ecosystem stability requires long-term observations over large spatial extents (House et al. 2003).
- Remote sensing approaches are uniquely suited to quantify ecosystem stability.
- Integrated field and remote sensing studies generally take a "bottom-up" and rarely use a "top-down" approach.

Definition:

• Bottom-up: Fusion of ground and remotely sensed data, and interpolation/upscaling of field observations over large spatial extents based upon correlations determined via statistical models (Marceau and Hay 1999).

• Top-down: Quantify landscape patterns from coarse, large-scale inventories, and identify their ecological significance by overlaying these patterns with fine-scale spatial and/or ground data (Noss 1990).

Objective and Research Questions

- **Apply a top-down remote sensing approach to investigate ecological stability in a Desert Grassland ecosystem that has a history of woody plant proliferation.**
- **Question 1:** Under what set of environmental conditions is the woody-herbaceous relationship [tree-grass ratio (TGR)] stable?
- **Question 2:** What is the range of stable TGRs within a given biogeographic region?
- **Question 3:** To what extent do areas of stable TGR vary from site to site within this region?

Methods

1. Study site

- TGRs were assessed across the 200 km² Santa Rita Experimental Range (SRER) (31.83° N, 110.85° W; elevation 900-1450 m ASL) in southeastern AZ, USA (Fig. 1).

2. Satellite Data

- Forty sets of Landsat TM/ETM+ data acquired from dry (May, June) and wet (August, September) months and spanning a 21 yr period (1984-2005).
- Images underwent ortho-rectification, atmospheric correction [the COST model (Chavez 1996)] and radiometric normalization.
- Woody (WCF) and herbaceous (HCF) cover fractions derived using the Automated Monte Carlo Unmixing (AutoMCU) algorithm (Asner and Lobell 2000) from dry (WCF only) and wet (WCF+HCF) season Landsat images.

3. Delineation of Stable TGR Sites

- Mean and coefficient of variation [CV (%) = 100 × standard deviation/mean] of WCF and HCF over the 21 yr period of observation were computed for each pixel.
- Pixels were labeled as 'stable' if WCF and HCF fell into the lowest 10% percentile of CVs. Unstable pixels with the highest 10% percentile of CVs were also selected for comparison purposes (Fig. 1).
- Biomass-based TGRs of stable sites were estimated by correlating remotely sensed fractional cover to biomass measured in 20-40 × 40 m plots representing a range of vegetation structures (Fig. 2) (bottom-up). Biomass in field plots was estimated using existing allometric equations relating plant cover (woody plants) and height (herbaceous plants) to biomass.

4. Areas of Exclusion

- Recently burned areas.
- Heavily grazed areas based upon their proximity (200 m) to water sources.
- Man-made infrastructures (100 m on each side of roads).

5. Stable TGR Sites Delineation

- Elevation, slope inclination and aspect and the heat index (HI) (Parker 1991) were derived from the USGS Digital Elevation Models.

$$HI = \cos[aspect(degrees\ azimuth) - 225^\circ] \times \tan[slope\ (^\circ)]$$

- The spatial distribution of soils and landforms was obtained from maps generated by the USDA Natural Resources Conservation Service.
- TGRs were evaluated with respect to these abiotic parameters (Fig. 4). The proportional and the inversely weighted proportional (IWP) contribution of each topo-edaphic class to the total number of stable or unstable pixels was computed. The IWP represents the contribution of a given stable class normalized by the contribution of that class to the total number of pixels evaluated.

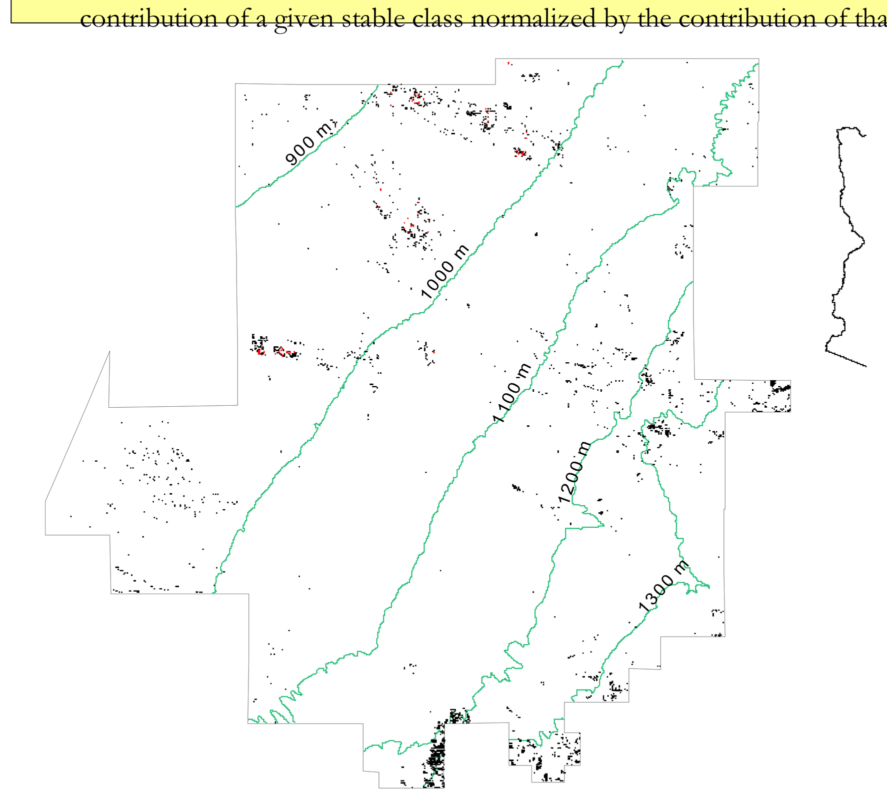


Fig. 1. Elevation contours on the Santa Rita Experimental Range (SRER). The sites in black are areas where woody and herbaceous biomass has been most stable over the past 21 years; the least stable sites are shown in red. The location of the SRER and major cities within Arizona is shown in the upper right corner.

Results

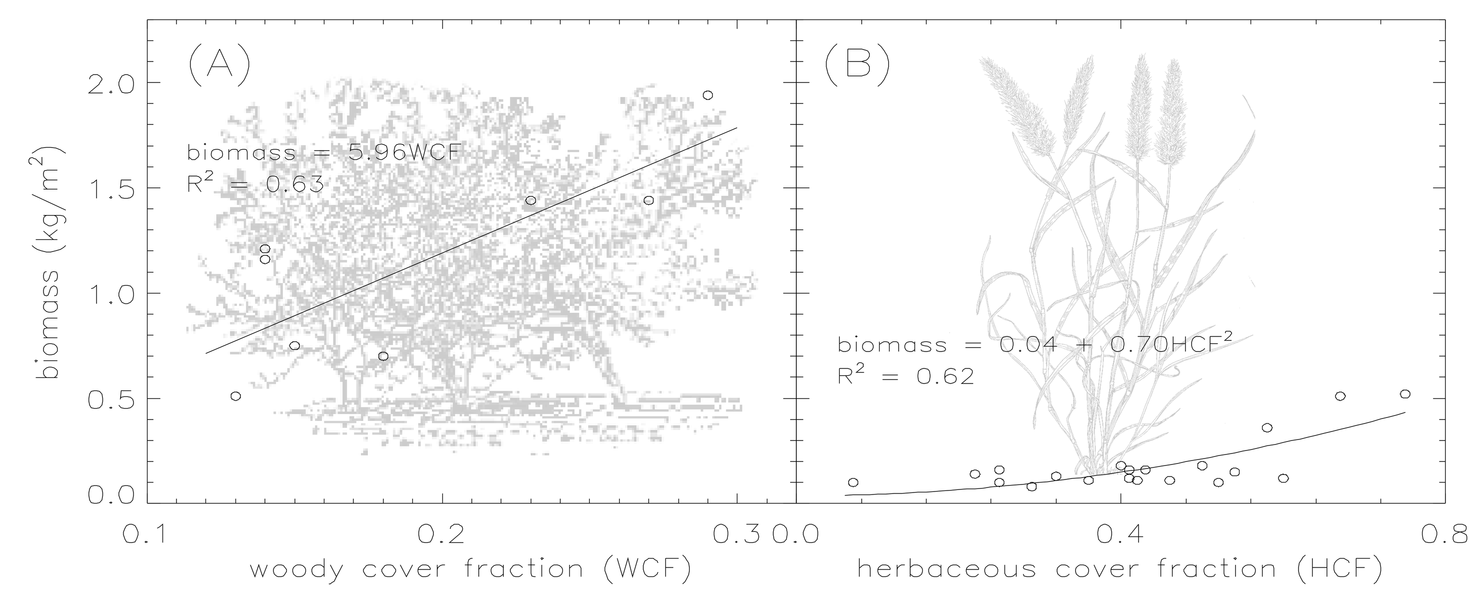


Fig. 2. Relationships between field woody (A) and herbaceous (B) biomass and remote sensing cover fractions. Our previous study (Huang et al. *in prep.*) found that the woody cover-biomass relationship can be significantly altered by fire disturbance. Therefore, only samples from sites without recent fire histories were used to estimate woody biomass (n = 8 plots). All samples were utilized to predict herbaceous biomass (n = 20 plots).

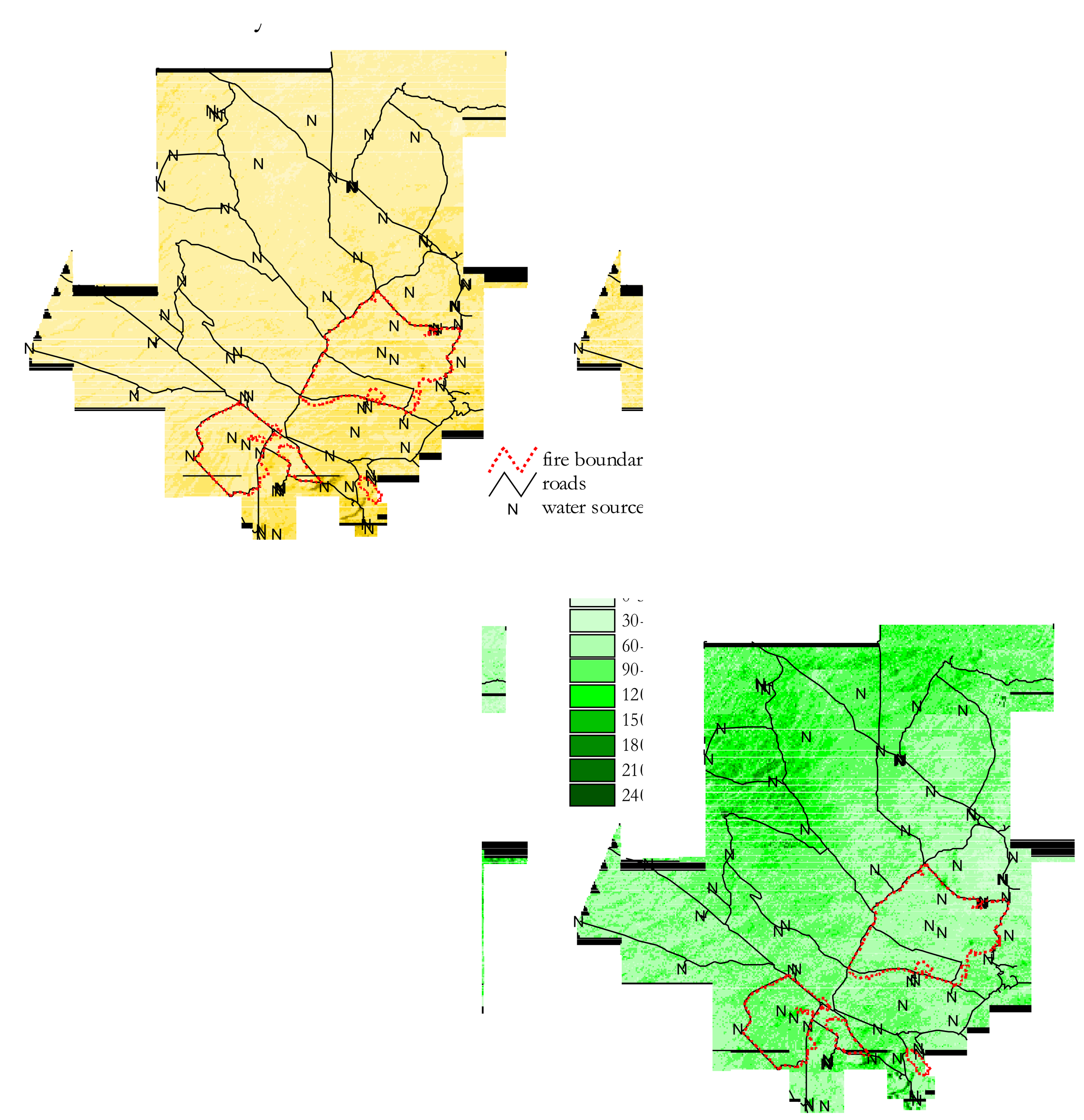
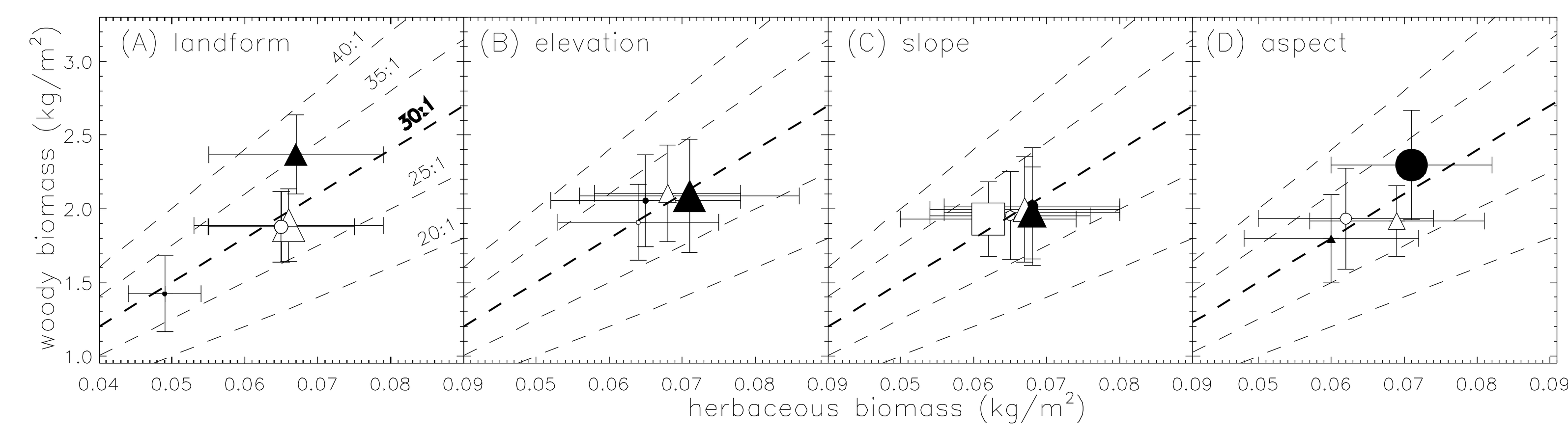


Fig. 3. Mean woody (yellow monochromatic gradients) and herbaceous (green monochromatic gradients) cover fractions and coefficient of variations (CVs) generated from long-term (1984-2005) dry and wet season Landsat TM and ETM+ images.

Table 1. Comparisons of dominant topo-edaphic classes, woody and herbaceous biomass and tree-grass ratios for stable and unstable sites. Precipitation data were obtained from McClaran et al. (2002).

	Most stable	Least stable
Soil texture	Coarse sandy loam	Clay loam, sandy loam
Soil depth (cm)	25-51	~ 150
Drainage	Well-drained	Well-drained
Permeability	Moderate	Relatively low
Elevation (m)	> 1,200	< 1,000
Precipitation (± SE) mm/yr	407 ± 13	340 ± 10
Aspect	East	West (No east facing)
Slope	Piedmont	Lowland
Heat Index (± SD)	-0.01 ± 0.23	0.004 ± 0.023
Mean (± SD) woody biomass (kg/m²)	1.9 ± 0.3	1.2 ± 0.2
Mean (± SD) herbaceous biomass (g/m²)	60 ± 10	50 ± 4
Mean (± SD) TGR	31.4 ± 7.1	27.7 ± 5.2

Abbreviations: SD = standard deviation; SE = standard error; TGR = tree-grass ratio



Symbols	(A) Land forms	(B) Elevation (m)	(C) Slope (°)	(D) Aspect
Empty circles (○)	Granitic hills	1,200-1,300	10-15	North
Filled circles (●)	Limestone hills	1,300-1,400	15-20	East
Empty triangles (△)	Shallow hills	1,400-1,500	20-25	South
Filled triangles (▲)	Granitic hills-shallow hills	1,500-1,600	25-30	West
Squares (□)			30-51	

Fig. 4. Mean and one standard deviation (horizontal and vertical error bars) of woody and herbaceous biomass for stable pixels segregated by dominant topo-edaphic classes (the table above). The size of each symbol is proportional to the inversely weighted proportion for each class. Broken isolines indicate the tree-grass ratios (TGRs), and the thick 30:1 TGR isoline is close to the mean TGR for all stable sites (31:1).

Discussion

- The most stable sites occurred on Shallow Hills, Limestone Hills, and Granitic Hills; the least stable areas occurred on Limy Fan and Clay loam Upland sites. Comparisons of natural conditions between stable and unstable sites are listed in Table 1.
- The range of herbaceous and woody biomass values giving rise to stable TGRs was broad with respect to landform and aspect; and narrow with respect to slope and elevation (Fig. 4).
- Mean TGRs of the most stable sites were higher than those on least stable sites (Table 1), and ranged from 28:1 to 35:1 (Fig. 4). Low TGRs thus appear to indicate locations areas where herbaceous production is susceptible to subtle environmental effects. In contrast, high TGRs may reflect areas where tree-on-tree interactions are strong and density-dependent.

Implications

- Targeting fine-scale field studies seeking to address circumstances conferring ecosystem stability and instability (Fig. 1).
- Facilitating the prediction of potential carbon stocks in drylands (Fig. 5).

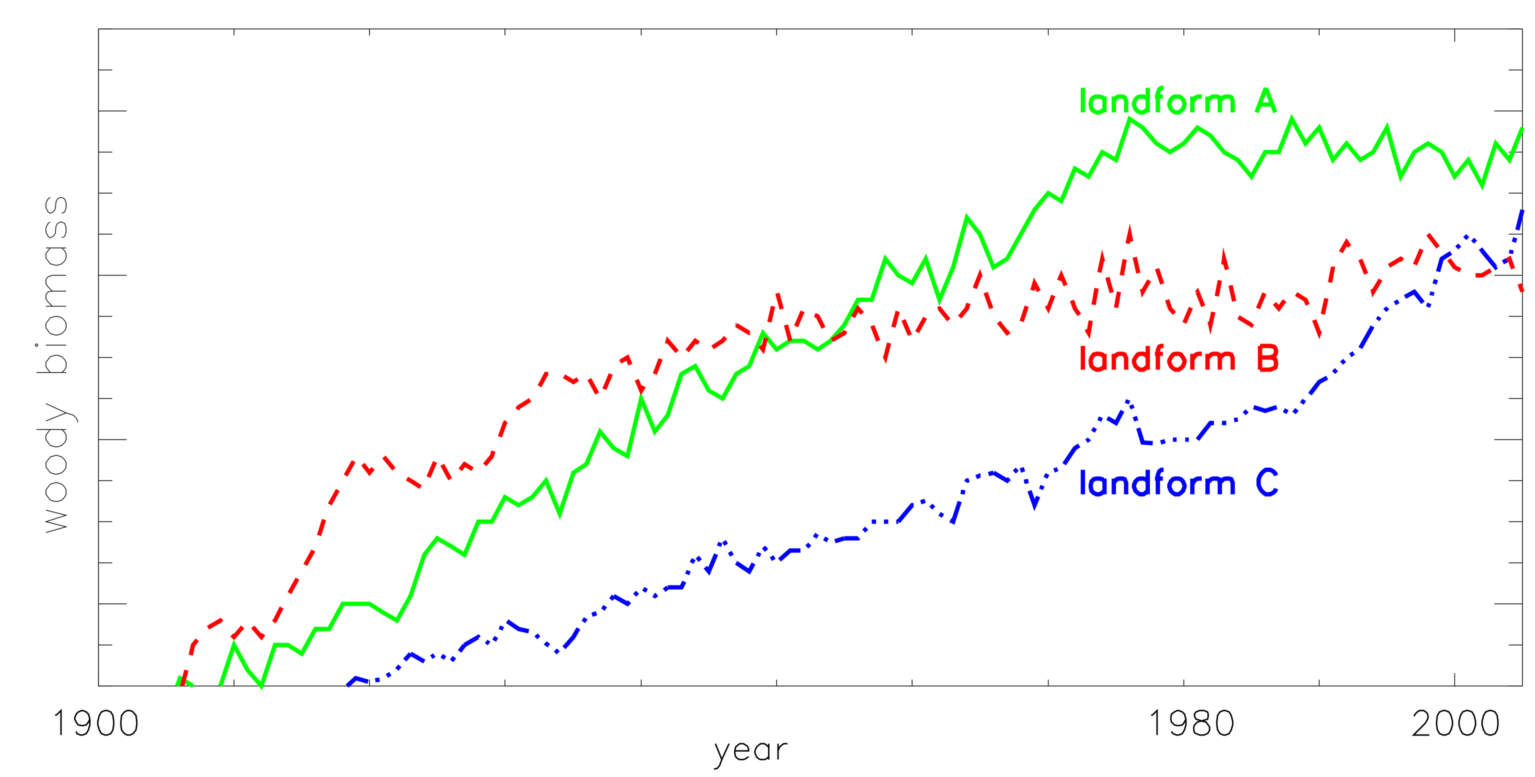


Fig. 5. Hypothetical scenarios of woody plant proliferation on three different landforms. Woody plant biomass on landforms A and B has been dynamically stable since ca. 1980 and has reached the maximum "carrying capacity" of aboveground woody carbon stocks. Conversely, woody encroachment is still in progress on landform C and it has not yet reached its upper limit. Retrospective analysis of the stability of tree-grass ratios enables determination of maximum woody cover that might be possible for a given landform. The status of sites within a region representing that landform could then be assessed relative to this upper limit

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