Shrub expansion in northern Chihuahuan Desert grasslands: spatial patterns and biophysical constraints

Darroc Goolsby[1,3], Brandon Bestelmeyer[1,3,4], Steve Archer[2,3]

[1] New Mexico State University; [2] University of Arizona; [3]Jornada LTER; [4]USDA/ARS

Introduction

Among the greatest contemporary threats to the structure, function and biological diversity of desert grassland and shrub savanna ecosystems is the displacement of mesophytic grasses by xerophytic woody plants. Information needed by land managers falls into two categories: (i) how to prevent shrub encroachment; and (ii) how to restore grasslands once shrub encroachment has occurred. Managers need to anticipate which landscapes are most susceptible to shrub encroachment and which are most likely to be restored once shrub encroachment has occurred. Information currently available from traditional inventory and monitoring programs and small-scale, short-term field experiments is not sufficient to make these predictions.

In order to develop a predictive understanding of shrub encroachment and grassland restorability, we are quantifying *long-term, large-scale* rates and patterns of shrub encroachment with the dual goals of :

(i) identifying the biophysical properties of grasslands that put them at risk to woody plant invasion; and
(ii) characterizing the properties of shrub-invaded grasslands that make them suitable candidates for restoration.

Here, we have focused on the first goal and asked:

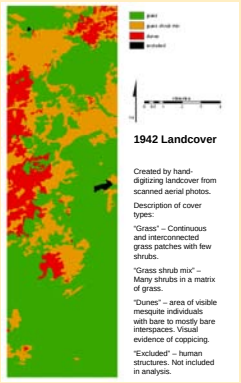
- **What soil characteristics are correlated with the occurrence of persistent grass patches (i.e., those that are uninvaded by shrubs)?**
- **Can an understanding of historic spatial patterns of shrub expansion help us predict future landscape change?**

Assembling Spatial and Plot Data

Site: Jornada Basin Long-Term Ecological Research site near Las Cruces, NM.

Land cover of a 11,700 ha area was digitized from aerial photography (1942) and a Quickbird satellite image (2003) using a combination of hand digitization and image-segmentation software (eCognition). Land cover classes/states included grass, grass-shrub mix, and degraded shrub coppice dunes. Within the grass class, we specified a subclass (black grama grassland; *Bouteloua eriopoda*) that is a primary conservation concern. Changes in shrub, perennial grass and dune patch structure and distribution and probabilities of transition were quantified by overlaying the two landcover datasets.

Perennial plant cover was quantified in 2007 in 20m x 20m plots (n=156) distributed across grassland-to-shrubland gradients. Soil was characterized to 150 cm or to restrictive calcium carbonate horizon.



1942 Landcover

Created by hand-digitizing landcover from scanned aerial photos.

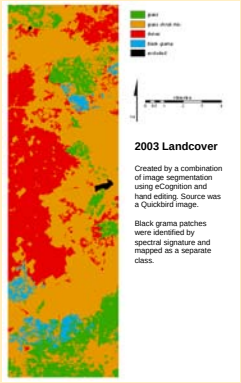
Description of cover types:

"Grass" – Continuous and interconnected grass patches with few shrubs.

"Grass shrub mix" – Many shrubs in a matrix of grass.

"Dunes" – area of visible mesquite individuals with bare to mostly bare interspaces. Visual evidence of coppicing.

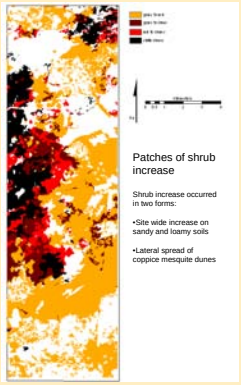
"Excluded" – human structures. Not included in analysis.



2003 Landcover

Created by a combination of image segmentation using eCognition and hand editing. Source was a Quickbird image.

Black grama patches were identified by spectral signature and mapped as a separate class.

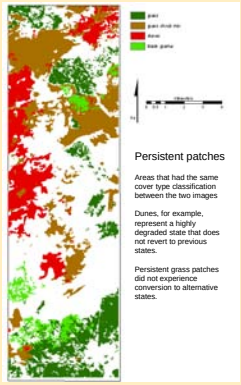


Patches of shrub increase

Shrub increase occurred in two forms:

•Site wide increase on sandy and loamy soils

•Lateral spread of coppice mesquite dunes



Persistent patches

Areas that had the same cover type classification between the two images

Dunes, for example, represent a highly degraded state that does not revert to previous states.

Persistent grass patches did not experience conversion to alternative states.

Grass

Grass – Shrub mix

Mesquite Coppice dunes

Transition proportions reflect the increase of shrubs, primarily mesquite (*Prosopis glandulosa*), on ~74% of the landscape.

Transition proportions for entire mapped area

	grass	mix	dune
grass	0.28	0.59	0.13
mix	0	0.74	0.26
dune	0	0	1.0

Within-patch plant-soil relationships

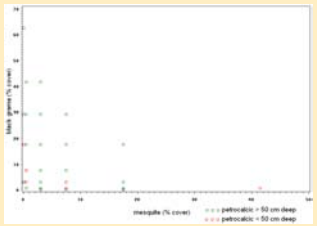
Plant-soil relationships considered soil properties that could be used to develop predictive maps and that capture existing knowledge about plant ecology. "Behavior spaces" (maximum potential abundance based selected soil properties or abundance of other plants) were defined for species of interest. The constraints revealed in these behavior spaces allow information derived from plant-scale patterns and soil maps to be used in landscape mapping.

Summary of relationships examined:

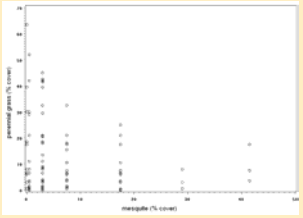
Clay soils – high perennial grass cover, very few mesquite. Depression landforms and plant assemblages, primarily *Pleuraphis mutica*. These soils contained about half of the persistent grass patches mapped.

Deep sandy soils – mesquite dominated, no black grama, grasses predominantly bunch-grasses such as *Sporobolus*, some *Aristida*. These soils contained both all mapped dune areas as well as perennial grass patches at highest risk of conversion to shrub cover.

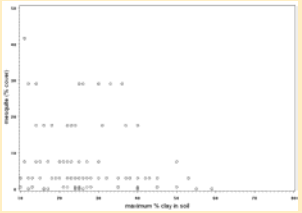
Soils with petrocalcic between 50 and 150 cm – includes most grass assemblages other than depression-related species. Black grama assemblages fall almost exclusively within this category. Rarely dominated by mesquite.



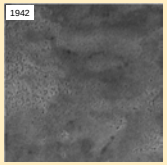
Black grama assemblages are confined to soils with petrocalcic horizons at depths <150 cm and further constrained by mesquite cover.



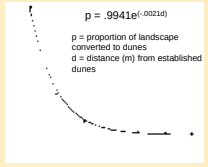
At low values of mesquite cover, grass cover can be high or low. At high values mesquite cover, grass is restricted to low cover amounts.



Mesquite cover is constrained by amount of clay in the soil.



Above: Expansion of dunes from the west to the east between 1942 and 2003. Photos are 1 km x 1 km. The proportion of the landscape converted to dunes was calculated as a function of distance from dunes present in 1942. This equation can be used to predict the spread of dunes in the future.



Potential Change

Potential change over the next 60 years. Prediction based on the dune spread function and transition probabilities for each cover type, for each 20 m pixel in the digitized study area.

This model does not directly account for soil constraints revealed above and assumes stationarity in the distribution of soils and other processes across the study area. Explicit mapping of heterogeneity in soil constraints could be used to refine this model, thereby intersecting a dynamic spatial process (dune expansion) with static spatial heterogeneity.

Conclusions

• Biophysical properties can be used to understand shrubland encroachment patterns and rates, and generally, spatial patterns of ecosystem resilience. For example, we discovered that remnant grass patches were associated with restrictive soil horizons.

• Shrubland expansion is highly spatially organized, likely due to the interaction of spatial processes (related to shrub colonization and wind-driven soil erosion) with soil heterogeneity and landscape context.

• The patterns revealed here suggest that predictive models of shrubland expansion can be developed.