WHAT DOES AN ECOLOGICAL THRESHOLD LOOK LIKE?

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1. INTRODUCTION

Recent concepts in rangeland health and management emphasize that ecosystem structure may shift abruptly in time and space (a transition) once critical thresholds of herbivory, vegetation cover, or soil loss are crossed. Upon crossing a threshold, novel constraints prevent the reestablishment of historic ecosystem states. Thus, management policy is being oriented towards identifying and avoiding these thresholds. One problem with implementing such policy is that land managers and ecologists are not sure what the 'critical thresholds' are and how to anticipate them. Shifts in rangeland structure can be interpreted as being caused by several factors at several levels along a chain of causation (Bestelmeyer *et al.* 2003), and managers need to ascertain ultimate causes in order to develop cost-effective interventions. Of these causes, the effects of precipitating events such as high, local livestock grazing intensities or droughts are difficult to observe, predict or manage. On the other hand, factors that predispose landscapes to transitions, such as soil characteristics or landscape position, are more easily measured. We asked, what can be observed from existing spatial transitions that will help managers understand and prevent similar transitions in rangelands?

We sought to explain a spatio-temporal transition from grassland to shrubland occurring within an apparently homogeneous area under relatively uniform management. For a variety of reasons, avoiding grassland-to-shrubland transitions is a key management goal. We examined patterns in topography, patch structure, and soil characteristics that may help explain why one part of an apparently homogeneous landscape shifted to shrubland and the other part did not.

2. STUDY AREA AND METHODS

We examined an abrupt transition between a shrubland (honey mesquite, *Prosopis glandulosa*; Berlandier's wolfberry, *Lycium berlandieri*; creosotebush, *Larrea tridentata*) and grassland (largely the C4 perennial tobosa, *Pleuraphis mutica*) located on an alluvial fan on the Corralitos Ranch, ca. 25 km E of Las Cruces in Dona Ana Co., New Mexico, USA. The 2.5-km^2 study area was within a single soil map unit (Berino-Dona Ana association) and exhibited no obvious differences in soil surface texture or slope across the transition. The dominant soils constituting this unit were classified as Typic Haplargids. The transition zone ran parallel to the direction of the slope, which was ca. 0.5%.

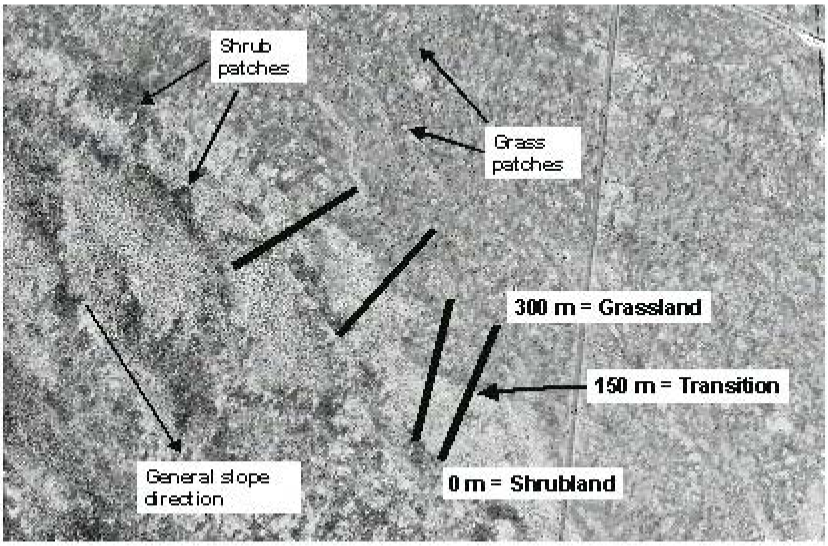

Figure 1. A 1996 aerial photograph of the transition zone with the positions of transects across it. Transect 1 is in the lower right and transect 4 is in the upper left. In this picture, lighter colors indicated sparsely-vegetated patch types.

We placed four 300-m long transects consisting of 61 points each (5-m spacing) perpendicular to the orientation of the transition boundary (Fig. 1). The point at 150 m was located on the transition boundary. Transects were spaced randomly along ca. 1 km of the transition zone. At each point in September-November 2001, we measured basal and canopy cover within a 1.96 m^2 quadrat and collected soil samples to a depth of 20 cm at 5-cm increments. Particle-size analysis was performed on each increment and carbonate content was assessed using a semi-quantitative effervescence test. In addition, we measured wetting depth at a subset of points (30) of each transect 12 hours following a 18 mm rainfall event in September of 2001, which generated some runoff on the study site. Wetting depth was measured by digging holes adjacent to the transect points and measuring the depth of the wetting front. Finally, we evaluated patch patterns and temporal changes in vegetative cover using aerial photographs of the study area taken in 1996 (U.S. Geological Survey Digital Ortho Quarter Quads) and 1936 (Soil Conservation Service).

3. RESULTS

3.1 Broad scale patterns

An examination of the entire study area in 1936 and 1996 aerial photographs revealed that the shrub-dominated side of the transition area was formerly occupied by a shrub-grass mixture. Patches of grass have been lost at the transition boundary. Within the grassland side, shrubs (largely honey mesquite) were rare in 1936 but had colonized many points by 1996. The photographs indicate that shrubs are expanding within the grassland side.

3.2 Intermediate scale patterns (10-100 m^2)

In 1996, patches of vegetation within the grassland were elongated in a direction perpendicular to that of the slope (Fig. 1). Vegetation patches within the shrubland, on the other hand, were elongated in a direction parallel to that of the slope. These parallel bands were not detected on the grassland side of the transition. Furthermore, patches exhibited a finer-scale, grainier texture (smaller patches of both vegetation and bare ground) in the shrubland than in the grassland.

3.3 Fine-scale patterns (1-10 m^2)

There were patches of shrubs and bare ground within the grassland and patches of grass within the shrubland. Across all transects, grass cover was negatively related to calcium carbonate content at the surface (0.5-5 cm; $F=7.03$; $df=5, 224$; $P < 0.0001$; Fig. 2). Soils under grasses had higher infiltration rates than bare patches. The relationship between grass cover and wetting depth, however, was poor ($R^2= 0.33$). Soil texture at varying depths had no significant relationship with grass cover.

4. DISCUSSION

Patterns at all three scales suggest that a hydrologic threshold has been crossed. The relatively uniform distribution of the shrubs compared to the grasses provides less obstruction to overland flow. Also, the horizontal pattern of grass patches perpendicular to the slope is typical of banded vegetation systems on similar soils in the Chihuahuan Desert, albeit at a finer scale (Montaña *et al.*, 1990). This structure has been shown to effectively capture runoff. At the broad scale, vegetation bands parallel the slope on the shrub side. Furthermore, a qualitative assessment using the indicators listed in Pyke et al. (2002) showed reflected increased overland flow on the shrub side. Finally, average wetting depth was greater in the grass patches dominating the grassland side (32 mm) than in bare patches surrounding shrubs (19 mm), despite the fact that these measurements were made following a relatively small storm with limited runoff. We would expect this difference to increase following a more intense storm.

The soil patterns suggest that we may be able to predict susceptibility to shrub invasion based on relatively easy to measure soil characteristics, though the lack of pre-invasion soil data makes positive interpretation of the results somewhat difficult. The significant differences in effervescence of the soil surface strongly suggest that soil carbonate content is much higher in the shrub-dominated area. Given the fact that the study area is part of an alluvial fan, and that the transition is parallel to the slope, it seems highly likely that the relative resistance of the remaining grassland area is related to one or more soil properties that are related to soil parent material. While there are no clear differences in soil texture, soil carbonate content would appear to be a relatively clear and easily measured indicator of susceptibility to shrub invasion. Calcium carbonate levels at the surface were highly related to grass cover, reflecting both the broader transition as well as patch patterns on each side of the transition (Fig.2). The two dominant soils comprising the soil map unit of the study area differ in the amount of calcium content, and multiscale gradients between these types are likely to be primary determinants of transition pattern. While we have not yet identified a mechanism for this correlation, it is well known that carbonates affect both nutrient availability (Lajtha & Schlesinger, 1988) and soil structure. Alternatively, the higher carbonate content may simply reflect higher rates of erosion on the shrub area, or may be correlated with another soil property that we failed to measure and which has a more direct effect on plant growth.

There were fairly clear relationships among many of the patterns we observed. Nonetheless, most of these patterns are a consequence of the transition rather than a cause of it, and would have limited utility in predicting a transition. The susceptibility of soils high in calcium carbonate to grass loss, on the other hand, might be used for prediction. We suggest that the continued identification of inherent risk factors and their spatial representation via soil maps will greatly complement rangeland conservation strategies.

5. REFERENCES

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