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Can ecological land classification increase the utility of vegetation monitoring data?

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A B S T R A C T

Vegetation dynamics in rangelands and other ecosystems are known to be mediated by topoedaphic properties. Vegetation monitoring programs, however, often do not consider the impact of soils and other sources of landscape heterogeneity on the temporal patterns observed. Ecological sites (ES) comprise a land classification system based on soil, topographic, and climate variations that can be readily applied by land managers to classify topoedaphic properties at monitoring locations. We used a long-term (>40 y) vegetation record from southeastern Arizona, USA to test the utility of an ES classification for refining interpretations of monitoring data in an area of relatively subtle soil differences. We focused on two phenomena important to rangeland management in the southeastern Arizona region: expansion of the native tree velvet mesquite (*Prosopis velutina* Woot.) and spread of the introduced perennial grass Lehmann lovegrass (*Eragrostis lehmanniana* Nees). Specifically, we sought to determine if a quantitative, ES-specific analysis of the long-term record would (1) improve detection of changes in plant species having heightened ecological or management importance and (2) further clarify topoedaphic effects on vegetation trajectories. We found that ES class membership was a significant factor explaining spatiotemporal variation in velvet mesquite canopy cover, Lehmann lovegrass basal cover, and Lehmann lovegrass density measurements. In addition, we observed that the potential magnitude of velvet mesquite and Lehmann lovegrass increases varied substantially among ES classes. Our study brings attention to a practical land management tool that might be called upon to increase the effectiveness of vegetation-based indicators of ecosystem change.

1. Introduction

Vegetation monitoring is one of the principal methods used to assess the ecological consequences of management actions and climate change at local to landscape scales (Herrick et al., 2005). Vegetation dynamics at these scales can vary strongly in response to topoedaphic heterogeneity (Bestelmeyer et al., 2011; Pringle et al., 2006; Wu and Archer, 2005). For example, even relatively subtle variations in soil profile properties, such as the depth to clay- or carbonate-rich horizons in otherwise similar soils, can cause variations in rates of shrub encroachment or grass mortality (Bestelmeyer et al., 2006; Browning et al., 2012). Vegetation monitoring programs, however, often do not consider the impact of topoedaphic heterogeneity on the temporal patterns observed, which can lead to misinterpretation of early warning indicators or the importance of anthropogenic or climatic variables being studied (Pringle et al., 2006).

To address the effects of topoedaphic properties, some authors have recommended that monitoring sites be linked to soil- and climate-based land classification systems (Herrick et al., 2006; Karl and Herrick, 2010) such as the ecological site (ES) classifications used widely in the United States (Brown, 2010; USDA-NRCS, 2013) and similar classifications used worldwide (Blanco et al., 2014; Green and Klinka, 1994; Ray, 2001; van Gool and Moore, 1999). ES classes are subdivisions of a landscape based on soil, topographic, and/or climate properties known to influence veg-

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etation composition and change (Duniway et al., 2010). Each ES class is associated with a state-and-transition model describing the vegetation changes that are likely to occur following specific management actions or natural events (Bestelmeyer et al., 2009; López et al., 2013). Land areas belonging to the same ES class are expected to provide the same general environment for plant establishment and growth. This expectation can give land managers increased confidence that the knowledge they have acquired from a particular vegetation monitoring effort can be effectively applied to other areas belonging to the same ES class (and only cautiously applied to other areas). In addition, the criteria used to differentiate ES classes are in most cases explicitly defined, which enables land managers to assess the degree of similarity between two classes and determine the suitability of applying ecological knowledge across class boundaries. In the United States separate ES classifications are created on a per-region basis, and individual ES classes are typically only utilized in that region they were developed for.

Given the important role of topoedaphic properties in controlling vegetation composition and dynamics, best practices commonly call for the incorporation of topoedaphic strata into vegetation monitoring designs. Use of ES classifications for landscape stratification is likely to increase with official commitment by three prominent US land management agencies – the Natural Resources Conservation Service, Forest Service, and Bureau of Land Management – to utilize ES classifications as a basis for monitoring, assessment, and planning in rangelands (BLM, 2010). ES classifications are already applied to a number of conservation activities and therefore represent a sensible tool for linking monitoring programs to other aspects of land management such as restoration projects and grazing plans. Nevertheless, there has been little empirical study aimed at supporting or refuting the utility of ES classifications with regard to ecosystem monitoring, despite recommendations to further incorporate ES classifications or similar frameworks into vegetation monitoring programs (Bestelmeyer et al., 2009; Herrick et al., 2006; Karl and Herrick, 2010).

We used an uncommonly long (>40 years), well-studied, and spatially extensive monitoring dataset available from the Santa Rita Experimental Range (SRER) to test for differences in vegetation trajectories among ES classes reflecting differences in subsoil properties in sandy soils of piedmont slope landforms. Long-term monitoring of ecological indicators is essential for resolving critical uncertainties in the detection of ecosystem trends, such as whether or not environmental degradation or improvement is taking place in ecosystems, like deserts, that respond slowly or episodically to management or climatic drivers. Increasing the effectiveness of ecological indicators may require addressing topoedaphic variation in a more systematic and detailed way than typically occurred in the past, and ES classification has been identified as one tool that could be used to address topoedaphic variation in such a manner (Bestelmeyer et al., 2009; Herrick et al., 2006). Our study provides a rare, empirical assessment of ES classification utility using an existing long-term monitoring dataset. By associating each SRER monitoring site with an ES class, we sought to determine if the detection of changes in plant species recognized as having heightened ecological or management importance in our study area would be improved. We also sought to determine whether previously unrecognized edaphic effects on vegetation trajectories had the potential to produce erroneous interpretations of vegetation monitoring data and associated indicators of ecosystem change. The ES classes studied here reflect differences in subsoil clay content that would likely go unnoticed by many observers without explicit consideration of ES classes, and earlier published analyses of the SRER long-term monitoring data did not address such soil variations. Finally, our study offered an opportunity to refine interpretations of a high-value long-term dataset and evaluate the need to modify the current ES classification system.

2. Methods

2.1. Focal species

We limited our analysis to two plant species having great management significance in the southeastern Arizona region: velvet mesquite (*Prosopis velutina* Woot.) and Lehmann lovegrass (*Eragrostis lehmanniana* Nees). Velvet mesquite is a small tree native to portions of Arizona, California, and New Mexico. Historically abundant on the SRER primarily along ephemeral drainages, the species has since colonized most upland areas of the research property (McClaran, 2003; McClaran et al., 2010). Expansion of velvet mesquite on the SRER is an example of a more widespread pattern of woody plant encroachment and thickening that has occurred across much of the western United States over the past century (Van Auken, 2000; Van Auken, 2009). Management of woody vegetation continues to be emphasized in many areas, and herbaceous-to-woody type conversions are featured prominently in state-and-transitions models currently described for US rangelands (Twidwell et al., 2013).

Native to southern Africa, Lehmann lovegrass was introduced to the SRER and other parts of the southwestern United States to increase livestock forage on degraded rangelands (Cox et al., 1988). Despite its benefits as forage, the species has proven to be an undesirable invader of areas managed to promote native vegetation and associated ecosystem services. The species is known to replace native grasses given suitable climatic and edaphic conditions (Angell and McClaran, 2001; Bock et al., 2007). Like expansion of the native velvet mesquite, the spread of Lehmann lovegrass exemplifies an ecological syndrome affecting large areas of the western United States – the replacement of native plants by invasive nonnative grasses. In some of the more extreme examples of this phenomenon, nonnative grass introduction has resulted in regime shifts from shrub and/or cactus dominated ecosystems to ecosystems dominated by grasses, often with important impacts on plant biodiversity and wildlife habitat (Knapp, 1996; Marlette and Anderson, 1986; Olsson et al., 2012; Whisenant, 1990).

2.2. Monitoring dataset

Permanent vegetation monitoring plots were established on the SRER by several independent and temporally disjointed studies. Monitoring locations were generally not selected in a strictly random or stratified-random fashion. Consistent collection methods enabled data from these plots to be later compiled into a single long-term monitoring dataset, available online from the University of Arizona (http://cals.arizona.edu/srer/data.html see On-going Long-Term Measurements; McClaran et al., 2002). Standard measurements performed at each monitoring plot included the total amount of velvet mesquite canopy cover and Lehmann lovegrass basal cover intersecting a single 30.4 m transect. Beginning in 1972, perennial grass density was estimated using plant counts within a 0.3×30.4 m belt transect running parallel to, and having one side bounded by, the line-intercept transect. The number of plots revisited on the SRER increased through time as new studies were initiated. Our analysis was limited to velvet mesquite canopy cover measurements collected from 1975 through 2012, Lehmann lovegrass basal cover measurements collected from 1984 through 2012, and Lehmann lovegrass density measurements collected from 1972 through 2012 (at the same 48 plots in each case). These time periods were selected based on our desire to maximize sample sizes while ensuring that the same number of samples were collected at each sample date. We also limited our analysis to those plots not altered by wildfire or intentionally cleared of velvet mesquite during the 41 year analysis period (McClaran and Angell, 2006) to