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Evaluating a State-and-Transition Model Using a Long-Term Dataset

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Abstract

State-and-transition models (STMs) are used in natural resource management to describe ecological site scale response to natural and anthropogenic disturbances. STMs are primarily based for expert opinion and literature reviews, lacking analytical testing to support vegetation community dynamics, thresholds, and state changes. We developed a unique approach, combining ordination and permutation MANOVA (perMANOVA) with raw data interpretation, to examine vegetation data structure and identify thresholds for a STM. We used a long-term monitoring dataset for an ecological site on the Santa Rita Experimental Range, Arizona. Basal cover of perennial grasses and canopy cover of shrubs and cacti were measured on permanent transects beginning in 1957. Data were grouped by drivers identified by the STM including species invasion, grazing, drought, and mesquite treatment. Ordination by nonmetric multidimensional scaling described the structure of the data. PerMANOVA was used to test for differences between groups of sample units. Analyses of combined key species (Lehmann's lovegrass and mesquite [*Prosopis velutina* Woot.]) and nonkey species patterns demonstrated an irreversible transition and occurrence of a structural threshold due to Lehmann's lovegrass invasion, as well as a short-term reversible transition (restoration pathway) following mesquite treatment. Sensitivity analysis, in which key species were removed from the dataset, showed that the relative composition of nonkey species did not differ between states previously defined by the key species. This apparent disconnect between dynamics of key and nonkey species may be related to changes in the functional attributes that were not monitored during this time series. Our analyses suggest that, for this ecological site, transition to a Lehmann's lovegrass state occurs when basal cover of this species exceeds 1–2%, which often occurs within 6 yr of its arrival. Evaluation of the restoration pathway showed a recrossing of the threshold within 6 yr of treatment and when mesquite canopy cover exceeded 10%.

Key Words: ecological site, nonmetric multidimensional scaling, permutation multivariate analysis of variance, thresholds

INTRODUCTION

State-and-transition models (STMs) describe the community dynamics of ecological sites and their response to natural and anthropogenic impacts (Westoby 1980; Briske et al. 2008). STMs are an effective means of communicating and synthesizing information about ecological sites, and land managers perceive them as a tool to guide management decisions (Knapp et al. 2011). STMs incorporate the concept of ecological resilience and multiple stable states into a model for vegetation changes (Peterson et al. 1998; Gunderson 2000), differing from the Clementsian succession (range condition) model (Dyksterhuis 1949) that guided range management for much of the 20th century. The range condition model identifies a single climax plant community with an "in place community" moving either toward or away from the climax community in a linear fashion in response to grazing and drought (Dyksterhuis 1949). In contrast, resilience-based STMs suggest that communities can reach equilibrium in different, alternative stable states and arrive there via feedback mechanisms (Gunderson 2000).

STMs are included in ecological site descriptions (ESDs) to describe each site's potential stable states. ESDs contain information about soils, other physical characteristics, vegetation (both historic and current), and general ecological function of an ecological site. Ecological sites are landscape units of similar soils, topography, and associated vegetation types. They have been adopted by land management agencies in the United States, including the Natural Resource Conservation Service (NRCS), the Bureau of Land Management, and the United States Forest Service, as appropriate units for establishing monitoring programs and assessing community changes, both biotic and abiotic, on rangelands (Brown 2010).

States represent a stable suite of abiotic and biotic factors that produce one or more vegetative community phases (Westoby et al. 1989; Stringham et al. 2003; Briske et al. 2008; Bestelmeyer et al. 2009). Community phases are connected by community pathways, which can be either natural or management drivers that cause changes in community phases within a state. Individual states are delineated by thresholds. Transitions describe the drivers (i.e., changes in climate or management) causing a state to cross a threshold into an alternative stable state. Unlike community pathways, transitions are reversible only with significant input of management in the form of a restoration pathway. Restoration pathways, when available, describe means of returning a site to a more desirable state. Thresholds are crossed when the feedback mechanisms maintaining a site in its current state are altered sufficiently to exceed a site's resilience and cause the site to transition to an alternative state (Stringham et al. 2003). Categorizing thresholds into two groups, structural and functional thresholds, has been suggested to help clarify the threshold concept and to improve the application of STMs (Bestelmeyer 2006). Functional thresholds are crossed when changes in ecological processes occur, and structural (compositional) thresholds are defined by changes in community

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