Threshold Concepts and Their Use in Rangeland Management and Restoration: The Good, the Bad, and the Insidious

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Abstract

Ecological thresholds describe abrupt changes in ecological properties in time or space. In rangeland management, thresholds reflect changes in vegetation and soils that are expensive or impossible to reverse. The threshold concept has catalyzed important advances in rangeland management thinking, but it has also introduced two classes of drawbacks. First, the ambiguity of the term "threshold" and the desire for simplicity in its application has led to an overemphasis on classification thresholds, such as vegetation cover values. Uncritical use of classification thresholds may lead to the abandonment of management efforts in land areas that would otherwise benefit from intervention. Second, it is possible that the invocation of thresholds and irreversible degradation may eventually result in the wholesale conversion of land areas that would have been recoverable or served important societal functions, such as biodiversity maintenance, that are not reflected in threshold definitions. I conclude with a recommendation to clarify the nature of thresholds by defining the relationships among pattern, process, and degradation and distinguishing preventive thresholds from restoration thresholds. We must also broaden the attributes used to define states and thresholds.

Key words: **biodiversity, exurban development, grazing, landscape ecology, rangeland health, state-and-transition models.**

Introduction

Nature is full of thresholds layered upon thresholds.

Wiens et al. (2002).

The threshold concept has become a major theme in ecology and natural resources management (Groffman et al. 2006). Ecological thresholds are used to describe the nonlinear and persistent reorganization of ecosystem properties (i.e., states) in response to gradual or discrete changes in environmental patterns and drivers. Crossing thresholds leads to loss or recovery of ecosystem functions and biodiversity. The significance of thresholds for management has made them a key emphasis in restoration ecology (Hobbs & Harris 2001), landscape ecology (Turner 2005), and rangeland ecology (Walker 1993). The concept has been used to discuss natural resource issues within the U.S. Senate (Watson 2003). In the United States, ideas about thresholds are beginning to influence public land management policies (e.g., USDI Bureau of Land Management 2004) and to determine federal assistance provided to private landowners (USDA Natural Resources Conservation Service 2003). In this essay, I relay my satisfaction and concerns with how the threshold concept is being (and could be) used in rangeland management.

Thresholds have been incorporated into rangeland management via potential-based land classification systems and associated state-and-transition models (STMs; e.g., Brown 1994; Stringham et al. 2003). STMs (Westoby et al. 1989) synthesize informal knowledge and published data to describe alternative states and the nature of thresholds between each state. For example, a transition from savanna to a shrub-encroached woodland state is precipitated by gradual or episodic loss of grass due to continuous grazing and drought, resulting in a loss of fuel connectivity and lack of fire disturbance. Without fire, grasses lose the advantage of fire tolerance and shrubs recruit and survive to adulthood. The shrubs are increasingly able to monopolize resources formerly used by grasses. The shift in feedbacks from one governed by fire disturbance to one governed by grazing and shrub–grass competition is depicted as a biotic threshold. Moving back across the threshold would require reduced grazing intensity and shrub removal. Dominance by shrubs, however, maintains bare areas, allowing accelerated erosion rates and surface soil degradation. With time, soils become degraded (or are lost) to the point that shrub removal and restoration actions such as grass seeding cannot be used to recover the original grassland state. This point marks a second (abiotic) threshold (Whisenant 1999).

The increasing adoption of conceptual models for rangelands that include or emphasize thresholds has far-reaching implications for rangeland assessment and management

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policies in the United States. Because threshold-based models are becoming increasingly integrated with procedures used to evaluate vast areas of public and private lands (e.g., Spaeth et al. 2003), we need to evaluate critically the roles that threshold concepts play. Below, I consider positive, negative, and insidious consequences of the application of threshold ideas. I conclude with some recommendations for promoting the positive contributions of threshold concepts while minimizing the damage that they might cause.

The Good

Recognition of states and thresholds has been tremendously useful for land evaluation and management. First, in regions where thresholds are discussed, managers often consider decisions with thresholds in mind. Processes associated with thresholds compel managers to consider a broader array of ecosystem behaviors and attributes when evaluating the status of rangelands (e.g., Pyke et al. 2002; Tongway & Hindley 2004). Thousands of managers are now better equipped to anticipate and understand the changes they observe and the options that are available to them.

Second, states and thresholds can be used to prioritize management and restoration efforts in management areas comprising tens of thousands of hectares (Suding et al. 2004). Land areas that have crossed abiotic thresholds that are unlikely to respond to restoration actions are considered low priority. Similarly, areas that do not indicate degradation toward biotic thresholds are low priority. Monitoring and restoration resources are then increasingly available to focus on the "intermediate" states where relatively low-cost grazing management and restoration actions are most likely to be effective. Thus, consideration of thresholds adds a sorely needed triage element to public and private lands management (Hobbs & Kristjanson 2003).

Finally, stakeholders are increasingly aware that threshold behavior is possible. Threshold concepts and STMs are increasingly important elements of scenario planning (cf Bennett et al. 2003). The development of increasingly realistic scenarios involving government agencies, ranchers, and environmentalists can reduce unnecessary conflict (R. A. Alexander, Bureau of Land Management, 2004, personal communication). Thresholds move the arguments from historically degraded and irrecoverable rangelands to areas where the "to graze or not to graze" controversy has meaning.

The Bad

Despite the benefits, successful application of the threshold concept has been limited by several problems. First, there is usually a lack of clarity in use of the term "threshold," especially in terms of pattern–process coupling. The often-used phrase "crossed the threshold" evokes a value of some variable beyond which ecosystem organization changes. This value is often represented in STMs using classification (or structural) thresholds (Briske et al. 2005) based on cover, reflectance, or a multivariate characterization of plant composition. Within STMs being developed by rangeland ecologists, the establishment of classification criteria for states is implicitly assumed to reflect process (or functional) thresholds that determine the efforts required to reverse a transition. Mechanistic linkages between classification and process thresholds, however, often are poorly developed.

Even when a pattern–process relationship is described, it is likely to be inconsistent in time and space. For example, threshold behavior can be based on a small change in a pattern (vegetation cover) that results in a large change in a process rate (e.g., erosion; Davenport et al. 1998). Many spatially and temporally varying factors, however, condition the relationship between pattern and process (e.g., soil erosion potential and climate), so a single predictive threshold value seems unlikely to emerge even for a specific application (Muradian 2001; Huggett 2005). Furthermore, a process rate and the duration of time at a given rate drive the environmental changes underlying physical (Groffman et al. 2006) or resource thresholds (Aguiar & Sala 1999) that determine the survival and establishment of particular species. Simple classification thresholds currently used for the sake of management expediency do not reflect the variable and hierarchical aspects of threshold phenomena and are inadequate indicators of possible future ecosystem behavior in many cases (Lindenmayer & Luck 2005).

The inadequate characterization of threshold phenomena leads to a second problem: how land parcels are managed based on land evaluations relative to thresholds. Classification thresholds may overemphasize the consequences of thresholds relative to the chronic vulnerability that permits a rapid transition, such as mismanaged grazing and low grass cover (Stafford Smith 1996). Commonly used classification thresholds in STMs (e.g., shrub dominance) are usually based not on the effects of vegetation pattern on process rates that could be used to mitigate degradation but on the ultimate changes to structural attributes that are easily measured but recognized too late to prevent degradation.

Moreover, once managers classify a land area to a state, the classification asserts the existence of restoration barriers described in STMs. If the classification is flawed, then land that might be recoverable toward a desired or healthy condition via simple adjustments (e.g., stocking strategies) might be made a low priority because the costs of restoration are incorrectly assumed to be too high (Bestelmeyer et al. 2003*a*; Briske et al. 2005). Once land areas are judged to be "past the threshold," the delayed management response or outright abandonment may permit continued degradation and a self-fulfilling prophecy of irreversible change.

The Insidious

The abandonment of active management in rangelands and their condemnation as "irreversibly degraded" via the threshold concept may have an insidious consequence for land use and human welfare in the American West. We often fail to appreciate that the assertion of degradation based on comparisons with "reference" or assumed pre-European vegetation types and associated agricultural uses (Bestelmeyer et al. 2003*a*) does not account for other functions of the land. Some components of biodiversity, for example, may be well represented in "degraded" vegetation types (James et al. 1999; Bestelmeyer et al. 2003*b*). The biodiversity in degraded lands adjacent to human communities, in turn, may be critical for maintaining human connections with nature that support quality of life and health (Miller 2005). Furthermore, ecosystems adjacent to urban or agricultural areas often have especially high value for biodiversity conservation (Scott et al. 2001) and would be priorities for restoration from this perspective.

Degraded public rangelands, however, may be at high risk for "disposal" to residential or industrial development and private rangelands may be subdivided and sold for the same purpose, especially near towns and cities (M. W. Brunson 2002, Utah State University, 2006, personal communication). With little hope for the restoration of agricultural uses, the relative value of the land for development should increase. Once developed, former rangelands are unlikely to be reverted to other uses for long periods of time (Hansen et al. 2005). Development is clearly a persistent transition based on the linkage of socioeconomic and ecological processes (Walker & Meyers 2004).

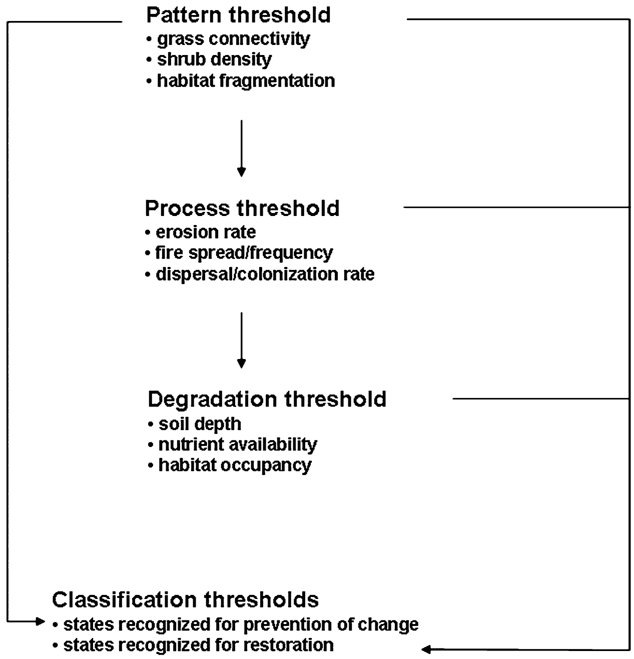

Figure 1. A classification of thresholds and their relationships. Example measurements after the bullets could be used to quantify position relative to a given threshold (if one exists). The arrows at the sides indicate whether pattern, process, or degradation threshold should be used to define the two types of classification threshold.

Overcoming the Bad and the Insidious

There is abundant evidence that some rangeland ecosystems exhibit thresholds, but critics point out that some rangelands are more equilibrial and resilient than we give them credit for (Stafford Smith 1996; Valone et al. 2002). Proper interpretation of system behavior can be achieved by greater experimentation at appropriate scales, restrictions of inference to truly similar environmental domains, and longer-term observations of system behavior. A second criticism is that we tend to focus on the consequences of threshold (catastrophic) shifts at the expense of the gradual, deterministic processes that precede them (Watson et al. 1996). This problem can be remedied by distinguishing the types of thresholds that ecologists have conceptualized and clarifying their roles in management.

I suggest a classification of thresholds and their linkages (Fig. 1). The classes link several existing threshold concepts and can be used to help conceptualize threshold research and management applications. The first class is the *pattern threshold* related to percolation theory, connectivity, and self-organization concepts (e.g., Pascual & Guichard 2005). If disturbance drives a pattern such as grass cover, bare patch size, or fragmentation to a critical value, then the rate of a process, such as erosion or dispersal, may change nonlinearly. Feedbacks between pattern values and process rates can create the nonlinearity. The pattern threshold leads to a *process threshold* that describes the consequences to an environmental condition of an altered process rate, such as the effect of increasing erosivity or erodibility on changes to soil depth or quality (Okin et al. 2006). In animal ecology, reduced dispersal rates/ability can create nonlinear reductions in habitat occupancy (With & King 1999). It is important to note that processes can also have linear relationships to environmental conditions. At a sufficient level of change in the environmental condition, a *degradation threshold* is reached whereby habitat becomes unsuitable to species that are used to recognize states, such as dominant plants, or species go regionally extinct. The relationships of degradation thresholds to pattern and process thresholds should, in the ideal world, be used to define *classification thresholds* used to identify states. In the real world, we seldom have data on these relationships and so are forced to make a best guess.

There ought to be two kinds of classification thresholds based either on preventive management or restoration. Preventive management should focus on regulating changes to patterns that make systems vulnerable to deterministic or event-driven change. Bare patch size, connectivity, and related indicators can be used in this way (Tischendorf 2001; Tongway & Hindley 2004; Herrick et al. 2005). Management failures result when degradation thresholds are used as the primary indicators of a problem because it is too late to regulate the patterns preceding degradation. In contrast, restoration of degraded rangelands needs to address degradation, process, and pattern thresholds simultaneously. Barriers to the dominance of desired species must be overcome alongside the stabilization of processes and recovery of patterns that preserve reestablished habitat conditions (Whisenant 1999). Restoration failures result when degradation thresholds are addressed but pattern and process thresholds are not.

Finally, we must broaden our consideration of relevant patterns, processes, and types of degradation. Applications of the threshold concept in rangeland ecology have been regarded as parochial due to an almost exclusive focus on plant composition and production. Biodiversity and sensitive species typically are ignored (for various reasons), and thresholds in their responses to environment are unlikely to be reflected in thresholds based on production-related attributes. This oversight has resulted in a schism between rangeland and wildlife/biodiversity managers working in the same landscapes. The schism is unfortunate because many changes to animal habitat are ultimately governed by processes studied by rangeland ecologists, despite differences in threshold definitions. By linking threshold concepts related to organismal behavior, demography, and diversity with those of a variety ecosystem functions, we will have a broader perspective on land management and restoration.

Implications for Practice

- Ecological thresholds and alternative states are captured in models that are used to decide when a management change or restoration practice is necessary.
- Consideration of thresholds can help prioritize management and restoration efforts, but threshold concepts may also be inappropriately used to "write off" land or abandon management where it is still needed.
- Threshold concepts would be better used in rangelands if preventive versus restoration thresholds were distinguished.
- Rangeland managers also need to consider a broader range of attributes to define states and thresholds, especially those related to biodiversity.

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