View Point

National Assessment and Critiques of State-and-Transition Models: The Baby with the Bathwater

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On the Ground

- Ecological site descriptions and state-and-transition models are national-level tools for organizing and delivering information about landscape dynamics and management.
- Recent papers criticized state-and-transition models because they overemphasize grazing, are inconsistently presented, and do not address climate change.
- I argue that the analysis of Twidwell et al. does not support an overemphasis on grazing, that inconsistent presentation is a necessary consequence of early model development efforts and immature science concepts, and that climate change effects should not be addressed in site-level models without evidence.
- Improving these important tools requires fair critique, but also the strong commitment of scientists and funders.

Keywords: ecological site descriptions, regime shifts, grazing, thresholds, climate change.

Rangelands 1–3
doi: 10.1016/j.rala.2015.03.004

Ecological site descriptions (ESDs) have been characterized as the world's largest land management framework.[1] They comprise a database and document collection used throughout the United States to provide management guidance in rangelands and, increasingly, in forests, wetlands, and croplands. ESDs are specific to fine-grained (1:12,000) land classes called *ecological sites* that differ in soil, landscape position, or climate, and therefore in potential plant communities. Different ecological sites call for differences in the details of management actions such as stocking rates, restoration seed mixes, and strategies for managing woody plants.

The focus of ESDs is on vegetation and soils as primary elements governing ecosystem services including forage for livestock, erosion control, and wildlife habitat. A core part of ESDs is the state-and-transition model (STM) that describes how vegetation responds to management and natural processes. STMs replace older "range succession" models that represented vegetation change as reversible linear trajectories driven by grazing and weather. The STM format encourages inclusion of a broader array of drivers, interactions among drivers, and multiple possible trajectories, reflecting recent advances in ecological science.

ESDs and STMs have become central tools for rangeland evaluation in the United States, primarily used by the USDA Natural Resources Conservation Service (NRCS), the Bureau of Land Management, and the US Forest Service. ESDs are used for activities including the evaluation of rangeland health, decision support for the selection of conservation or restoration practices, communication with land managers, and stratification and interpretation of monitoring data. Thousands of ESDs (9,341 as of 2014) in varying stages of completion have been created, spanning the United States.

Twidwell et al.[1,2] offered a severe critique of ESDs. The critique was based on an evaluation of 340 STMs to quantify and compare among ESDs the particular kinds of states (e.g., herbaceous or herbaceous shrub mix), types of transition between alternative states (e.g., woody plant encroachment, shifts in composition of herbaceous species), and drivers of transition or restoration (e.g., grazing, fire, brush management). Several of their conclusions are ultimately constructive, but others are incorrect or overstated. My primary concern is that their critique leaves the impression that, collectively, ESDs provide poor or even damaging guidance to land managers. Based on the critique, ESDs may appear to some readers to be a poor investment and not be worth the involvement of scientists or potential funders. ESDs have much to improve on, no doubt, but they offer unprecedented advantages for organizing and delivering information about landscape dynamics and management.

I will be transparent about my potential biases. I have worked with STMs and ecological sites since 2000. I have worked closely with ESD developers. Like others, I am frequently frustrated by how ESD development has progressed. Yet I continue to believe in the value of ESDs, for reasons described here.

This article will focus first on what I regard as misinterpretations about the ESDs analyzed by Twidwell et al. and misunderstanding of the function and evolution of ESDs. I also point to disagreements and research shortfalls within the broader science community that are merely reflected in ESDs, rather than being specific to ESDs. I then describe, and amplify from the Twidwell et al. critique, what I feel would improve the rigor and utility of ESDs.

The Critique

Grazing Is Overemphasized

Twidwell et al.'s primary critique centers on an apparent inconsistency. They found that grazing is featured as a driver in a larger number (268) of STMs than is fire (235) or brush management (208). Yet woody plant encroachment (239 STMs) is the most common transition process, followed by woody plant reduction (223), and shifts in herbaceous species (163). Twidwell et al. consider these patterns to reflect a "grazing-woody plant fallacy" in which "grazing is listed as the number one driver of both degradation and restoration when woody plant encroachment and reduction characterize the two dominant state changes in ESD[s]." They go on to state that "Decades of scientific research suggest grazing management does little to prevent the conversion of grass-dominated ecosystems to woody-dominated ecosystems upon the onset of woody plant encroachment." Twidwell et al. also point out that, in one ecological site that the authors are familiar with, "long-term increases in woody plants are observed … irrespective of grazing pressure" and that "Grazing-induced reduction of fine fuels is one of many pathways that influence fire intensity and its effects."

The assertion that a "grazing-woody plant fallacy" is responsible for flawed STMs is not supported by their analysis. First, in their reference to Archer et al. (2011) that grazing management does little to prevent woody encroachment after its onset, they overlook another statement in the same review: "However, grazing management influences on [woody plant] encroachment are indirectly important in terms of how they affect the amount and continuity of fine fuels available for wildfire or prescribed burning." Even if this is not true in Great Plains sites known to Twidwell et al., grazing management can be an important part of managing woody plant encroachment in other systems.[3] By electing to examine only transitions to and from the reference state (see p. 7[1]), the evaluation emphasized the initial triggers of woody plant encroachment in which grazing management can be especially important.[4,5] Grazing management is similarly an important part of grassland recovery following woody plant removal and "Brush management conducted in isolation of grazing management is therefore treating symptoms rather than addressing the root causes of the problem."[6]

In fact, multicausality in transitions was apparently common in the narratives; there were 340 models analyzed yet there were 1,328 records of "drivers," yielding an average of about four drivers per model (Table 2[1]). Because grazing is ubiquitous in rangelands and interacts with other drivers, it is not surprising that it is a commonly discussed feature in STMs. For example, grazing management is important for both managing and adapting to woody plant encroachment.[6] For herbaceous community shifts (163) and reseeded rangelands (133), attention to grazing management is critical.[7,8] Grazing management is also important in managing erosion rates.[3,9] The fact that grazing is included as an important driver in rangelands experiencing different kinds of transition is not evidence that grazing is overemphasized.

Second, it is important to recognize that existing ESDs had been developed by NRCS to interact with stakeholders that have primary interests in grazing uses. ESDs implicitly consider humans and their actions as part of ecological systems, known now as social-ecological systems.[10] Especially since 2011, interagency teams are in the process of expanding ESDs to encompass new stakeholders (e.g., national parks) and broader interests (wildlife populations). Accommodation of multiple ecosystem services and new land uses will take time and must

Figure 1. A word cloud representing the frequency of 55 informative terms used in transition narratives cataloged in the Ecological Site Information System (as of 2014). Each term is sized according to its total number of occurrences (e.g., grazing = 1,828, fire = 1,290, native = 730, bare = 204). Narratives contained a total of 95,538 words (3,291 unique terms) after punctuation, numbers, and standard English stop words were removed. In all, 1,001 ecological site descriptions and 3,304 transition narratives were analyzed. Terms deemed to have little informative value (e.g., plant. can, state, increase) were removed from the data set before creating the word cloud.

continually evolve. But ESDs are fundamentally tools for management and grazing management continues to be a central activity in most rangelands. The diversity of drivers in STMs revealed in the Twidwell et al. analysis (Fig. 1) should be a point for encouragement rather than criticism.

Inconsistent Presentation

Twidwell et al. criticized STMs for being inconsistent in design and concepts. This is an important problem, but it can hardly be blamed on STM developers. Twidwell et al. noted that, despite a 2011 ESD users' guide, "the presentation of state-and-transition models, how they were developed, how information was organized in the text, and how components were defined within each state-and-transition model differed among individual creators, with large discrepancies observed among regions." Readers should know that the four STMs highlighted in Twidwell et al.'s Fig. 10[1] as examples of inconsistency were developed from 2004 to 2009 (Ecological Site Information System, available at https://esis.sc.egov.usda.gov/, accessed January 17, 2015; B. Gillaspy, personal communication, January 2015), well before the 2011 guidance and recent directives were available.[11] The guidance that Twidwell et al. apparently take for granted emerged from these early efforts.

It is also important to recognize that confusion about the identity of reference states, alternative stable states, and how to describe state transitions (known elsewhere as "regime shifts") is apparent throughout the primary science literature,[12–14] not only in STMs. Recent academic papers proposing multiple alternative states based on the utility of management interventions, often represented as three- or four-state models[5,15] do not necessarily agree with representations of the same systems based on the mathematics of alternative attractors, which might comprise only two states.[13,16] For example, juniper (*Juniperus ashei*) encroachment could be conceived as having a single tipping point between two regimes: a reference (grassland) regime in which fire limits juniper recruitment and an alternative (juniper) regime in which reduced fuel loads lead to increasing juniper survival and recruitment rates (Fig. 2A[17]). Alternatively, states can be defined according to the nature of the management interventions needed to either prevent or reverse the regime shift, involving four states in a recent paper (Fig. 2B[5]). Descriptions of state transitions—even for the same ecosystem—can vary depending on the approach taken. If even research scientists do not consistently describe state transitions, blame for past inconsistency should not be laid entirely at the feet of STM developers or NRCS. Recent recommendations provided by two handbooks[11,18] now provide guidance for revision of older ESDs and development of new ESDs, and this guidance should continue to evolve with the science.

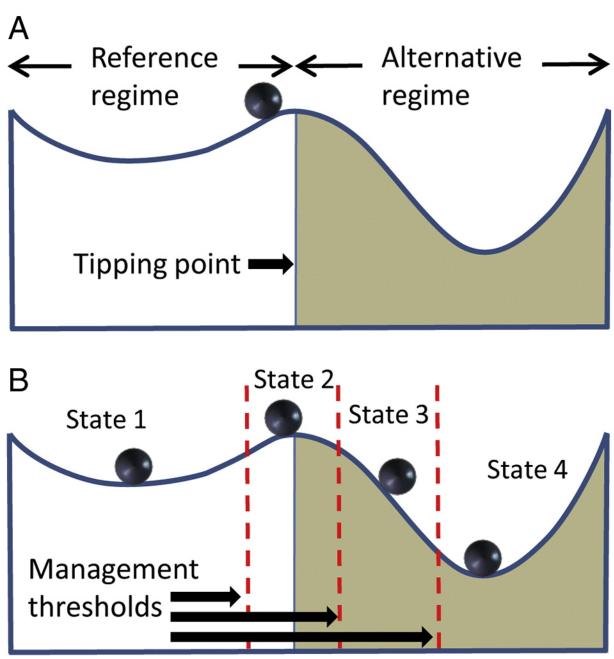

Figure 2. Two perspectives on state transitions following the ball-and-cup analogy, in which the community state or phase is the ball and the cup is the basin of attraction (or the forces that pull the state toward an equilibrium at the bottom of the cup). (A) represents a classical tipping point (or ecological threshold) between two alternative regimes (cups). (B) represents states that are based on the nature of management interventions to either prevent or reverse a regime shift, superimposed on the regime shift. Both approaches have been taken in developing state-and-transition models, leading to variations in model format.

Climate Change

Twidwell et al. criticized STMs for not consistently addressing climate change. In the same section, they criticized the lack of evidence used in STMs and admonished model developers to "cite specific outcomes from ecological field experiments when identifying transitions between alternative states and assess the degree of similarity between the field experiment and a given ecological site." Unfortunately, there is little experimental or even model-based evidence to downscale climate change projections to the level of ecological sites and states. The recent fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) states that "predicting the response of terrestrial and freshwater ecosystems to climate and other perturbations, particularly at the local scale, remains a major impediment" and that "Probabilistic statements about the range of outcomes are possible, … but ecosystem science is as yet mostly unable to conduct such analyses routinely and rigorously."[19] Although it is critically important to address climate change, it would be irresponsible to speculate on specific effects at the ecological site level without evidence. Summaries of potential climate change effects on vegetation would probably be most effectively generated at higher levels of the land unit hierarchy, such as land resource units or Major Land Resource Areas,[i] but even this awaits future scientific efforts.

Shortcomings and Benefits of ESDs

Existing ESDs are usually far from complete, are poorly supported by empirical studies, and feature logical and formatting

[i] For more information on Major Land Resource Areas, see http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053624.

inconsistencies. These shortcomings are a consequence of the youth of the initiative to expand the role of ESDs in land management, limited funding, and the limitations of ecological science. Although ESDs have existed in concept for 15 years, specific initiatives to expand development of ESDs using new data and dedicated specialists date only to 2010.[20] The primary funder of these interagency efforts has been, and continues to be, NRCS. When the bulk of the STMs that were included in the Twidwell et al. review were developed, there was little guidance and expertise in science and literature synthesis available. Even today, funding for the national ESD effort, estimated at $7 million for 2014 in dedicated USDA salaries nationwide (J. R. Brown, personal communication, January 2015), pales in comparison to other national initiatives, such as the National Ecological Observatory Network ($434 million for 6 years to develop only the infrastructure).

The science itself greatly limits what content can be included in STMs. Although ecological site-based STMs are sometimes disparaged as being "conceptual," the concepts are the vital link between quantitative empirical research and on the ground management decisions. But in most cases, the quantitative research simply isn't available or adequately linked to soils/ecological sites. Even one of the main sources used in the Twidwell et al. critique, a nationwide review of rangeland conservation practices, concluded that "conservation practices have seldom been sufficiently monitored to obtain the ecological and socioeconomic data necessary for a thorough assessment of conservation practice outcomes."[21] Therefore, local and expert knowledge is called on to fill this gap. With regard to climate change effects, site-scale predictions are even less well supported and local knowledge is usually unavailable. The current state of ESDs reflects the magnitude of the task before us, the lack of scientific investment to date, and the urgency of providing guidance for ongoing land management decisions.

The Twidwell et al. review provided no indication of what ESDs do well, despite their limitations.[22,23] Among their many capabilities, ESDs can:

1. Communicate plant–soil relationships and the basics of ecosystem dynamics to nontechnical users (now for specific locations via mobile devices);
2. Provide clear, yet modifiable, statements of reference conditions for land managers that form the basis for monitoring and assessment;
3. Outline options for management goals—noting that sometimes, reference conditions may not be preferred for particular goals (in contrast to statements in Twidwell et al.);
4. Provide guidance on restoration practices (e.g., seed mixes) and how their effects are believed to vary across a landscape; and
5. Capture local knowledge where science is inadequate, linking it to a nationwide soil mapping and database system.

No other land management framework in the United States has such broad coverage and diverse capabilities.

The Path Forward

Although elements of the Twidwell et al. critique are incorrect or overstated, it highlights several areas were the ecological site program can be improved. First, ecological site development needs to be approached more systematically. Based on the variety of ideas and experiences reflected in existing ESDs, specific guidelines and quality control measures were recently introduced in the 2014 National Ecological Site Handbook[ii] and staff positions dedicated to ESD review have been established within NRCS. Quality control efforts now have direct links to National Cooperative Soil Survey protocols and to the National Soil Information System. It is important, however, to recognize that the science underpinning descriptions of ecosystem dynamics continues to evolve and the structure of STMs should reflect this evolution.

Second, statements in ESDs and STMs should be more detailed and rigorous. New and revised ESDs should be based where possible on a critical evaluation of the science literature. For those elements of ecosystem dynamics that have not been sufficiently studied or that feature equivocal conclusions—which are the most common situations[21]—other forms of evidence, including unpublished case studies and local knowledge, are invaluable. The sources of assertions in STMs should be clearly referenced and the degree of uncertainty should be acknowledged.[24] Most important, as identified in Twidwell et al., a broad range of expertise should be consulted in developing STMs. Inclusive workgroups are part of current guidelines, and scientists should take time to become involved in them. Recruiting scientists for workgroups remains a challenge, perhaps because incentives for scientists are limited.

Finally, ESD developers need collaborations with researchers investigating the potential effects of climate change. Species distribution models,[25] models examining the role of soil profile properties in mediating water availability,[26] or even careful documentation of recent extreme events[27] would be useful and transparent tools for anticipating future climate change effects. But it is not wise to make assertions about climate change effects based on uninformed speculation.

For many of the reasons outlined here, STMs might be most effectively developed at the level of multiple ecological sites or landscapes rather than single ecological sites. In addition to reducing redundancy (many ecological sites within a region feature very similar STMs) and workload, broad-level STMs may be better matched to existing literature and more easily linked to climate change models. Rather than accepting current guidelines as immutable, the science and management communities should continue to imagine new ways to communicate our collective knowledge about ecosystem responses to land use and policy.

The critical element needed for such advances is continued support from the science and management communities. Critiques, such as that provided by Twidwell et al., are important for motivating these communities and government agencies to improve ESDs and STMs. To be fully effective, however, such critiques should be grounded in fair evaluations, be linked to solutions, and acknowledge the important benefits that ESDs and STMs already provide for land management.

[ii] Download the 2014 National Ecological Site Handbook at https://esis.sc.egov.usda.gov/Files/NESHcomplete%2007-14.pdf.

Acknowledgments

The author acknowledges Joel Brown, Jamin Johanson, Jason Karl, Kendra Moseley, and Dean Stacy for comments that improved the article, even if they do not necessarily agree with everything written. Jeb Williamson graciously provided the word cloud. This work is funded by appropriated funds to the USDA Agricultural Research Service.

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