Conceptual Pitfalls and Rangeland Resilience

By Peter Sundt

The history of rangeland ecology has been largely a struggle to overturn the early-20th-century notions of climax, balance of nature, stability, and equilibrium.[1] These ideals prevailed for decades under the influence of Clements' super-organismic model of vegetation,[2] Dyksterhuis' practical method for evaluating rangeland trends on the basis of similarity to climax vegetation,[3] and the Stoddart, Smith, and Box textbook on range management, which relied on succession to climax for grazing management and the balance-of-nature interpretation of ecology.[4] These ideas were challenged by plant ecologists such as Henry Gleason, whose mapping of vegetation convinced him as early as 1917 that plant species assorted individualistically,[5] and by Robert Whittaker, whose work showed that plant species respond individualistically to environmental gradients.[6] By 1975 it was generally agreed among ecologists that "the Gleasonian paradigm had overthrown the Clementsian one."[7] The rangeland profession somewhat belatedly questioned the climax and balance-of-nature paradigms as evidence mounted that reducing or eliminating grazing did not necessarily cause succession toward climax[8] and that rangelands often did not exhibit equilibrial properties.[9,10] In one of the most influential papers in rangeland ecology, the state-and-transition model of nonequilibrium vegetation dynamics was introduced by Westoby, Walker, and Noy-Meir in 1989.[11]

It seemed by the 1990s that rangeland ecology had embraced a nonequilibrium, individualistic view of the world in which vegetation dynamics and responses to management were contingent on the myriad details of local environments: the physical characteristics of ecological sites, including topography, soils, and microclimates; the traits of individual plant species, including grazing and drought tolerance; and the long history of events at particular sites, including weather, grazing, flood, fire, and accidents of seed dispersal. The achievement of this historically contingent, individualistic, nonequilibrium viewpoint was a triumph for rangeland ecology.

Today I see a danger to this achievement lurking in the recent developments of rangeland ecology that embrace complex adaptive systems as models of rangelands. This viewpoint takes the form of management for ecosystem health and resilience, which has effectively become the new dominant paradigm in rangeland ecology.[12,13] Most of the theorists and scientists who have developed this paradigm understand that such terms as self-regulation, self-repair, integrity, and health[14] are metaphors and analogies, not actual properties of rangelands. However, the formalization of rangeland health as a goal of US public land management,[15] the Bureau of Land Management's process of standards and guidelines that stress ecosystem "integrity,"[16] and the National Park Service's "vital signs"[17] pose conceptual pitfalls for range practitioners and the public, whose view of rangelands may slide comfortably into the recently vacated niche of the balance-of-nature, super-organism interpretation. In this paper I urge caution about a wholesale acceptance of the complex systems approach to rangelands, and I hope to clarify the conceptual basis of the new range management paradigm by a critical evaluation of three central concepts: ecosystem, function, and resilience.

Healthy Skepticism About Complex Adaptive Systems

The context of the new paradigm of management for ecosystem resilience is the theory of ecosystems as complex adaptive systems.[18,19] Resilience is an emergent property of complex systems and describes the amount of change that a system can undergo before a rapid shift to an alternate state.[20] The study of complex adaptive systems is popular and expanding rapidly; in addition to ecosystems, many other entities have been proposed as examples, including cells, economies, brains, ant colonies, and the entire biosphere/atmosphere (Gaia).[21] Key features of complex adaptive systems include hierarchical self-organization, self-regulation, and adaptive capacity, which emerge spontaneously from the interactions of multiple individual agents.[22] Although rangelands are certainly complex and composed of many interacting elements, I urge that we be cautious, even skeptical, about attributing to rangelands the claimed emergent properties of complex adaptive systems such as self-regulation, self-repair, integrity, and health.

Common to these concepts is the idea that the behaviors of an ecosystem's component organisms and processes are controlled for the good of the whole.[23] This idea poses several problems, including defining “the whole” and “the good of the whole,” and identifying the mechanisms of control. An ecosystem is an arbitrary collection—its spatial boundaries must be specified by people and its composition varies over time—so it is not clear exactly what constitutes the “whole” entity that benefits from ecosystem self-regulation and health. Some organisms are harmed and some benefited by virtually any event or process (e.g., fire benefits grasses and harms woody seedlings; phosphorus input to lakes benefits algae and harms fishes). Thus it is not clear what change or process constitutes a benefit to the whole system. Control is most often portrayed as negative feedback, such as predators limiting prey or the interactions of grass cover and fire in maintaining grassland. But it is not at all clear that the collective effects of grass growth, lightning, and woody seedling mortality constitute a cybernetic control mechanism rather than simply a causally linked set of events.[24] A large and controversial literature in the philosophy of science debates the emergence of novel properties in complex systems[25,26] and the possibility of “downward causation” from one hierarchical level to a lower level.[27,28] There are many conceptual pitfalls and no consensus of opinion, so rangeland people should tread carefully in the territory of complexity. Terms such as self-regulation, resilience, integrity, and health should be recognized as metaphors and analogies and not be taken too literally.

Epistemology and Ontology

Clarity of the concepts involved with ecosystem resilience can be aided by contrasting epistemology and ontology. The Greek word *episteme* means knowledge; an epistemological concept is one that aids us in seeking knowledge. The Greek word *ontos* means that which exists, and ontology is the study of being and reality. As an illustration, consider the hierarchy of organization in biology: cell, tissue, organ, organism, population, community, ecosystem. Of these, cells, tissues, organs, and organisms are identifiable biological entities: each has a distinct boundary—cell wall, membrane, or skin. Populations, communities, and ecosystems, by contrast, are concepts made by humans to help us understand the world, and their physical boundaries are arbitrary or abstract. They are epistemological concepts, not ontological entities.

Of course, I have simplified the issue of what entities are real. Viewed at a very fine scale even the membrane of a cell is seen to be an indefinite boundary, as atoms are separated by empty space and electrons are wave-like probability clouds. At the opposite extreme galaxies viewed from Earth seem to be definite, bounded entities, but we know them to be vast collections of stars without clear boundaries. One can argue that populations and ecosystems exist whether or not we recognize them, or that cells and organisms are not real entities; my point is not to make an assertion about reality, but to highlight the contrast between human concepts created to help us understand the world and the entities that exist in the world independently of us.

Ecosystem

What is an ecosystem? The concept begins with a collection of organisms interacting with one another and the abiotic environment within a geographical boundary. What makes this collection a *system* are the emergent properties of structure, function, and behavior—all concepts we invented to help us understand nature.

- Structure has to do with the composition of components, their identity, relative abundance, and spatial arrangement
- Functions are processes linking components, e.g., energy and nutrient flows
- Behavior refers to the dynamics of whole systems, due to the changes over time to structures and functions. Examples include oscillations, equilibrium, chaos, and transitions.

A typical structural analysis of an ecosystem groups the organisms and nonliving matter according to the function each group performs, for example, as producers (plants and algae), consumers (herbivores and carnivores), and decomposers (earthworms, bacteria, fungi). Note that these categories are artificial and abstract: the organisms that we classify as consumers—for example, rabbits and coyotes—did not evolve to fulfill a “consuming” function in the ecosystem, but rather to multiply their genes by converting food into offspring. The presence of rabbits provides an economic opportunity—a niche—for coyotes and other predators, and the consumption of rabbits by coyotes facilitates the flow of energy and materials among organisms. In this sense the coyotes are performing an ecosystem function, but it is a by-product of individual behaviors. Structure, function, and system behavior are parts of an epistemological scheme for understanding nature, not real entities in nature.

The boundaries and scale of an ecosystem are subjective—from an elephant’s eyelash to the entire biosphere, according to one account—and must be specified. That there is no objective, natural boundary to an ecosystem is illustrated by trying to imagine the spatial limit of the factors that affect a single grass plant. It includes the neighboring plants whose root systems overlap, the nearby tree that casts shade in the morning, the range of rabbits and other potential herbivores that might eat it, the range of coyotes and potential predators that might eat the rabbits, the ranges of the rabbit’s and the coyote’s parasites, the abiotic environment of topography, rainfall, sheet flow, temperature, nutrients, etc. These influences attenuate with distance from the target plant, but there is no “natural” or distinct boundary beyond which influences drop to zero. A common understanding of an ecosystem boundary is cited on page 24 in Golley’s article:[29] “an arbitrary point where the flow rate [or direction] changes,” but this point will obviously vary according to which flow variable (e.g., phosphorus, energy, water) is considered. Golley concludes that “ecosystem boundaries are fuzzy, that is they are imprecise, changing and dynamic.”

The properties of an ecosystem can vary dramatically as its scale changes. The resilience management paradigm focuses attention on single ecological sites for the analysis of multiple vegetation states, transitions, and management options. But the ecosystem properties, including resilience, of a 200-acre ecological site could be quite different from those of the entire four-section pasture within which the site occurs, which might include riparian areas and a variety of other ecological sites, and would be different again from the ecosystem properties of the whole ranch. Thus when talking about ecosystem properties—whether measurable properties such as productivity and biodiversity, or emergent system properties such as structure, function, and behavior—one must carefully specify the geographical boundaries of the ecosystem.

Ecosystem Function

The concept of ecosystem function is teleological (from the Greek *telos*)—that is, it implies a purpose. For a process to perform a function it must contribute to the overall purpose of the system; if the system had no purpose, we would simply call it a process, not a function. A container of gas molecules has properties and processes, such as pressure and heat conduction, but no purpose. The same molecules in the cylinder of an engine, however, *would* have a purpose—turning the driveshaft—and the process of compression would have a function related to the engine's purpose.

What is the purpose of an ecosystem? We humans can define a purpose, such as providing habitat for the greatest number of species or maintaining maximum flow of energy, or—as in the current rangeland management paradigm—producing the desired state of vegetation, but these are our projections onto the natural world. The real ontological entities—organisms and minerals and photons of sunlight—are in no sense working together for a common purpose. Ecosystem processes, for example, nitrogen cycling, are by-products of individual behaviors and are not functions unless we define an ecosystem purpose. This semantic issue is not a problem so long as we recognize that function is a concept that helps us to understand and manage nature for our purposes, not an actual entity *in* nature. It becomes a problem when people talk at cross-purposes about ecosystem functions, not recognizing that their views of the ecosystem's purpose or goals are different. An example is the oft-cited "function" of fire in a savanna; the *process* of fire reduces woody plant establishment and contributes to dominance by grass. If the management goal is grassland, then fire serves a useful *function,* but if the goal is habitat for quail (i.e., woodland), then fire is a process that impairs the function of woody plant establishment. My point is that "function" is an inherently value-laden term that should be used with caution because it implies a specific purpose.

Resilience

The concept of ecosystem resilience came from the development of mathematical models and is a measure of how much the variables of a model system can change before the system moves to a different state. Tuning the parameters of model systems allows theorists to discover multiple stable states to which the systems are inexorably drawn. The deterministic dynamics of mathematical models and their graphical representations[30] may have contributed to a misperception that ecosystem resilience is a force, like gravity or elasticity, that actively restores a system to a stable state. Resilience is not self-regulation of the ecosystem exerting its influence from above; resilience is a descriptive meta-property that integrates those properties of organisms and the environment contributing to the persistence of a particular state in the face of perturbation. In rangelands these are the key processes of resource acquisition by plants,[i] including biological traits such as grazing and fire tolerance of particular grasses and shrubs, their spatial arrangements, the frequency, intensity and timing of grazing and fire, the weather, and the operations of water infiltration, seed dispersal, and nutrient cycling.

As we saw with the term "function," resilience is a value-laden term (who could be against resilience?), and as such it suggests that the resilient state is intrinsically good—rather than simply persistent. But a shrub-invaded and eroded state may be very resilient because it persists despite changes in grazing management, climate, and fire regime. The goal of rangeland management is not resilience per se, but rather the desired vegetation state. Ultimately management for ecosystem resilience is an epistemological scheme that focuses attention on the myriad ontologically real details of topography, soils, plant physiology, hydrology, weather, and history that together determine whether we get the services we want from rangelands.

Summary

The systems approach to rangelands has conceptual pitfalls for the unwary. Uncritical acceptance that rangelands are complex adaptive systems can create expectations of self-regulatory homeostasis, an organismic ideal that took most of the 20th century to overcome. Remember that what is certainly out there is a lot of individual organisms each pursuing its own survival and reproduction! The ecosystem concept is often used vaguely and metaphorically, but to be of utility in rangeland management the precise spatial boundaries must be specified; otherwise the emergent systems properties of structure, function, and behavior cannot be described, much less managed. Ecosystems do not have an inherent purpose, and so the term function is appropriate only when a purpose is specified. Does a given process contribute to the management goal? Then it is performing a function. And resilience is not a natural force or tendency;

[i] This formulation is due to B. Bestelmeyer, personal communication, 2010.

rather it is a catch-all term for the traits of individual organisms and of the physical environment that allow the persistence of desired vegetation at one of the places we call an ecosystem.

Acknowledgments

Brandon Bestelmeyer, Alex Conley, Charles Curtin, Janet Fox, Jim Malusa, Joe McAuliffe, Lamar Smith, Myles Traphagen, and anonymous reviewers made helpful comments on early drafts of this paper.

References

1. Reviewed in Briske, D. D., S. D. Fuhlendorf, and F. E. Smeins. 2003. Vegetation dynamics on rangelands: a critique of the current paradigms. *Journal of Applied Ecology* 40:601–614.
2. Clements, F. E. 1936. Nature and structure of the climax. *Journal of Ecology* 24:252–284. [Note that Clements' own views have often been oversimplified: Eliot, C. 2007. Method and metaphysics in Clements's and Gleason's ecological explanations. *Studies in History and Philosophy of Biological and Biomedical Sciences* 38:85–109.]
3. Dyksterhuis, E. J. 1949. Condition and management of rangeland based on quantitative ecology. *Journal of Range Management* 2:104–115.
4. Stoddart, L. A., A. D. Smith, and T. W. Box. 1975. Range management. 3rd ed. New York, NY, USA: McGraw-Hill. 532 p.
5. Gleason, H. A. 1939. The individualistic concept of the plant association. *American Midland Naturalist* 21:92–110.
6. Whittaker, R. H. 1953. A consideration of the climax theory: the climax as a population and pattern. *Ecological Monographs* 23:41–78.
7. Simberloff, D. S. 1980. A succession of paradigms in ecology: essentialism to materialism and probabilism. *Synthese* 43:3–39.
8. Smith, E. L. 1988. Successional concepts in relation to range condition assessment. *In:* P. T. Tueller [ed.]. Vegetation science applications for rangeland analysis and management. Boston, MA, USA: Kluwer Academic Publishers. p. 113–133.
9. Ellis, J. E., and D. M. Swift. 1988. Stability of African pastoral ecosystems: alternate paradigms and implications for development. *Journal of Range Management* 41:450–459.
10. Ilius, A. W., and T. G. O'Connor. 1999. On the relevance of nonequilibrium concepts to arid and semiarid grazing systems. *Ecological Applications* 9:789–813.
11. Westoby, M., B. H. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* 42:266–274.
12. Briske, D. D., B. T. Bestelmeyer, T. K. Stringham, and P. L. Shaver. 2008. Recommendations for development of resilience-based state-and-transition models. *Rangeland Ecology & Management* 61:359–367.
13. Pyke, D. A., J. E. Herrick, P. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management* 55:584–697.
14. Bertuglia, C. S., and F. Vaio. 2005. Nonlinearity, chaos and complexity. Oxford, United Kingdom: Oxford University Press. 387 p.
15. National Research Council. 1994. Rangeland health: new methods to classify, inventory, and monitor rangelands. Washington, DC, USA: National Academy Press. 180 p.
16. US Department of the Interior Bureau of Land Management. 1997. Grazing and rangeland management standards and guidelines for Colorado. Available at: http://www.blm.gov/co/st/en/BLM_Programs/grazing/rm_stds_guidelines.html. Accessed 7 July 2010.
17. Miller, M. E. 2005. The structure and functioning of dryland ecosystems—conceptual models to inform long-term ecological monitoring. US Geological Survey Scientific Investigations Report 2005-5197. Reston, VA, USA: US Geological Survey. 73 p.
18. Levin, S. 1998. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems* 1:431–436.
19. Jørgensen, S. E., and F. Muller. 2000. Ecosystems as complex systems. *In:* S. E. Jørgensen and F. Muller [eds.]. Handbook of ecosystem theories and management. Boca Raton, FL, USA: Lewis Publishers. p. 5–20.
20. Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1–23.
21. Waldrop, M. M. 1992. Complexity: the emerging science at the edge of order and chaos. New York, NY, USA: Simon and Schuster. 380 p.
22. Holland, J. H. 1992. Complex adaptive systems. *Daedalus* 121:17–30.
23. Rapport, D. J., R. Costanza, and A. J. McMichael. 1998. Assessing ecosystem health. *Trends in Ecology & Evolution* 13:397–402.
24. Engelberg, J., and L. L. Boyarsky. 1979. The noncybernetic nature of ecosystems. *American Naturalist* 114:317–324.
25. Corning, P. A. 2002. The re-emergence of emergence: a venerable concept in search of a theory. *Complexity* 7:18–30.
26. Kim, J. 2006. Emergence: core ideas and issues. *Synthese* 151:347–354.
27. Campbell, D. 1974. Downward causation in hierarchically organized biological systems. *In:* F. J. Ayala and T. Dobzhansky [eds.]. Studies in the philosophy of biology: reduction and related problems. London, United Kingdom: Macmillan. p. 179–186.
28. Hulswit, M. 2006. How causal is downward causation? *Journal for General Philosophy of Science* 36:261–287.
29. Golley, F. 2000. Ecosystem structure. *In:* S. E. Jørgensen and F. Muller [eds.]. Handbook of ecosystem theories and management. Boca Raton, FL, USA: Lewis Publishers. p. 21–32.
30. Ludwig, D., B. H. Walker, and C. S. Holling. 2002. Models and metaphors of sustainability, stability and resilience. *In:* L. Gunderson and L. Pritchard, Jr. [eds.]. Resilience and the behavior of large scale systems. Washington, DC, USA: Island Press. p. 21–48.

Author is a rangeland consultant, 460 S 6th Ave, Tucson, AZ 85701, USA, petesundt@gmail.com.