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. These ideals prevailed for decades under the influence of Clements’ super-organismic model of vegetation, Dyksterhuis’ practical method for evaluating rangeland trends on the basis of similarity to climax vegetation, 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. 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 individually, and by Robert Whittaker, whose work showed that plant species respond individually to environmental gradients. By 1975 it was generally agreed among ecologists that “the Gleasonian paradigm had overthrown the Clementsian one.” 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 and that rangelands often did not exhibit equilirial properties. 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.

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. Most of the theorists and scientists who have developed this paradigm understand that such terms as self-regulation, self-repair, integrity, and health are metaphors and analogies, not actual properties of rangelands. However, the formalization of rangeland health as a goal of US public land management, the Bureau of Land Management’s process of standards and guidelines that stress ecosystem “integrity,” and the National Park Service’s “vital signs” 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. 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. 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). 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. 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. This idea poses
several problems, including defining “the whole” and “the
good of the whole,” and identifying the mechanisms of con-
trol. 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-regula-
tion and health. Some organisms are harmed and some ben-
efited 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 feed-
back, 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, light-
ning, and woody seedling mortality constitute a cybernetic
control mechanism rather than simply a causally linked set
of events. A large and controversial literature in the phi-
losophy of science debates the emergence of novel properties
in complex systems and the possibility of “downward
causation” from one hierarchical level to a lower level. 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 biolog-
cal entities: each has a distinct boundary—cell wall, mem-
brane, 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 con-
cepts created to help us understand the world and the enti-
ties 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 struc-
ture, 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 arrange-
- 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 decom-
posers (earthworms, bacteria, fungi). Note that these categ-
ories 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 eco-
system, 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
cyotes 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 pred-
ators that might eat the rabbits, the ranges of the rabbit’s and
the coyote’s parasites, the abiotic environment of topogra-
phy, 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:
“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 con-
sidered. Golley concludes that “ecosystem boundaries are
fuzzy, that is they are imprecise, changing and dynamic.”

August 2010
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 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, 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;

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1 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**


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