Ecological Models Underpinning Rangeland Systems:

Equilibrium, Non-equilibrium and Beyond

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Global Drylands

40% total land area (6B ha)
Rangelands 70%
2 billions humans
50% global livestock
Diverse ecosystem services

Millennium Ecosystem Assessment 2005
Rangeland and Pastoral Vulnerability

Rangelands characterized by:

- Climate variability
- Scarce resources
- Marginalized populations
- Local knowledge
- Cultural heterogeneity

Climate Change

Socio-political Drivers

Stafford-Smith 2008
Sufficient Ecological Model?

Global Rangeland Systems

Rangeland Health

Non-equilibrium

Range Condition

Equilibrium

Sustainability Science

Resilience
Stability of African pastoral ecosystems: Alternate paradigms and implications for development

JAMES E. ELLIS AND DAVID M. SWIFT

Abstract

African pastoral ecosystems have been studied with the assumptions that these ecosystems are potentially stable (equilibrium) systems which become destabilized by overstocking and overgrazing. Development policy in these regions has focused on internal alterations of system structure, with the goals of restoring equilibrium and increasing productivity. Nine years of ecosystem-level research in northern Kenya presents a view of pastoral ecosystems that are non-equilibrium but persistent, with system dynamics affected more by abiotic than biotic controls. Development practices that fail to recognize these dynamics may result in increased deprivation and failure. Pastoral ecosystems may be better supported by development policies that build on and facilitate the traditional pastoral strategies rather than constrain them.

Key Words: pastoral ecosystems, equilibrium ecosystems, non-equilibrium ecosystems, pastoral development

Opportunistic management for rangelands not at equilibrium

MARK WESTOBY, BRIAN WALKER, AND IMANUEL NOY-MEIR

Abstract

We discuss what concepts or models should be used to organize research and management on rangelands. The traditional range succession model is associated with the management objective of achieving an equilibrium condition under an equilibrium grazing policy. In contrast, the state-and-transition model would describe rangelands by means of catalogues of alternative states and catalogues of possible transitions between states. Transitions often require a combination of climatic circumstances and management action (e.g., fire, grazing, or removal of grazing) to bring them about. The catalogue of transitions would describe these combinations as fully as possible. Circumstances which allow favorable transitions represent opportunities. Circumstances which threaten unfavorable transitions represent hazards. Under the state-and-transition model, range management would not see itself as establishing a permanent equilibrium. Rather, it would see itself as engaged in a continuing game, the object of which is to seize opportunities and to evade hazards, so far as possible. The emphasis would be on timing and flexibility rather than on establishing a fixed policy. Research under the state-and-transition model would aim to improve the catalogues. Frequencies of relevant climatic circumstances would be estimated. Hypotheses about transitions would be tested experimentally. Often such experiments would need to be planned so that they could be implemented at short notice, at an unknown future time when the relevant circumstances arise.

Key Words: equilibrium, climax, succession, models

Ellis & Swift REM1988

Westoby et al. REM1989
Initial Rangeland Model

- **A.W. Sampson** 1919. Plant succession in relation to range management. USDA Bul. 791

- **E.J. Dyksterhuis** 1949. Condition and management of range land based on quantitative ecology. JRM 2:104
Range Condition

Clementsian Theory

Successional Tendency

Community Composition

Grazing Intensity

Rangeland Health

Briske et al. 2005
Non-equilibrium Persistent Model

Ellis & Swift 1988
‘New’ Rangeland Ecology

Non-equilibrium models contributed to alternative management and policy recommendations that *rejected*:

- Density-dependent regulation of plant production by livestock
- Concepts of carrying capacity and stocking rate
- Ability of grazing animals to adversely impact rangeland resources.

Behnke, Scoones & Kerven 1993
Motivation for Rangeland Debate

Identify and correct deficiencies in range science.

Emergence of non-equilibrial ecology 1970-80’s

Failure of pastoral development programs in Africa 1960-70’s

Rangeland marginalization narrative established in colonial era.
History of Rangeland Science

Nathan F. Sayre
Political Ecologist
Geography Department
Berkeley

University Chicago Press
2017
ON THE RELEVANCE OF NONEQUILIBRIUM CONCEPTS TO ARID AND SEMIARID GRAZING SYSTEMS

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Abstract. The dynamics of arid and semiarid grazing systems are prone to the effects of highly variable rainfall, with droughts causing frequent episodic mortality in herbivore populations. This has led to the suggestion that they are nonequilibrium systems, in which animal impacts on plants are strongly attenuated or absent. We examine the utility and appropriateness of nonequilibrium concepts for understanding ecosystem processes in African rangeland, attempt to distinguish disequilibrium from nonequilibrium, and argue that such concepts do not justify the view that herbivory has little impact in climatically variable systems. We present evidence for an alternative view of African rangeland function. We argue that, despite the apparent lack of equilibrium, animal numbers are regulated in a density-dependent manner by the limited forage available in key resource areas, which are utilized in the dry season. This model asserts that strong equilibrial forces exist over a limited part of the system, with the animal population being virtually uncoupled from resources elsewhere in the system. Spatially and temporally, the whole system is heterogeneous in the strength of the forces tending to equilibrium, these diminishing with distance from watering and key resource areas and during the wet season. We argue that wet-season range is more heavily utilized by animal populations sustained by key resource areas than would apply in the absence of key resources, and that uncoupling of the animal population from vegetation carries an increased risk of degradation. Droughts may impose intense and localized defoliation on vegetation, and this may result in altered species composition, reduced rain-use efficiency, soil erosion, and loss of productive potential. Rather than ignoring degradation, policy-makers and ecologists should seek to identify the characteristics of grazing systems that predispose some systems toward degradation, while others appear to be resistant. Development policies should focus on the spatial heterogeneity in susceptibility to grazing impacts and on preserving the productive capacity of key resource areas.

Key words: climatic variability; consumer-resource dynamics; degradation; grazing; livestock.

Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia

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Summary

1. Few studies have tested the applicability of current non-equilibrium models of rangeland vegetation dynamics to a particular ecosystem, or across a range of systems that might be expected to respond differently to grazing. This study assessed the extent to which the non-equilibrium persistent (NEP) model of rangeland vegetation dynamics applies to three distinct Mongolian rangeland ecosystems, the desert-steppe, steppe and mountain-steppe.

2. Standing biomass, vegetation cover and composition, and species richness and diversity were examined along grazing pressure gradients in ecological zones of differing productivity and interannual variability in precipitation.

3. In the desert-steppe, biomass, functional group cover, richness and diversity did not vary along grazing pressure gradients, but all vegetation variables except the cover of weedy annuals and unpalatable forbs varied significantly between years. Vegetation dynamics in this zone largely conformed to the NEP model of rangeland dynamics.

4. In the mountain-steppe, grass and total biomass, total vegetation cover, the cover of grasses, weedy annuals and unpalatable forbs, and richness and diversity varied along grazing pressure gradients. With increasing grazing pressure, grasses decreased and forbs and weedy annuals increased, as the conventional range condition (RC) model predicts. Interannual variation in precipitation influenced total vegetation cover, species and functional group cover, and richness and diversity.

5. In the steppe, forb biomass, grass, forb, unpalatable forb and weedy annual cover, and diversity varied along grazing pressure gradients. Grass biomass and total vegetation cover responded interactively to rainfall and grazing. Forb biomass, grass, forb and weedy annual cover and richness varied between years. Grasses decreased and forbs and weedy annuals increased with increasing grazing pressure, conforming to the RC model.
Reinterpretation NEP Model

Model overlooked heterogeneity of forage resource use.

- Herbivores are *coupled* to a subset of ‘key’ resources accessible in dormant season i.e., biotic feedback.
- Herbivores *uncoupled* from abundant growing season forage resources.
- NEP emphasized unique herbivore feedbacks with E and NE forage resources within landscapes.
- Key resource areas determine long-term herbivore persistence on the landscape.

Illius & O’Connor 1999
Hempson et al. 2015
Resilience Theory

Capacity of ecosystems to absorb disturbances and reorganize while undergoing change so as to retain similar function, structure, identity and feedbacks.

Walker et al. 2004
Resilience presents an equilibrial interpretation of ecosystem behavior.

- Non-equilibrium replaced by multi-equilibrial in ecological resilience.
- Species fluctuate within a single basin of attraction in response to environmental stochasticity.
- Slow variables and feedbacks maintain dynamic biotic community in a single basin of attraction.

Petraitis 2013
Application to Rangelands

Briske et al. REM 2006

A Unified Framework for Assessment and Application of Ecological Thresholds

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Abstract

The goal of this synthesis is to initiate development of a unified framework for threshold assessment that is able to link ecological theory and processes with management knowledge and application. Specific objectives include the investigation of threshold mechanisms, elaboration of threshold components, introduction of threshold categories and trajectories, and presentation of an operational definition of ecological thresholds. A greater understanding of ecological thresholds is essential because they have become a focal point within the state-and-transition framework and their occurrence has critical consequences for land management. Threshold occurrence may be best interpreted as a switch from the dominance of negative feedbacks that maintain ecosystem resilience to the dominance of positive feedbacks that degrade resilience and promote the development of post-threshold states on individual ecological sites. Thresholds have been identified to serve as ecological benchmarks to describe the extent of threshold progression and increase insight into feedback mechanisms that determine threshold reversibility. Threshold trajectories describe the developmental pathway that post-threshold states may follow once a threshold has been exceeded. These trajectories may produce a continuum of potential post-threshold states, but the majority of them may be organized into four broad states. This framework lends itself to management applications by providing an operational definition of thresholds that is based on a probabilistic interpretation. Probabilities associated with 1) the occurrence of triggers that initiate threshold progression, 2) the trajectory of post-threshold states, and 3) threshold reversibility will provide an operational procedure for threshold assessment and application. If thresholds are to play a central role in rangeland ecology and management, then the rangeland profession must accept responsibility for their conceptual development, ecological validity, and managerial effectiveness.

Briske et al. REM 2008

Recommendations for Development of Resilience-Based State-and-Transition Models


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Abstract

The objective of this paper is to recommend conceptual modifications for incorporation in state-and-transition models (STMs) to link this framework explicitly to the concept of ecological resilience. Ecological resilience describes the amount of change or disruption that is required to transform a system from being maintained by one set of mutually reinforcing processes and structures to a different set of processes and structures (e.g., an alternative stable state). In light of this concept, effective ecosystem management must focus on the adoption of management practices and policies that maintain or enhance ecological resilience to prevent stable states from exceeding thresholds. Resilience management does not exclusively focus on identifying thresholds per se, but rather on within-state dynamics that influence state vulnerability or proximity to thresholds. Resilience-based ecosystem management provides greater opportunities to incorporate adaptive management than does threshold-based management because thresholds emphasize limits of state resilience, rather than conditions that determine the probability that these limits will be surpassed. In an effort to further promote resilience-based management, we recommend that the STM framework explicitly describe triggers, at-risk communities, feedback mechanisms, and restoration pathways and develop process-specific indicators that enable managers to identify at-risk plant communities and potential restoration pathways. Two STMs representing different ecological conditions and geographic locations are presented to illustrate the incorporation and application of these recommendations. We anticipate that these recommendations will enable STMs to capture additional ecological information and contribute to improved ecosystem management by focusing attention on the maintenance of state resilience in addition to the anticipation of thresholds. Adoption of these recommendations may promote valuable dialogue between researchers and ecosystem managers regarding the general nature of ecosystem dynamics.
Evolution of Rangeland Models

F.E. Clements

1st Model – Equilibrium
- (1920-90)

2nd Model – Nonequilibrium
- (1990-2007)

3rd Model – Resilience
- (2008 - present)

C.S. Holling
Lessons Learned

- Functional *heterogeneity* affects herbivore persistence
  - Key resource areas within landscape
- Biotic feedbacks are dependent upon *scale*
  - Availability of E and NE forage categories
- Semi-arid rangelands more resilient than assumed
  - Large compositional changes occur within stable states
- Management has important implications even in highly stochastic environments.
  - Biotic and abiotic drivers coexist in these systems.
Sufficient Ecological Model?

Global Rangeland Systems

- Rangeland Health
- Non-equilibrium
- Range Condition
- Equilibrium
- Sustainability Science
- Resilience
Is a 4th Model Required?

Anthropocene has accelerated since debate began.
Socio-political drivers rival those of ecology.

- Population growth
- Globalization
- Land use change
- Climate change
- Governance
Rangeland Systems Framework

Global rangelands function as complex, adaptive social-ecological systems.

- Meaningful integration of these subsystems required.
- Recognize full complement of ecosystem services.
- Value rangeland similar to forest and cropland
  - How might this framework be best achieved?
  - What may provide a sufficient catalyst for action?
  - How may academia most effectively contribute?