



Non-equilibrium then and now

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Abstract

Non-equilibrium is a fundamental characteristic of rangelands and pastoralism. The non-equilibrium (NE) paradigm emerged primarily in response to problems in management, especially in the context of pastoral development. Aiming their arguments at the World Bank and other multilateral organizations, anthropologists and development professionals demonstrated that the use of equilibrium ideas – such as climax to evaluate range conditions, carrying capacities to set stocking rates, and succession to remedy degradation – had backfired repeatedly. Such shortcomings were familiar in the scientific community, but an alternative paradigm remained elusive until after the 2nd International Rangeland Congress in Adelaide in 1984. Following seminal publications on the topic (Ellis and Swift 1988; Westoby et al. 1989; Behnke et al. 1993), the NE paradigm was widely analyzed, debated, and largely adopted by global scholars, especially for drier, more variable rangelands (Illius and O'Connor 1999; Vetter 2005). Tools reflecting NE, such as state-and-transition models and satellite-based assessments of rangeland productivity, are now widely produced (Allred et al. 2022, Bestelmeyer et al. 2017). Widespread acceptance among scientists has not translated readily into the practices of pastoral development, however. In this paper we reflect on how the NE paradigm has shaped global rangeland management and governance over the past 30 years. Are rangeland systems better managed because of it? What are the prospects for the NE paradigm to support adaptation to global change in rangelands in the years ahead? We argue that while debates about NE concepts have faded into the background, the implications of NE are more important than ever.

Introduction: Is rangeland management better because of NE concepts?

In contrast to the equilibrium paradigm, the NE paradigm posited that 1) rangeland condition is determined primarily by abiotic drivers and non-linear (or threshold) responses to those drivers, 2) rangelands exist as alternative stable states best described by state-and-transition models rather than simple succession models, and 3) the high degree of spatial and interannual variability in rangelands requires careful attention to pastoralist mobility and flexibility, alongside governance structures that ensure access to land at needed spatial extents (Scoones 1995). NE characteristics are especially relevant to the most arid, variable, and extensive rangelands (von Wehrden et al. 2012) which have been least likely to be converted to cropland or intensified pasture systems.

While many organizations now advocate for pastoralism and mobility to conserve imperiled rangelands, and technology is providing increasingly effective solutions for perceiving and reacting to NE rangeland behavior,

policies continue to limit pastoralists' ability to implement those solutions. Pejorative narratives about pastoralism and limited societal valuation of extensive rangelands continue to drive policy prescriptions irrespective of the scientific advances (Davis 2016). Especially in the Global South, governments are pressured to convert land and livestock into financial opportunities and reliable revenue streams by connecting rangelands with urban and international markets. Exclusive land tenure, capital investments (e.g., in livestock breeds), consistent output, and optimized rates of return-on-investment are viewed as necessary to meet these goals. In short, the core management requirements of NE – flexibility, mobility, and reciprocity at multiple scales – suffer not from a lack of scientific support but from incompatibility with neoliberal globalization.

Pastoralists continue to experience political and economic marginalization, compromised management autonomy, diminished access to land, and sedentarization (UNCCD 2024), reducing the spatial scale and sustainability of livestock management. With powerful outside interests seeking to appropriate land and water resources for more lucrative land uses, policies and development efforts often reduce options for livestock movements and flexibility by encouraging the conversion of rangeland to cropland to increase economic returns, afforestation to 'restore' ecosystem functions, and intensification/modernization of livestock production (via fencing, wells, and harvested forages) to increase production efficiency (Nori and Scoones 2023). And as climate change advances, the variability of precipitation on rangelands is increasing (Sloat et al. 2018). The complications associated with NE are expanding and intensifying with losses in forage productivity, amplified abiotic extremes, and widening scalar mismatches in rangeland administration. Thus, NE is becoming both more relevant and more challenging than ever.

Prospects for improved application of the NE paradigm

For practical, management purposes, the core challenge of NE is the combination of spatio-temporal variability and unpredictability. Technological advances now allow pastoralists and policymakers to perceive and react to NE in ways that were unimaginable decades ago. First, the recognition of NE behavior in rangelands catalyzed the global development of state-and-transition models (STMs) that emphasize the potential for threshold responses in different rangeland types (Bestelmeyer et al. 2017). These models provide indicators and, more importantly, have expanded the mental models of managers to include the possibility of abrupt and persistent changes in natural resources. Operationally, STMs have guided grazing strategies and the selection of restoration practices that account for spatial heterogeneity in resilience due to climate, soils, and history, and the role of climatic variability. Where STM-based thinking has been adopted, managers are more attuned to variability, risk, and opportunity (Knapp et al. 2011).

Second, the fusion of satellite-based remote sensing, standardized databases of ground-based measurements, and user-friendly web and mobile applications has produced a revolution in information about rangeland conditions (Allred et al. 2022). A manager can now detect short-term changes and long-term trends in vegetation at the scale of patches that are a few hundred square meters in size and across thousands of hectares. While this technology is recent and most advanced in the United States, progress is underway in rangelands across the world and is improving rapidly with the use of artificial intelligence.

Third, sensor technologies under the umbrella term of 'precision ranching' are also becoming more effective and attainable, including Global Positioning Systems (GPS)-based tracking collars, water-level sensors, and automated rain gauges (Spiegel et al. 2024). These sensors allow managers to track variable resource conditions and animal movements (particularly in the Global North where herding is seldom practiced; McIntosh et al. 2022). Virtual fencing combines GPS with stimuli on collars that control livestock movements. Thus, virtual fencing allows for adaptive rotational grazing and rest that does not depend on expensive physical infrastructure and fixed pasture locations and dimensions. When combined with remote sensing-based production maps and analytics, GPS collars and virtual fencing can allow grazing pressure to adapt to NE behavior of rangelands (Bestelmeyer et al. 2024).

Conclusion

NE calls for flexible access to land, variable output (including wide swings in herd sizes), traditional ecological knowledge and bottom-up decision making to cope with inherent uncertainty (Scoones 1995). How do we overcome the policy barriers to supporting NE rangeland social-ecological systems, with assistance from technological advances? In practical terms, this question remains open and will be addressed by participants in our symposium. Several approaches, however, will be essential. First, rangeland and pastoralist advocates need to reinforce the broad societal benefits of rangeland social-ecological systems and their right to exist. Society and policymakers should treat the loss of rangelands with the same sense of urgency that they treat the loss of wilderness and forests. Second, development strategies should be designed from a deep understanding of local context, communities, and livelihoods (Allington et al. 2024). Third, policies should reflect careful consideration of the heterogeneity, connectivity, and scale needed to preserve those livelihoods and the natural resources on which they depend, taking advantage of technology. Carefully crafted socio-technical solutions may at last harness the insights of NE thinking to improve rangeland sustainability and pastoral livelihoods.

References

- Allington GRH, Fernández-Giménez ME, Reid R, Ulambayar T, Angerer J, Jamsranjav C, Baival B, Bayjav B (2024) Context matters: Rethinking resource governance theories for Mongolian pastoral systems. *Land Use Policy* 142, 107170.
- Allred BW, Creutzburg MK, Carlson JC, Cole CJ, Dovichin CM, Duniway MC, Jones MO, Maestas JD, Naugle DE, Nauman TW, Okin GS, Reeves MC, Rigge M, Savage SL, Twidwell D, Uden DR, Zhou B (2022) Guiding principles for using satellite-derived maps in rangeland management. *Rangelands* 44, 78-86.
- Bestelmeyer BT, Ash A, Brown JR, Densambuu B, Fernández-Giménez M, Johanson J, Levi M, Lopez D, Peinetti R, Rumpff L, Shaver P (2017) State and transition models: Theory, applications, and challenges. In 'Rangeland Systems: Processes, Management and Challenges'. (Ed DD Briske) pp. 303-345. (Cham: Springer International Publishing).
- Bestelmeyer BT, McCord SE, Browning DM, Burkett LM, Elias E, Estell RE, Herrick JE, James D, Spiegel S, Utsumi SA, Webb NP, Williamson J (2024) Fulfilling the promise of digital tools to build rangeland resilience. *Frontiers in Ecology and the Environment* 22, e2736.
- Davis DK (2016) 'The Arid lands: history, power, knowledge', (MIT Press: Cambridge).
- Knapp CN, Fernández-Giménez ME, Briske DD, Bestelmeyer BT, Ben Wu X (2011) An assessment of state-and-transition models: Perceptions following two decades of development and implementation. *Rangeland Ecology & Management* 64, 598-606.
- McIntosh MM, Cibils AF, Estell RE, Gong Q, Cao H, Gonzalez AL, Nyamuryekung'e S, Spiegel SA (2022) Can cattle geolocation data yield behavior-based criteria to inform precision grazing systems on rangeland? *Livestock Science* 255, 104801.
- Nori M and Scoones I (2023) Rethinking policies for pastoralists – governing the rangelands. *The Rangeland Journal* 45, 53-66.
- Scoones I (ed) (1995) 'Living with Uncertainty: New directions in pastoral development in Africa', (Intermediate Technology Publications: London).
- Sloat LL, Gerber JS, Samberg LH, Smith WK, Herrero M, Ferreira LG, Godde CM, West PC (2018) Increasing importance of precipitation variability on global livestock grazing lands. *Nature Climate Change* 8, 214-218.
- Spiegel S, Estell R, Cibils A, Cox A, McIntosh MM, Browning DM, Duniway MC, Funk M, Macon L, McCord SE, Reed M, Tolle C, Utsumi S, Walker J, Webb N, Bestelmeyer BT (2024). The LTAR Grazing Land Common Experiment at the Jornada Experimental Range: Old genetics, new precision technologies, and adaptive value chains. *Journal of Environmental Quality* 53, 880-892.
- UNCCD (2024) 'Global Land Outlook Thematic Report on Rangelands and Pastoralism', (United Nations Convention to Combat Desertification: Bonn).
- Von Wehrden H, Hanspach J, Kaczensky P, Fischer J, Wesche K (2012) Global assessment of the non-equilibrium concept in rangelands. *Ecological Applications* 22:393-399.