

Earth Stewardship of rangelands: coping with ecological, economic, and political marginality

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Rangelands encompass 30–40% of Earth's land surface and support 1 to 2 billion people. Their predominant use is extensive livestock production by pastoralists and ranchers. But rangelands are characterized by ecological, economic, and political marginality, and higher value, more intensive land uses are impinging on rangelands around the world. Earth Stewardship of rangelands must address both livestock management and the broader socioecological dynamics that promote land-use changes, fragmentation, and degradation. We identify specific gradients on which human–rangeland systems can be arrayed, including issues of variability, adaptation to disturbance, commercialization, land-use change, land-tenure security, and effective governance, and we illustrate the gradients' interactions and effects in sites worldwide. The result is a synthetic framework to help in understanding how rangeland Earth Stewardship can be achieved in the face of marginality, globalization, and climate change.

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Rangelands – including grasslands, shrublands, savannas, deserts, prairies, steppe, and tundra – comprise 30–40% of Earth's ice-free terrestrial surface (depending on one's definition and data sources; Asner *et al.* 2004) and account for 91% of the world's grazing lands (Reid *et al.* 2008). Encompassing watersheds for vast downstream populations and containing approximately 30% of the world's soil carbon (FAO 2009), rangelands are also highly diverse, biologically and otherwise. The estimated extent (and definition) of rangeland degradation varies widely, from as little as 10–20% to as much as 70–80% (MA 2006). An estimated 1 billion people depend on rangelands for their livelihoods, primarily through exten-

sive livestock production, and roughly twice that number derive animal protein, water, or other resources from these biomes (MA 2006; FAO 2009).

Importantly, rangelands are often defined negatively, as a residual category for areas that are not defined as something else (eg forest, woodland, agriculture, urban). Much of the world's prime cropland (such as the corn and wheat belts of central North America) was once rangeland, for example, but no longer counts as such in many land-type classifications. This is not simply a classificatory peculiarity. Rather, it reflects actual land-use dynamics and economic valuation; in a real sense, rangelands are lands that have not (yet) been converted to other uses with higher rates of economic production and return, and their extant ecological diversity persists precisely because they have not been altered by more intensive land uses, which typically result in simplification.

With few exceptions, rangeland inhabitants are politically and economically marginalized, limited by low per-hectare economic output and small or dispersed populations. Drylands (a highly overlapping though not identical land type) correlate closely with global poverty (Verstraete *et al.* 2009), and are judged to be among the most imperiled biomes on Earth due to low inherent productivity and rapid population growth (MA 2006). The aggregate economic value of rangeland production may be quite high (FAO 2009), but it is spread across large areas where collective action to address competing land uses is difficult. Moreover, rangeland inhabitants have often been labeled “traditional” or “backward”, blamed for rangeland degradation (often erroneously; Niamir-Fuller 1999; Goldman *et al.* 2011), and targeted for “modernization” or “development” programs. Although a few of these programs have narrowly benefited some range-

In a nutshell:

- Rangelands constitute 30–40% of Earth's land surface and contribute to the livelihoods of 1–2 billion people
- Ecological, economic, and political marginality expose rangelands to degradation, land-use change, and fragmentation worldwide
- Earth Stewardship of rangelands must include responses to all three dimensions of marginality to be successful
- Direct involvement of rangeland users with scientists and policy-making processes is key to achieving this success

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land communities (Sandford and Scoones 1994; Banks 2003), most have failed and many have proved to be socially and/or ecologically disastrous (Behnke *et al.* 1993; Scoones 1995; Niamir-Fuller 1999).

In this review, we argue that Earth Stewardship of rangelands must begin with a multifactorial view of the sources of their marginality, the ecological and social forces driving their transformation to other land uses, and their potential for sustainable use. We describe six gradients – two ecological, two economic, and two political – that structure human–rangeland systems (Figure 1), and provide examples of how these gradients can be used to develop a synthetic framework to guide research, policy, and management. The framework could be applied to socioecological systems anywhere, but rangelands are unique in the degree to which they experience marginality along all six gradients.

■ Ecological dimensions

Rangelands can be arrayed along two major ecological gradients.

(1) Effective moisture

Defined as the availability of moisture in the plant-rooting zone during the growing season, this gradient integrates precipitation, evapotranspiration, and temperature, and it correlates closely with aboveground net primary production (ANPP). Comparatively mesic rangelands tend to be converted to crop agriculture, and most of the remaining rangelands lie toward the drier end of the gradient when compared to other land types. More xeric rangelands require larger areas to support a given quantity of livestock, and also tend to be more temporally variable and spatially heterogeneous in ANPP (Illius and O'Connor 1999; von Wehrden *et al.* 2012). Pastoralists have typically adapted to these conditions through flexible mobility and seasonal or ephemeral use of productive sites within these large areas.

(2) Degree of similarity between current and evolutionary disturbance regimes

Disturbances such as grazing, fire, drought, and flood consume, constrain, and/or redistribute key resources. As in other ecosystems, evolutionary adaptation to rangeland disturbance regimes tends to produce resilience to those disturbances. Global assessments indicate that rangelands with long evolutionary histories of herbivory have ANPP values and plant community compositions that are more resilient to subsequent grazing pressures (Milchunas and Lauenroth 1993), and in some sites forage plants may benefit or depend indirectly on grazing for their persistence (McNaughton 1979 but see Belsky 1986). Similarly, many semiarid rangelands are adapted to recurrent fire and may experience marked shifts in composition, such as shrub encroachment, if fire is suppressed (Schlesinger *et al.* 1990; Sankaran *et al.* 2004). Complex interactions among

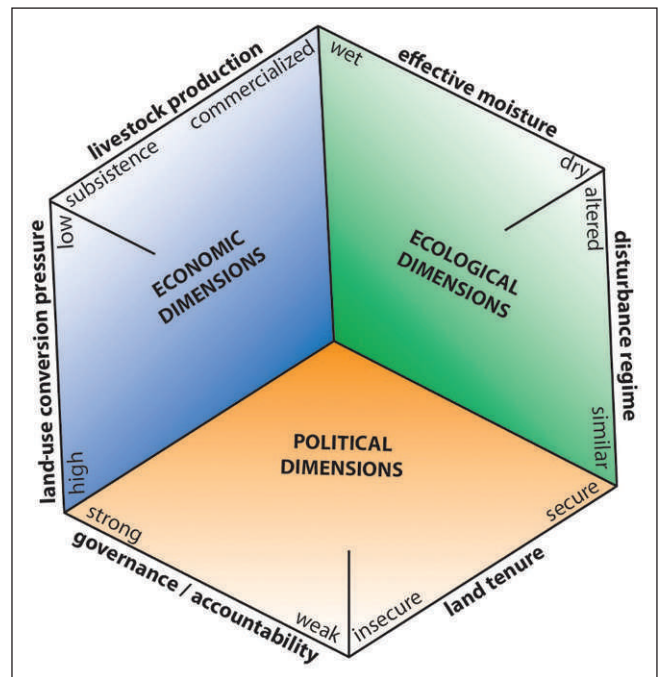


Figure 1. Conceptual diagram of ecological, economic, and political gradients that structure the prospects for effective Earth Stewardship of rangelands worldwide.

disturbances, including novel ones and suppression or removal of old ones, structure system responses to human uses. Rangelands encompass a broad array of positions on this gradient, from a very high degree of similarity between current and evolutionary disturbance regimes in much of Africa and parts of Asia, to highly altered disturbance regimes in the arid and semiarid zones of Australia and North America. The effects of grazing as a disturbance also depend on timing, intensity, and duration, which may be altered by management practices in ways that resemble or deviate from evolutionary norms.

■ Economic dimensions

Rangelands may also be arrayed along two key economic gradients.

(3) Degree of commercialization and market penetration of rangeland livelihoods

Commercializing or “modernizing” rangeland livestock production has been promoted by countless companies, governments, and development agencies around the world. Virtually all rangeland inhabitants combine subsistence and market production to some degree, but the spectrum remains extremely broad. At the subsistence-oriented extreme, livestock serve as stores of wealth as much as a means of income, and pastoralists seek to minimize risk rather than maximize the harvest of animals (de Bruijn and van Dijk 1995; Krätli and Schareika 2010). Mixed (multiple species) herds are common; land is typically state-owned and/or collectively used and managed; and capital inputs and infrastructural invest-

ments (eg roads, wells, fences, supplementary feed, genetically “improved” breeds, veterinary care) are limited. At the commercial extreme, by contrast, ranchers purchase a wide variety of inputs and sell their animals to maximize the return on investments in forage, genetics, water, fences, and labor. Land is more likely to be privately owned and/or exclusively allocated by lease, and single-species herds predominate. Commercialization, then, has strong effects on management practices and incentives, livelihood strategies, land tenure, and pressure for land-use change.

(4) Disparity of economic returns between livestock production and alternative land uses

On a per-unit-area basis, extensive rangeland livestock production is almost always less profitable than other land uses, where such alternatives are feasible (Scoones 1989; Behnke 2008), making land-use change a perennial issue. Competing land uses include crop agriculture (in moister areas or where irrigation is developed), mining, energy production (petroleum, natural gas, solar, wind, biofuels), urbanization (including suburban or exurban development), tourism, and water-related developments (eg dams and aqueducts). The effects of these competing uses tend to be concentrated on subunits of rangelands with particular resource attributes, such as more fertile soils; greater water supplies, wildlife/scenic values, minerals, and energy sources; or improved access to roads and markets (Wright and Wimberly 2013). Land-use change often targets key resource areas (eg dry-season pastures or water sources) whose importance to pastoralist production is disproportionate to their size. Even in cases where the alternative land use is not more productive than traditional uses, the economic returns may be favored as more amenable to state taxation (Behnke and Kerwen 2013).

■ Political dimensions

Finally, rangelands may be arrayed along two political gradients.

(5) Degree of land-tenure security

Land tenure is notoriously insecure for pastoralists, especially near the subsistence end of the commercialization gradient. The “paradox of pastoral land tenure” (Fernández-Giménez 2002; Fernández-Giménez and LeFebvre 2006) refers to the need to secure access to fixed, discrete, key resource sites (eg dry-season water sources) while maintaining the flexibility to move to larger, less clearly defined areas in response to variable conditions. Traditional pastoralist societies resolved this paradox through flexible, reciprocal, community-sanctioned systems of land access and allocation. Globally, under the influence of capitalization, political trends have moved many rangelands along a continuum away from communal grazing and land tenure and toward more exclusive or

privatized systems (Behnke 2008). At the commercialized extreme, secure land tenure may be afforded by private ownership and/or by leases or other legal mechanisms overlaid on public or communal land ownership. This accentuates the temporal variability experienced by pastoralists, given that bounded grazing areas restrict access to spatially heterogeneous resources (Stokes *et al.* 2006). Moreover, all of these systems may be undermined – and land tenure threatened – as competing land uses become more economically powerful. Thus, it is not the type of land-tenure system per se that matters but rather the perceived uncertainty surrounding tenure currently and in the foreseeable future.

(6) Degree of democratic representation, transparency, and accountability in governance of rangeland systems

Pastoralists in many places (especially subsistence-oriented pastoralists) are politically marginalized or relatively powerless as compared with other land users and the centralized state. Corruption, violence (or the threat of violence), poverty, ethno-linguistic or educational barriers, discrimination, or disenfranchisement characterize governance in many rangeland settings, undermining cooperation with inhabitants, disempowering resistance to land-use changes, and promoting land-tenure insecurity (Niamir-Fuller 1999; Galvin 2009). The process of changing tenure systems, for example, may be co-opted by elites who exclude others with less opportunity to survey, register, title, or lease land (Alimaev and Behnke 2008).

■ Interactions among gradients

Temporal variability and spatial heterogeneity are key metrics for understanding the interactions of effective moisture and disturbance regimes (gradients [1] and [2] above) with livestock grazing. In relatively large, unfragmented rangelands, for example, pastoralists have generally coped with spatiotemporal variability by tracking variations in ANPP (Panel 1; WebFigure 2; Niamir-Fuller 1999; Schareika 2003; Behnke *et al.* 2011; Moritz *et al.* 2013). Variability and heterogeneity are scale-dependent, however, and the spatial and temporal scales of observation and management strongly affect what “sustainable” or “resilient” means for a given rangeland system. As rangelands are fragmented and/or mobility is restricted, livestock are more likely to graze in areas of low forage availability and the probability of both persistent reductions in plant productivity and human suffering (through livestock loss) increases.

Both mobility and fragmentation are fundamentally influenced by economic patterns of commercialization and land-use competition (gradients [3] and [4]). Mobility requires large, unfragmented landscapes and/or secure access to routes for livestock movement. But pressures to fragment rangelands for more intensive land uses

Panel 1. Issues of rangeland Earth Stewardship in Sudano-Sahelian Africa

This region lies south of the Sahara Desert, with average annual rainfall increasing from 200 mm (at the desert edge) to 800 mm (approximately 900 km southward of the edge). The sharp gradient in effective moisture correlates closely with the ecological, economic, and political gradients described in the main text.

- Ecologically, the zone encompasses a very sharp vegetation gradient. The perennial vegetation of the southern savanna is shaped by the interaction of fire and grazing, and productivity is limited by soil fertility. As one transitions to annual grassland/steppe vegetation in the north, composition and productivity are governed more by seasonal rainfall. Throughout this gradient, vegetation has evolved under a long but spatially heterogeneous history of fire and/or grazing.
- Economically, the major competing land use leading to the loss of rangeland is rain-fed crop agriculture, whose viability declines rapidly north of the 400-mm isohyet (map-based demarcation of equal rainfall). Rural peoples, no matter their ethnicity, are best viewed as agropastoral, integrating both livestock husbandry and crop agriculture, depending on their wealth, status, and home area. Greater reliance on crop agriculture in the south is due not only to greater crop yields but also to disease and nutrition constraints on livestock husbandry. Road density and access to markets also decline as one moves north into more arid zones.
- Politically, land institutions are dominated by informal conventions, and both customary and state-sanctioned private tenure is generally obtained through the clearing of land for agriculture. Private land sales are still rare except in urban areas where commercial agriculture predominates. Despite major strides in some places, levels of accountability and transparency in governance remain low in the region.

Patterns of livestock mobility are driven both by predictable seasonal changes in forage phenology across the latitudinal rainfall gradient at the regional scale (which determines large-scale migration, or transhumance, of pastoralists and their animals) and by unpredictable variation in forage availability at finer spatial scales. Within the region, the pastoral conundrum is largely associated with competing land uses. Where agricultural pressure is limited, there may be little need for common property institutions as conventionally defined (eg Ostrom 1990). Such pastoral systems can best be described as open systems where there are no social or natural boundaries. Mobile pastoralists have the freedom to move within and between pasture areas, as all pastoralists, regardless of class, ethnicity, or nationality, have free access to common-pool grazing resources (Moritz *et al.* 2013). Where agricultural pressure is higher, however, pastoral flexibility is limited by increasingly fragmented landscapes with more conventional territorial forms of common property (protected corridors, water points, grazing areas) increasingly evident (Figure 2).

Programs of development and conservation, by ignoring these intersecting gradients, have generally increased the vulnerability of both the region's rangelands and the rural peoples who depend wholly or in part on livestock husbandry. The infamous drilling of boreholes in the Sahel reduced livestock mobility and thereby created "halos" of degradation (Bernus 1974; Thébaud and Batterbury 2001). Despite conventional wisdom, livestock rearing has generally been found to cause less environmental stress than crop agriculture on grassland and savanna ecosystems in the region. Thus, the promotion of crop agriculture often works against the stewardship of the region's natural ecosystems. Moreover, agricultural outreach programs, ignorant of the seasonal importance of key bottomlands to livestock husbandry, have facilitated the enclosure of these key sites for gardening and other projects and, in so doing, made the stores of wealth (livestock) created by these programs more vulnerable.

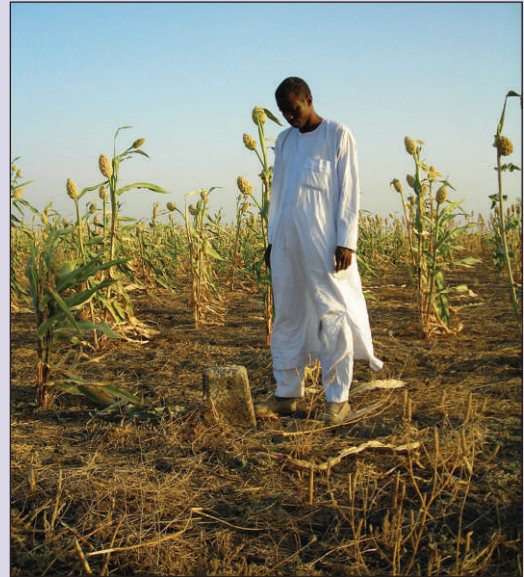


Figure 2. A cement marker delimiting a corridor for pastoralist and livestock migration or transhumance – now surrounded by a field of sorghum – in the far north region of Cameroon, Africa.

threaten mobility around the world (Panels 1 and 2; WebPanels 1 and 2; Hobbs *et al.* 2008). Fragmentation may occur as a result of fencing (which commonly accompanies commercialization), degradation, conversion to agriculture, construction of roads or other infrastructure, or urbanization. Where fragmentation reduces the spatial extent of management, it also reduces livestock producers' abilities to cope with temporal variability and spatial heterogeneity, increasing the likelihood of degradation and/or land-use conversion. Unconverted rangelands across the effective moisture gradient provide

critical ecosystem services that cannot easily be replaced or matched by more intensive land uses.

Land-tenure security and rangeland governance (gradients [5] and [6]) often function synergistically with economic forces (gradients [3] and [4]). What might be termed the "paradox of rangeland tenure" is that formalization of property institutions may be necessary to protect pastoralist production from competing land uses but may also undermine such production (through reduced mobility), depending on the spatial scale of the allocated grazing units, the political power of different stakehold-

Panel 2. Issues of rangeland Earth Stewardship in the US

Rangelands in the US span a wide range of effective moisture and evolutionary disturbance regimes. Moister rangelands have largely been converted to crop agricultural production, and many drier rangelands have also been converted, through irrigation. Of the remaining rangelands, semiarid areas evolved in the presence of frequent fires, large ruminant grazing animals, or both, whereas in arid rangelands, which did not evolve with frequent fire or grazing, the spread of invasive grasses in the 20th century has brought fire into the disturbance regime. Livestock have been present in almost all of these rangelands, at least since the late 19th century.

US range livestock producers are highly commercialized, and disparities between returns to livestock and alternative land uses are varied but generally high. Land tenure is secure for private lands, which make up roughly one-half of extant US rangelands, although economic pressures to convert to residential or other land uses are often very strong (Figure 3). Conversion of private parcels to exurban uses can cause nearby rangeland owners to perceive their own impermanence and sell their properties (Liffman *et al.* 2000). Security of access to public lands, provided by leases generally 10 years in duration, is highly varied and unpredictable. Many leases have been challenged by environmental groups on legal grounds, and mineral and energy development also impinge on public land grazing in many areas. Fragmentation is both an ongoing threat to US rangeland systems and an underlying characteristic of the mosaic of landownership types (private, state, tribal, and various federal agencies) and their respective statutory regimes.

In response to pressures for land-use change and fragmentation, uncertain public land tenure, and challenges from environmental groups, ranchers in many parts of the US have diversified their operations and organized community-based conservation efforts to resolve conflicts, protect unfragmented rangelands, and restore historical disturbance regimes such as periodic fire (Sayre *et al.* 2012). The Malpai Borderlands Group in southern Arizona and New Mexico, for example, involves ranchers, scientists, environmentalists, and government agencies committed to restoring fire, reversing shrub encroachment, protecting biodiversity, preventing fragmentation, and supporting local livelihoods in a 325 000-ha area of semiarid rangeland and montane woodland (Sayre 2005). Regulatory problems relating to fire and rare wildlife species are more easily addressed at scales larger than individual ranches. Many rangeland conservation groups, including Malpai, also operate as (or collaborate with) local land trusts, purchasing conservation easements that permanently restrict subdivision and development on private lands. Indeed, there is some evidence that the area of western lands protected by easements in recent decades exceeds the area converted to suburban and exurban land uses.



Figure 3. Cattle grazing on rangelands above San Jose, Santa Clara County, California. Note the smog layer – a source of excess nitrogen deposition to surrounding lands – visible above the city.

ers, and the economic force of other land uses (Fernández-Giménez and LeFebre 2006; Turner 2011). Transitioning from traditional or informal (ie non-state-sanctioned) land tenure to more legally secure systems may help to inhibit land-use change, but doing so may also encourage land-use change by enabling private land to be sold or encumbered with debt, or by facilitating leases or concessions on public lands for higher value activities (eg mineral or energy development, agriculture). Moreover, even where formalized land tenure does prevent land-use change, it may entail fragmentation (eg

by fencing) and reduce management flexibility in response to variability and heterogeneity.

■ Discussion

The potential for Earth Stewardship of rangelands depends principally on the capacities of pastoralists and ranchers to manage for the spatial and temporal variability of the resources available to them. Many individuals from both groups have extensive practical knowledge of how to sustain long-term production in these

unpredictable, highly variable ecosystems, through mobility and flexible rules of access (Niamir-Fuller 1999). However, their management practices are mediated by political and economic forces that define access rules and property rights. As rangelands are fragmented, pasture and water rights are formalized, and climate change accentuates ecological extremes (FAO 2009), coping with variability will likely become ever more challenging.

Rangeland degradation is a common outcome of complex, cross-scale interactions among the ecological, economic, and political factors we have described above. Even where local actors are the proximate cause of degradation, the ultimate drivers are rarely local but instead are larger scale economic and political forces that impinge on livestock management and excise key areas for alternative uses. Although the proximate causes of rangeland fragmentation vary widely, the root causes are often “the growing power of centralized, bureaucratic states and the spread of capitalism” (Behnke 2008). However, these seemingly inexorable forces do not automatically “spell the end” for pastoralism or functioning rangelands (Panel 2). Exclusive land-tenure systems can serve to protect extensive production against competing land uses, especially where land ownership remains vested in state or communal institutions and access is granted through legally enforceable leases.

Whether and how rangelands can be managed for Earth Stewardship depends on the legacies of the past, current and potential pressures for land-use conversion, and the political and governance systems that mediate land use, tenure, and management. Careful attention to the social and ecological details of a given rangeland system is required to understand the intersecting ecological, historical, and political-economic drivers that enable or constrain effective stewardship. Access to knowledge and information about all these factors is critical, especially for marginalized groups.

Rangelands should be understood and valued positively for the full suite of economic and ecological services they provide, rather than as a residual category that invites their continued loss to more intensive uses. Policies to sustain rangeland uses, cultures, and the diverse services they support should aim to stabilize land tenure and dampen or control land-use change to minimize the effects of fragmentation on social-ecological systems (WebPanel 2). Governance systems that enable users to cope with spatiotemporal variability should be fostered or revived to avoid triggering threshold shifts in ecological states, particularly in anticipation of the projected aridification of many rangelands (FAO 2009). Rangeland Earth Stewardship will require policy, management, and research initiatives, conducted collaboratively with stakeholder groups, tailored to diverse and variable site-specific circumstances, and informed by knowledge from across the spectrum of developed to developing economies.

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Tenure-Track Position in Climate Modeling University of Colorado Boulder



The Institute of Arctic and Alpine Research (INSTAAR) and the Department of Atmosphere and Oceanic Sciences (ATOC) at the University of Colorado Boulder invite applications for a tenure-track faculty position in climate modeling.

Candidates who specialize in regional climate modeling are of particular interest, but we seek applicants from any relevant area of focus who complement existing Department and Institute strengths in climate modeling as well as in geophysics, hydrology, biogeochemistry, paleoclimatology, atmospheric chemistry and oceanography.

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