Dynamics and Resilience of Rangelands and Pastoral Peoples Around the Globe

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Abstract

Rangelands cover more of Earth's land surface than any other type of land. They have variable and harsh climates, are sparsely populated and remote from markets, produce significant quantities of livestock, and are mostly used and managed in common. Under this already unpredictable and harsh climate, pastoral peoples and rangelands face new and accelerating political, economic, and climatic stresses that challenge their coupled resilience and ability to adapt. In response, pastoralists are creating new ways to manage rangelands through conservancies and community-based institutions on state, common, and private land. In this review, we focus on recent advances in our understanding of rangeland social-ecological systems, as well as on the causes and consequences of change in these systems. We then explore how pastoral peoples, governments, and businesses are responding to these changes to build resilience to sustain both pastoralism and rangelands. We close with a description of unresolved issues, challenges, and questions for the future.

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INTRODUCTION

Rangelands—primarily native grasslands, shrublands, savannas, and marshes grazed by wildlife and livestock (1)—cover more of Earth's land surface (25–45%, depending on how these lands are defined) than any other type of land (2, 3). Where rangelands are warm and dry (60% of rangelands), pastoralists and their herds inhabit the drier parts of rangelands; where rangelands are cold (16% of rangelands), grazers use the warmer and wetter places (2). Herding people (or pastoralists) hold diverse flocks of livestock, usually cattle, sheep, and goats, ranging from reindeer in the north to alpaca in the south. Herders share the more thinly populated grazing lands with a much wider variety of wild grazers and browsers, from elephants to kangaroos to bison.

Rangelands, whether warm or cold, share basic features: They have variable and often harsh climates, are sparsely populated and remote from markets (4), produce significant livestock, and are mostly used and managed in common. Most rangelands have low productivity because most highly productive rangelands are now plowed for crops. About 91% of global rangelands are open (sometimes called extensive) rangelands with few landscape boundaries (e.g., fences) and have limited crop agriculture (3). The remaining 9% support a mix of grazing and cultivated land with boundaries and have low to moderate human populations. Although only 3% of the world's people live in open or extensive rangelands, 35% of the world's sheep, 23% of the goats, and 16% of the cattle and water buffalo graze here (3). Two-thirds of global rangelands are in Asia (36%) and Africa (30%) (3), where most rangelands are used in common (5). Most of the remaining rangelands are privately owned and used, with 13% of all global rangelands in North America, 10% in Australia, 8% in South America, and 3% in Europe.[1]

[1] Calculations in the first two paragraphs are based on a map (figure 1-1 in Reference 3) created from global land-cover databases to include places dominated by shrubs and herbaceous plants with little to no cover of forest, woodland, or cropland.

Most of the world's people live far from rangelands (6), often in urban, forested, or farm-based systems, where climate dynamics are more predictable and sedentary lifestyles are viable. In rangelands, by contrast, vegetation and water resources are usually ephemeral in time and patchy in space, and movement of herds to these ephemeral patches means livestock produce more milk and meat (7). These and other unique features of rangelands have led to major misconceptions about how rangelands work, which we describe in this review.

As they cope with an already unpredictable and harsh environment, pastoral peoples face new and accelerating political, economic, and climatic stresses that challenge their resilience and ability to adapt (8). As human populations and consumption grow, so does the pressure to convert wetter rangelands to towns, suburbs, and cropland. Mining, oil, and gas extraction and renewable energy production are spreading across rangelands (9). Land scarcity often leads to subdivision of formerly intact communal land into fragmented private land, although some historically private lands are starting to consolidate management across property boundaries (10, 11). Climate change adds new challenges with warmer temperatures, changing rainfall, and increasing frequency of extreme events (drought, storms, floods) (12, 13).

Rangeland ecosystems and the ecosystem services they provide sometimes do and sometimes do not respond to these pressures. Wetter rangelands can be overgrazed, whereas drier rangelands seem resilient to grazing and are principally affected by climate (14, 15). Soils can degrade, but, at least in drylands, this is currently limited in extent, with only about 12% of drylands moderately to extremely degraded (16). Worldwide, woody plants are replacing grasses in rangelands (2), sometimes because of heavy grazing or even grazing abandonment, and invasive species are becoming more common (17). Despite fears of the desertification of rangelands, many rangelands are becoming greener recently, probably caused by increasing CO_2 (18).

Pastoral families, communities, governments, nonprofits, and businesses respond to these changes by adapting their livelihoods and creating new ways to manage rangelands through new rules and institutions. As economic demands grow for pastoral families, they diversify into new sources of income beyond livestock and invest more into livestock to intensify production (8). Around the world, pastoralists are creating new ways to manage land through community-based and market-based institutions on state, common, and private lands (10, 19).

In this review, we focus on recent advances in our understanding of rangeland social-ecological systems and on the causes and consequences of change in these systems. We then explore how pastoral peoples, governments, and businesses are responding to these changes to build resilience to sustain both pastoralism and rangelands. We close with a description of unresolved issues, challenges, and questions for the future.

Ecosystem services: the benefits people receive from nature, in contrast to "environment" and "ecosystem," which refer to the totality of our world and not just to the parts of our environment that benefit people

Common land or the commons: land owned or used collectively by a group of people with agreed-upon rules on how it is to be used

OUR EVOLVING UNDERSTANDING OF RANGELANDS AND PASTORAL PEOPLES

We start by defining rangelands and pastoral peoples and describing the recent revolution in our understanding about them. Today, for example, scholars are expanding the meaning of rangelands so the term applies more broadly to new uses on these lands (9). A long-standing definition is that developed by a joint committee of the International Grasslands Congress and International Rangelands Congress (1, p. 5):

> Land on which the indigenous vegetation (climax or sub-climax) is predominantly grasses, grass-like plants, forbs or shrubs that are grazed or have the potential to be grazed, and which is used as a natural ecosystem for the production of grazing livestock and wildlife. Rangelands may include natural grasslands, savannas, shrublands, many deserts, steppes, tundras, alpine communities and marshes.

Other definitions, although agreeing that rangelands consist of low grazing vegetation, go beyond use by livestock and wildlife to include cropping, settlement, and mining (9). Others suggest adding to the utilitarian view of rangelands by including conservation of critical ecosystem services (20). Here, we define rangelands broadly by their vegetation (or more generally, land cover) but recognize that rangelands provide a wide range of ecosystem services, much more than just grazing. Thus defined, rangelands do not include forests and woodlands. They also differ from the accepted definition of drylands (6) because rangelands also include wet grazing lands.

This definition makes no mention of the people who use rangelands: pastoralists/ranchers, agropastoralists, hunters, conservationists, recreationists, and others. Pastoralists or ranchers are people who make their living primarily (more than 50% by some definitions) from herding livestock but also exploit other resources in diverse combinations (21). In this article, we principally use the term pastoralist because it has a longer history of use and is more global than the term rancher; we adopt rancher as commonly used to refer to range livestock producers in North America. Like Huntsinger et al. (22), we see strong commonalities between pastoralists and ranchers. The term agropastoralist refers to settled people who both grow crops and herd livestock, meaning that only part of their lands are rangelands because the rest has been plowed for crops. Many rangelands formerly grazed by livestock are now in conservation areas with varying levels of restriction on livestock use. And people, including pastoralists themselves, are busy using rangelands in new ways, for farming, mining, settlement, energy production, and other uses.

In this review, we conceptualize rangelands as linked social-ecological systems (**Figure 1**). As such, each place-based system has a unique ecological, historical, political, and cultural context, such that changes and innovations that apply to one place may not apply in others. At the household and community scale (**Figure 1**), climate changes affect vegetation and livestock directly and, in turn, affect families and communities. Markets and policy influence how pastoralists make decisions about how to use and manage rangelands through household strategies and, more broadly, community institutions. The social system and ecosystem adapt to each other, and their linked resilience depends, in part, on this capacity to adapt. In this review, we often shorten the cumbersome term rangeland social-ecological systems to either rangeland systems or pastoral systems.

Our understanding of rangelands and pastoral peoples has evolved dramatically over the past half century, yet many past assumptions linger on, partly because few people are familiar with rangelands and partly because rangeland dynamics are surprisingly counterintuitive. In the past, for example, we assumed that most rangelands used in common by herders were overgrazed and degraded. Now we understand that many drier rangelands have nonequilibrium dynamics, where climate has more impact on vegetation than grazing does (but these rangelands can still be overgrazed) (14, 15, 24). In wetter rangelands, exhibiting equilibrium dynamics, overgrazing of vegetation is more widespread. We now also understand that rangelands often exhibit nonlinear dynamics, where vegetation can shift from one state to another over thresholds or past tipping points, rather than smoothly following a predictable vegetation succession (25). Globally, many rangelands are shifting from grass- to shrub- or tree-dominated ecosystems (2), which we attributed to livestock grazing in the past. Today, there is no universally accepted explanation of those changes (18). In the past, pastoralism was thought to be the root cause of the spread of deserts, especially in Africa (26). But recent evidence suggests that pastoralists sometimes promote greening by planting or conserving trees (27, 28) and that land degradation is not a widespread phenomenon, at least in Africa's Sahel (29).

Conventional wisdom about how pastoralists manage rangelands has changed just as dramatically. In 1776, Adam Smith's *Wealth of Nations* popularized a notion that the natural advancement of livelihoods and land use is from hunter to pastoralist to farmer. We now know that pastoralism evolved from crop agriculture in many parts of the world, rather than vice versa. And it is clear

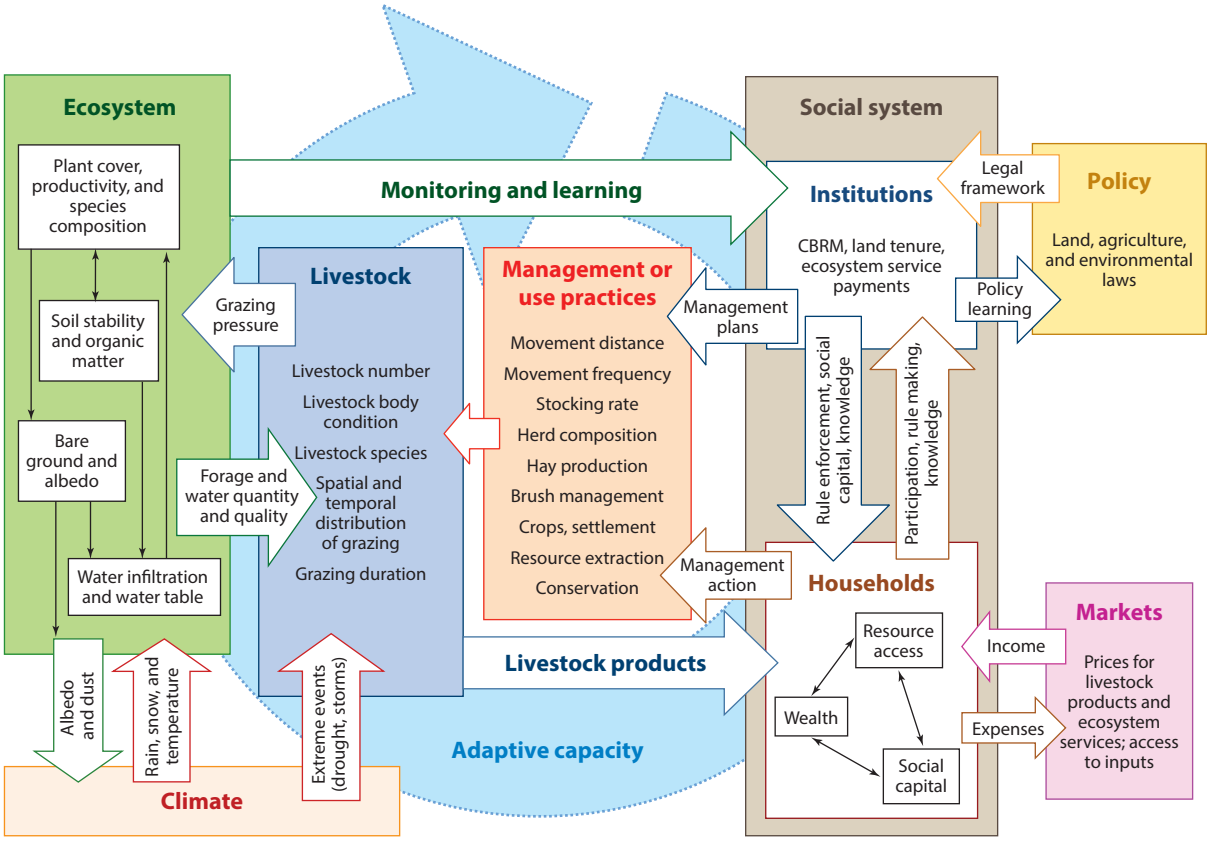

Figure 1

Model of a rangeland social-ecological system (23). Abbreviation: CBRM, community-based rangeland management.

that pastoralism is one of the most efficient ways to turn sunlight into food in marginal lands. Misunderstanding of pastoral risk management led to the idea that it would be irrational for pastoralists to hold large herds (30), whereas today this is understood to be a sound way to manage the risk of livestock loss in the face of recurrent dry seasons, drought, and winter storms. Hardin's "Tragedy of the Commons" (31) promoted the idea that joint grazing of rangelands by multiple herders inevitably leads to overuse because no herder has the incentive to restrain from overgrazing the commons. In our view, this tragedy is misnamed and should be called the tragedy of open access because most pastoral communities have agreed upon rules of use for their commons (32). Further work suggested what might be called a tragedy of enclosure, when common lands become privatized and fragmented by boundaries, such as fencing (10). Settlement of nomadic pastoralists and intensification of livestock production were promoted in the past to exert political control over mobile populations, collect taxes, provide health and education services, and increase productivity. As climate becomes more variable and pastoral movement more important, it is not clear that privatization, settlement, and agricultural intensification are the right approaches to these problems. Comparing livestock weights on commercial ranches and pastoral common lands gave the impression that commercial ranches are more productive. But the opposite is true because high labor inputs and opportunistic grazing over large landscapes gives common land pastoralists the edge in production per unit area over commercial enterprises (34).

Open access: term for when multiple people use a resource with no shared rules for how it is to be used or by whom

Scholars also learn about rangelands differently now than in the past. We once dissected knowledge into discrete disciplines, but we now see the utility of working across disciplines to understand linked social-ecological systems. Once, much of the science on rangelands may have been too reductionist to be useful to managers (35), but today a new use-driven and more holistic science is emerging (36). And scientists are no longer the only recognized source of knowledge about rangelands because of the increasing integration of traditional ecological knowledge (TEK), indigenous knowledge (IK), and local knowledge (LK) with science (35).

Traditional ecological knowledge (TEK): knowledge, practice, and belief transmitted through the generations and through culture "about the relationship of living beings (including humans) with one another and with their environment" (129, p. 7)

Indigenous knowledge (IK): "the local knowledge held by indigenous peoples or local knowledge unique to a given culture or society" (129, p. 9)

Local knowledge (LK): similar to indigenous knowledge, but of more recent nature or not unique to a given culture or society

Commodification: the ability to be bought and sold

CAUSES OF CHANGE IN PASTORAL SOCIETY AND RANGELANDS

Changing Populations, Consumption, Economies, and Climate

The causes of change in rangelands are principally climatic, cultural, technological, social, political, and economic, originating locally, nationally, or globally (9, 37, 38). Underlying these global forces are the double accelerants of increasing human populations and their rising consumption of food, fuel, technology, and other resources. Most of this growth in population and in consumption—even of meat and milk—originates outside rangelands in densely populated urban and agricultural areas, but the consequences have greatest impact on the rangelands and the people who inhabit them. As for livestock products, a growing middle class is now doubling its consumption of meat and milk (between 2002–2030) in the developing world, whereas consumption is only increasing 20% in industrialized countries (39, 40).

People who live in the rangelands also have higher expectations, with increasing demands for schools, health care, media, and communication access (8). Income from livestock can no longer satisfy the growing needs of pastoral families, so many are diversifying their livelihoods by including farming, energy production, wildlife conservation, tourism, and mining, often working off-ranch.

Despite this global growth in population, there is some prospect that rangelands will empty in the years to come. The lack of economic opportunity is progressively emptying pastoral lands as young people move away for jobs in towns and cities (41). In rangelands where climate drying occurs (42), it will become increasingly difficult for the remaining pastoralists to sustain viable enterprises.

The spread of capitalism around the world has driven the commodification of land and livestock. When pastoralists buy and sell land and livestock, they see individual profit as important, which promotes the decline and fragmentation of communal systems of pastoral land use (43). Capitalism often drives changes in pastoral land ownership and use, resulting in decreased pastoral movement and fragmented landscapes, a process under way at different speeds around the world today (43).

Along with the spread of consumption and capitalism, globalization and the demand for food, fuel, and recreation are rapidly extending the reach of global markets and nonpastoral people into rangelands. Rangelands are increasingly attractive for their oil and gas reserves and abundant wind and sun. Foreign governments—led by the United Kingdom, the United States, and China—and corporations lease or buy land (and access to water) principally in Africa and Asia, including rangelands for agricultural crop and industrial biofuel production, initiating a new wave of colonialism (44). Where water is available, flower and food crop greenhouses are linking rangelands to international markets, often at the expense of local land use and water availability (45). The economic drivers of these changes are often stronger than the forces maintaining rangelands and the ecosystem and social services they provide (9).

Currently, climate change is accelerating, and even if greenhouse gas emissions stopped, warming would continue for decades (13). Projections of future climates show strong certainty and global

consistency in the trends for warming and CO_2 enrichment, with less certainty and consistency about changes in precipitation (amount and intensity), frequency of extreme events (drought, floods, winter storms), and other changes (12, 13). In most rangelands, rainfall will become more variable and unpredictable. In some places, rainfall is now decreasing, but in others, there is either no change or an increase. In equatorial rangelands of Africa, for example, warmer temperatures will likely offset much of the advantage of the predicted greater rainfall because, overall, evapotranspiration will increase (42). But African rangelands far from the equator will be universally hotter and drier.

Land tenure: the rights and obligations associated with possession, use, or management of land

Instrumental observations of climate change often match those of pastoralists, who we view as early warning observers of climate change in their lands. Pastoralists in Pakistan have observed heavier winter snowfall and longer and more intense summer droughts over the past 10–15 years; these observations match instrumental records in the region (46). As climate changes, Pakistani herders also observe shifts in vegetative composition and reduced forage yield for their livestock. Pastoralists in Mongolia now see longer and more intense drought and sand storms, as well as delayed and more patchy summer rainfall, which means they have to move farther and more frequently to reach green pastures (47). The instrumental record also largely supports these observations.

Changing Land Use and Land Tenure

Perhaps the greatest immediate force changing rangelands is human land use, driven by people's demand for rangeland ecosystem services. Productive rangelands and those near urban areas and markets are increasingly converted to cropland for food and biofuel, housing developments (48), or towns and villages (8). In the United States, entrepreneurs and wealthy individuals purchase ranches for their open-space amenities, but this subdivision creates fragmented exurban land development (48). In Australia, pastoral ranches provide open land for subdivisions and absorption by growing towns (49).

People see rangelands as open land available for diverse uses and application of new technologies (9). Many rangelands are prime locations for energy development (wind, solar, oil, and gas), mineral extraction, wildlife conservation, and tourism, among other land uses (8, 9, 44). Built infrastructure is globally spreading across rangelands in the form of settlements, roads, railways, energy projects, irrigation, boreholes, quarries, and mines (37). Invention and application of new technologies can accelerate land-use change (37) through the expansion of farming with new drought-resistant crops and better irrigation technology, as well as through expanded energy extraction by horizontal drilling or through new solar technologies.

Land tenure determines who decides how lands are used and managed, and thus how human society impacts those lands. In rangelands, tenure has inordinate importance because much of the land is owned by the state and is still used in common by pastoral families, but this is rapidly changing. Water tenure is also very important, but its description is beyond the scope of this review. Ultimately, changes in land tenure are driven by economic and political changes, such as the shift from socialist to market economies (43) still under way in central Asia. Market economics, by contrast, drives privatization of common rangeland in Africa. Where market economies are long established, tenure is not changing; instead, novel efforts to collaborate across property boundaries are under way.

We see four general types of and trends in land tenure in rangelands around the world: (*a*) maintenance or expansion of state ownership and pastoralist use of rangeland (e.g., US public land; most rangelands in Africa, Asia, and western Australia), (*b*) quasi-privatization of state land or devolution to local control (Asia, Africa), (*c*) privatization of commonly used (often state-owned)

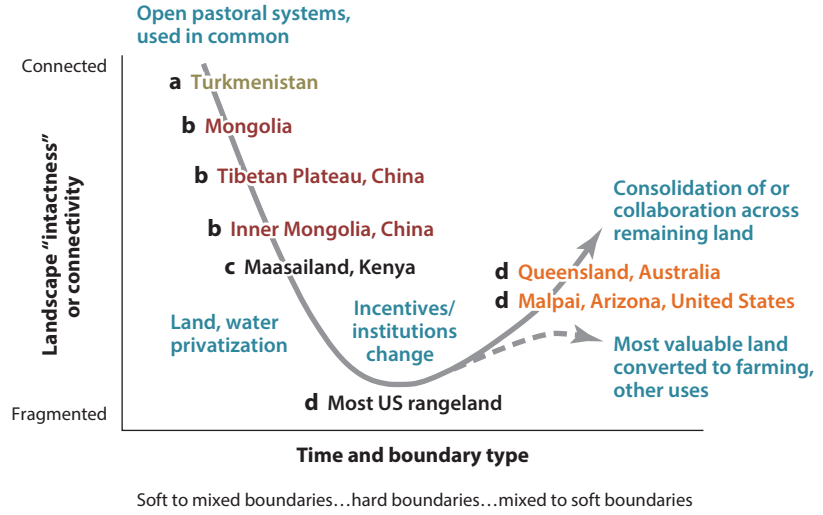

Figure 2

Hypothesized model of landscape fragmentation (intactness, connectivity) in response to changes in the tenure, management, and use of major rangelands in different countries (adapted from References 11 and 43). Boundary type varies from soft to hard to soft as rangelands fragment and re-aggregate over time. The letters associated with locations refer to the four types of tenure change processes: (*a*) maintenance or expansion of state ownership and pastoralist use of rangeland (e.g., Turkmenistan), (*b*) quasi-privatization of state land or devolution to local control (e.g., Tibetan Plateau), (*c*) privatization of commonly used (often state-owned) land (e.g., Maasailand, Kenya), and (*d*) maintenance of private ownership and use with some consolidation or collaborative management of private lands (e.g., Queensland, Australia). Modified with kind permission from Reference 43, © 2008 Springer Science and Business Media.

land (e.g., Africa, Asia), and (*d*) maintenance of private ownership and use with some consolidation or collaborative management of private lands (e.g., Australia, North America) (**Figure 2**).

The most widespread type of tenure is state (or government) land, which is expanding in rangelands in some cases. In the United States and Australia, much state land is leased to grazers, but governments (and sometimes corporations, nonprofits) are reducing the land for grazing to accommodate land protection policies in the United States (22) and are buying back pastoral leases in western Australia (50). In Turkmenistan, state land is not expanding, but the maintenance of collective tenure for pastoralists using state land is slowing fragmentation of the rangeland (43).

In central Asia, Mongolia, and China, quasi-privatization is occurring, where some parts of rangelands are in private exclusive use or long-term leasehold. In Kyrgyzstan, although land is still under state ownership, wealthy herders are establishing de facto private land rights by establishing barns and camps on critical season pastures (51). District-level governments now grant individuals rights to use pastures in Tajikistan (51). In Mongolia, critical winter shelters can now be owned, bought, and sold by individual families; the campsites they stand on are held via long-term leases, and the surrounding grazing lands remain a commons (19). In China, the state assigns long-term use rights to individual households in rangelands like those in Inner Mongolia and Tibet (43). Here, herders build fences to protect their leased rangelands, blocking long-distance movements that are critical for pastoralists to cope with frequent drought and disasters (52).

In other parts of the world, governments are supporting privatization of pastoral land. In Mexico, agropastoralists now have the right to buy, sell, and rent former communally used *ejidos* (53). In some Kenyan rangelands, there has been a decades-long transition from communal to

group ranches to private land, with pastoralists privatizing parcels to secure their right of use (54). Privatization increases land values and often promotes more intensive crop or livestock production, especially near Nairobi's urban areas (45). Land-tenure changes also cause pastoralists to settle, especially around markets, towns, water sources, schools, shops, and health centers (55, 56).

Finally, where private ownership is common, some landholders are consolidating use across property boundaries (11). In Queensland, Australia, pastoralists are consolidating properties through land purchases to increase the scale of their livestock enterprises, which allows them to spread climatic risk (49). In newly private lands in Kenya, pastoralists are using new institutions to unify the fragmented landscape through cooperative arrangements (see below). Samburu pastoralists of northern Kenya privatized some of their lands and kept others communal as a result of local negotiations allowing movement of livestock (57).

Pastoral paradox: pastoralists' twin (and sometimes conflicting) needs for both secure and flexible access to rangeland and its ecosystem services (58)

CONSEQUENCES FOR PASTORAL PEOPLES AND RANGELANDS

Diversification and Intensification

These drivers of change create a diversity of consequences in rangeland households, communities, and landscapes around the world. Many pastoral households, whether on private or common land, are rapidly diversifying their sources of income and intensifying their land use. Many improve their ability to adapt to change and reduce vulnerability by striking a delicate balance between increasing security and maintaining flexibility in their access to their land and water resources, which resolves a classic pastoral paradox (see below) (58). Shifts in pastoral land-use practices are causing diverse changes in rangelands themselves from contraction, loss, and fragmentation to expansion and reaggregation (**Figure 2**). All of these changes are altering rangeland integrity and the amounts and flows of rangeland ecosystem services (59).

At the household level, diversification is widespread (60). In Africa, pastoralists are increasingly becoming farmers, wage laborers, teachers, doctors, and shopkeepers (61). All over the world, pastoralists diversify into conservation uses on their lands, through, for example, public-private partnerships with tourism companies in Africa or by adding hunting and fishing operations on private ranches in the United States. Livestock ranches in the US Rocky Mountains, for example, traditionally owned by families for livestock production, are now being sold to amenity buyers (for recreation, ambiance), conservation organizations, corporations, developers, churches, loggers, and grazing cooperatives (62). In southern Africa, diversification reduces incentives for pastoralists to continue collaborative agreements to manage land together (43).

The growing urban demand for livestock products pushes up livestock prices, encouraging producers to intensify (increase inputs/unit output) and sometimes specialize production. In Kenya, intensification causes changes in livestock herd structure and size, as well as livestock productivity (e.g., 63, 64). Pastoralists in Kenya and Mongolia are shifting livestock breeds to increase profits from meat (small stock, Kenya) and fiber (cashmere, Mongolia) (8, 19). Although profits may rise, new breeds are sometimes less drought resistant, ensuring significant livestock mortality during drought (64, 65). In the United States, demand for local and organic food encourages about 4% of ranchers to shift from finishing cattle in feedlots to finishing cattle on grass, using organic methods, or raising other species like bison, ostriches, and llamas (66).

Loss of productive lands to other uses and privatization of land may make pastoralists more vulnerable and less resilient. Land conversion to exurban development reduces the demand for and viability of supporting services (like veterinary services or nearby markets) for US ranchers (22), making ranching less viable. In dry rangelands, farmers and settlements usually occupy key resources, such as wetlands or riverine edges, pushing herders onto more marginal land. Colonial

authorities established most of the protected areas in east Africa where wildlife congregate in the dry season, effectively excising critical dry-season grazing reserves from use by pastoralists and their livestock (61), making pastoralists more vulnerable to drought.

The Pastoral Paradox, Tenure, and Boundaries in Rangelands

Land privatization creates a paradox for pastoralists (58): They need both flexible and secure access to land to ensure future grazing, but if they settle on that land to secure it, their lack of movement means poorer livestock production (7). Often settlement by one family denies other community members access to common resources and interferes with traditionally coordinated grazing systems, especially in times of scarcity (67). Pastoralists resolve this paradox in different ways around the world. In the United States, ranchers have secure private ownership of land, but many depend on the flexibility of leasing public land allotments for summer grazing (22). Samburu pastoralists split their land into private and communal land as their solution to the paradox (57). China's Inner Mongolian pastoralists appear unable to resolve this paradox because they have little access to flexible tenure or collective institutions, which is particularly important in the drier, nonequilibrium rangelands (52). Elsewhere, many pastoralists are experimenting with community-based institutions to negotiate flexible but secure use of land, and some are taking advantage of market-based institutions (see the next section).

Conversion of rangeland to other land uses causes the contraction and loss of rangelands. Globally, 4,734 mammal species are less endangered in rangelands and wildlands, regardless of human population density, compared to croplands and urban areas (68). This means loss of rangelands is a threat to global biodiversity, with some species more sensitive to rangeland loss than others. In Africa, for example, expanding farms damage species with large home ranges (African wild dogs), slow reproductive rates (elephants), and lower population sizes (black rhinos) (61). However, the opposite occurs for small animals in Ethiopia, where rangelands with scattered farms support more species of plants, birds, and butterflies than rangelands with no farms (61, 69).

In Europe, the contraction of extensive grazing is allowing forest that was cleared historically for farming and grazing to reestablish (70). Here, replacement of pastures by forest creates tradeoffs between loss of grassland ecosystem services and restoration of forest and shrub services, like biodiversity and soil organic matter (70).

Another example of contraction occurs when pastoralists lose former grazing land to conservation areas. Protected areas, if they prevent heavy grazing or expansion of farmland, have a strong role in maintaining rangeland integrity. But in east Africa, some wildlife prefer to graze in the short grass around pastoral settlements, so pastoral lands may have an unexpected role in conservation (61). And there is some evidence that removing pastoralists to create protected areas actually increases wildlife poaching (61, 71).

By contrast, expansion of rangelands can occur either because of conservation policy, climate change, or civil conflict. In the United States, the Conservation Reserve Program encourages farmers to convert farmland into grassland (or forest), which expands land for restricted grazing (72). Under future climate change, farmers may abandon land where significant drying occurs and crop cultivation fails too frequently. In Africa, significant areas of the Sahel and southern Africa will become drier by the 2090s, so that croplands may flip into rangelands because of declining rainfall (73), although abandoned croplands may take years to become healthy rangelands. Civil war or strong intertribal conflict sometimes creates a no-man's-land between warring groups: places empty of people and their livestock (37). This expansion of rangelands should restore the integrity of rangeland soils and biodiversity on formerly cultivated and settled lands.

Changes in land use and tenure cause fragmentation of rangelands (**Figure 2**). Fragmentation is the dissection of land into smaller pieces, either by erecting physical boundaries or by creating social boundaries with strong rules of use (e.g., tenure) (11). Resources most strongly affected by fragmentation are usually shared public goods, relying on ecosystem flows such as water, migration, seed dispersal, fire, and weed spread.

How much these boundaries impact rangeland ecosystems and their services depends largely on whether the health of those services relies on movement or connection beyond boundaries and how much those boundaries slow or sever those important connections (61). In hard boundary landscapes, infrastructure or ownership laws can prevent movement of water, people, livestock, and wildlife. Soft boundary landscapes exist where movement of people and resources is more fluid and unconstrained. In east Africa, for example, hard boundary landscapes currently make up 6% of rangelands, and these may double to 12% coverage by 2050 (61). Soft boundary landscapes represent 62% of landscapes today and may fall to 47% in 2050. The remaining rangelands are mixed boundary landscapes, containing both soft and hard boundaries.

The four types of land-tenure change processes described in **Figure 2** are differing institutional paths to resolving the pastoral paradox, varying in the speed and effectiveness with which they build boundaries and fragment rangeland landscapes. State ownership and control, whether through public lands in the United States or collective pastures in Turkmenistan, effectively stops or slows fragmentation, maintaining soft boundary landscapes. If these joint use pastures have no rules and are therefore open access, a tragedy of the commons can still occur, but true open access is relatively rare in rangelands. Quasi-privatization of land, like the long-term leasehold of summer pastures in central Asia, creates limited social and physical boundaries in soft to mixed boundary landscapes. Privatization of rangeland, as in parts of east Africa, the United States, Australia, and South America, creates mixed to hard boundary landscapes and sometimes a tragedy of enclosure. Conversion of part of the land to farming or settlements, and thus changing land use, creates hard boundaries in rangelands.

Hard boundaries like roads, buildings, and fences slow down or stop herders, livestock, and wildlife from accessing key resources and migration routes (11, 48, 61), making wildlife and livestock vulnerable to drought (65). The wildebeest migration out of Nairobi National Park nearly stopped in 2002, caused by fencing and poaching in their dispersal areas in rangelands around the park (45, 74). In Colorado, subdivided ranches with more buildings, fences, roads, and human presence support fewer native carnivores and ground-nesting birds, more invasive plants, and more domestic cats and dogs than large intact ranches (75).

More subtle effects of fragmentation and land loss can also occur. Restrictions on grazing in pastoral conservancies in the Mara region, Kenya, pushes pastoralists to graze livestock inside nearby protected areas (76). When livestock are restricted to smaller single-family parcels in Gansu, China, grasslands support less biomass and fewer species than larger parcels managed in common by multiple households (52). After colonists privatized and fragmented communal rangeland in Namibia, woody vegetation spread across former grasslands (77).

In a few places, fragmented rangelands are actually reaggregating (**Figure 2**, also see the next section) (11, 43). Ranchers and their neighbors in countries with a long history of private land ownership are starting to reinvent the commons through consolidation or collaborative management. In southwestern Arizona, for example, ranchers still own their ranches but are managing fire and species together across ranch boundaries (78). In Australia, pastoralists lease grazing across paddocks of different ownership in agistment arrangements (49). In rangelands that are just beginning to privatize or with quasi-privatization, some pastoralists are slowing fragmentation by building new community institutions. In Kenya, for example, pastoralists are collaborating across

newly privatized lands by creating institutions that control use, such as conservancies (79) and grazing associations (80). In all cases, this reaggregation should restore the flows and integrity of rangeland services that depend on connectivity in these landscapes.

Rain-use efficiency: the amount of aboveground net plant production per unit rainfall

Beyond fragmentation, most rangelands are greener today than they were 30 years ago (18, 81). One cause may be fertilization by increased concentration of atmospheric CO_2, which improves vegetation production and plant water use. Another explanation may be the spread of shrubs (2). Increased CO_2 favors the growth of plants with C_3 metabolism, such as shrubs, trees, and forbs, over those with C_4 metabolism, which are predominantly grasses. A third possibility, particularly in the African drylands, is that tree planting around settlements is part of this greening (27, 28). Some greening may be rainfall related, but most is not (82). Clearly, processes promoting global greening outweigh those that promote browning, like degradation caused by livestock.

Rangelands are also warming, which often means less soil moisture and plant production. In warm dry rangelands of the United States, for example, warming is already causing drying and desiccation of some rangelands, but in cold rangelands, warming is extending the vegetative growing season (12). Warming may reduce the effects of CO_2 enrichment on plants because warming favors drought-tolerant C_4 plants over C_3 plants (12). In cooler rangelands of Asia, such as the Tibetan Plateau and Mongolia, changes in precipitation patterns are resulting in more frequent and severe winter storms (83, 84).

Degradation and Desertification

Since the early 1990s, land degradation has been defined as the reduction or loss of the biological (vegetation, soils) or economic productivity of the land, whereas desertification is land degradation in drylands (85). More recent scholars, focusing on drylands, suggest broadening the definition of degradation to include reduction or loss of ecosystem services beyond vegetation and soils (38) that could include water, native biodiversity, plants palatable to livestock, carbon sequestration, and other services. Others suggest that what is judged degradation can change depending on one's perspective (86). A pastoralist, for example, might see exclusion of livestock from parks as degradation of grazing land, but a conservationist might consider this aggradation of wildlife habitat.

Also changing are the estimates of the extent of rangeland degradation. From 1700 to 1990, about 17% of global rangelands (savanna/grassland/steppe) were degraded when they were plowed under for cropland (87). In the 1990s, range experts concluded that about 12% of the soils in global drylands (about 65% rangelands) were moderately to extremely degraded (6, 16). Authors of another global assessment (88), although admitting their estimates were based on poor data, suggested that a full 73% of the vegetation in global dry rangelands were degraded (or desertified), ranging from 55% of rangelands in Australia to 85% in North America.

Recent assessments suggest a more moderate picture of degradation. Global losses of vegetative production because of soil degradation in drylands may be as little as 5% (89). Globally, the maximum annual leaf area index in drylands increased over the past 30 years, suggesting better pasture productivity (81). In the Sahel of west Africa, rain-use efficiency of dryland vegetation increased from 1982 to 2010, showing no sustained degradation caused by livestock (29). Only about 1.3% of US rangelands show declines in biotic integrity, hydrologic function, and soil stability, but nonnative plants are widespread (90). Although nationwide assessments suggest degradation is widespread in China (91), principally caused by cultivating rangelands, the magnitude of degradation in Tibet remains unknown because monitoring programs are subjective and poorly documented (92).

This is not to suggest that degradation, caused by livestock, cannot occur. It is difficult to measure degradation well (38, 92), and thus it is rarely done. It is important to have indicators

that measure fundamental changes in pastoral systems, such as grass basal area, soil water–holding capacity, and household income (38). Also important is a strong experimental design that separates out the effects of grazing and climate (such as adjacent fenced and unfenced plots) (92). In Mexico, clearing forests for grazing had obvious effects, reducing soil carbon by 75% and soil depth and perennial basal plant cover by 60% (53). In Senegal, the effects were more subtle: It took 27 years of remeasuring fenced and unfenced plots to show that grazing caused significant declines in rain-use efficiency (93). And the effects of livestock only became apparent when climate became less variable, mimicking equilibrium system dynamics.

CBRM: community-based rangeland management

And if livestock-caused degradation occurs, is it permanent or easily recovered? If livestock use causes a shift from one vegetation state to another, such as grassland to shrubland, and that new state is strongly self-reinforcing, this change can be largely irreversible without long time periods and heavy capital investments. Some grazing appears to have little effect on vegetation, especially in the driest rangelands far from continual heavy grazing, as was recently shown in arid Australia (94). By contrast, wetter, semiarid rangeland in Australia took a half century to recover from sheep grazing, but there were no predictable recovery trajectories, even for nearby plots (95). It is important to note that rangelands can change often and significantly in response to rainfall alone, emphasizing the critical role of well-designed studies of the causes of degradation (96).

DEVELOPING RESILIENCE IN RANGELAND SOCIAL-ECOLOGICAL SYSTEMS

In this section, we suggest that recent innovations in institutions are critical to developing social, economic, and ecological resilience in rangeland social-ecological systems in the face of recent rapid change (97, 98). These innovations include refinement of community-based institutions and experimentation with market-based institutions, as well as better integration of indigenous and scientific knowledge and reorientation of science to support pastoral needs.

Collaborative Governance and Community-Based Rangeland Management

From forests to fisheries, participatory, community-based, collaborative, and decentralized democratic forms of environmental governance have become ubiquitous over the past several decades. Rangelands are no exception to this trend, as seen in efforts as diverse as community-based programs to protect wildlife and support livelihoods in Zimbabwe and networks of Australian landowners who joined forces to repair damaged watersheds as part of the Landcare movement. Different types of community-based rangeland management (CBRM) institutions exist on state-owned land, such as public land grazing allotments in the United States (99), communally held lands in the developing world (19, 100), and private property in North America (101) and Australia (102). CBRM can lead to improved social, environmental, and livelihood outcomes. Local institutions that foster deliberative decision making, knowledge exchange, network development, and cooperation may help pastoralists to adapt to both gradual change and sudden disasters (103). By promoting local people's involvement in resource monitoring and management, CBRM promises to help rangeland communities detect and respond to changes, reducing the chance of overuse and increasing the possibility of changing management in time to avoid harm to ecosystems and the benefits they provide (19).

After several decades of implementation, critiques of community-based and collaborative environmental governance are widespread. Conceptual challenges include, for example, understanding and defining the word "community." Community is at the heart of CBRM, yet what it refers to is not always clear (104)—geographic proximity or shared norms, interests, or identity? In many rangeland settings, there is no clearly defined user group or community, and belonging to a user

group may depend on the context. A pastoralist may be considered a member of the group with certain rights for some purposes, but not a member in other situations (58, 105). Many pastoral land management systems are based on culturally embedded norms, not on explicitly stated rules. These norms are flexible and context dependent, and the norms are constantly being negotiated and reworked. As such, pastoral institutions often do not conform to the predictions of commons theory, which holds that successful commons management institutions have clearly defined group membership and resource boundaries (58, 105).

Social capital: connections among people that help society function; they include social networks and norms of reciprocity and trust, and can produce equality or inequality

Design and implementation of collaborative and community-based institutions are also challenging, partly because democratic decentralization is seldom achieved in its ideal form (106). Likewise, many initiatives fail to overcome preexisting power dynamics within or between communities, resulting in unequal access to participation in CBRM or in an unequal distribution of benefits. Elite capture can occur when more powerful social groups or individuals take control of community institutions and direct the benefits in their own self-interest (107, 108). However, initially marginalized community members may resist and eventually gain representation (109). In African community-based wildlife groups, members received some economic benefits but not the promised community development benefits (110, 111). Collaboration does not always increase social capital and sometimes decreases trust (112). In northwestern Kenya, institution building to deal with increasing conflict over rangeland resources is proving illusive (113, 114). This is, in part, because of the lack of multistakeholder participation in decision making critical to land-use planning and dispute resolution (115).

Institutional barriers include a lack of enabling legislation that gives communities the right to self-organize and secure exclusive rights to resources (116). Legal pluralism, or the coexistence of multiple formal and customary institutions, challenges the effective functions of community-based management, especially in Africa (117). In the US and Australian contexts, changing government policies and the organizational cultures of government land management agencies create obstacles to success (118, 119). Externally facilitated CBRM projects are criticized for top-down implementation and cookie-cutter designs that fail to appreciate local context and social dynamics (105), and these projects falter when external financial and technical support is withdrawn (107).

Finally, in rangeland systems, low productivity and environmental variability combined with mobile land-use strategies and contingent definitions of community make community-based institutions especially difficult to implement and sustain. In these systems, customary management often depends on dispersed and overlapping social networks over large landscapes, rather than closely knit communities associated with small and clearly bounded territories. In such systems, there is a clear need for interlinked governance institutions at different levels of social organization (local community, multiple adjacent communities, region, and nation) and corresponding geographic scales (e.g., valley, watershed, basin, ecoregion). Community-based management alone is insufficient to coordinate resource monitoring, pastoral movements, and land use across jurisdictional boundaries and at distinct geographic scales (83, 105). Formal government institutions are needed, working together with pastoralists at each level of organization.

Despite these challenges, CBRM has registered measurable successes in improving environmental conditions, livelihoods, and social relationships. Communal conservancies in Botswana's Okavango Delta (100) have decreased illegal hunting and led to recovery of some species. Burn cooperatives in the central plains of the United States have successfully used prescribed fire to restore desired ecosystem structures and functions (101). Areas managed by community-based groups in Mongolia's Gobi Desert saw significant improvements in plant production and cover (120). The Malpai Borderlands Group in Arizona and New Mexico, United States, has prevented subdivision of private lands using conservation easements, has restored fire as an ecological process, and has protected sensitive wildlife species (78).

Livelihood benefits are most clearly seen where CBRM participants receive direct benefits from high-value resources, such as wildlife tourism (110), but modest livelihood improvements and poverty reduction can also occur without tourism and hunting revenues (116, 120). Community-wide improvements are slower to emerge (110, 111), as are changes in livelihoods of pastoralists in areas without high-value resources, and improvements depend on the feedback between improved forage condition and livestock productivity or on improved and value-added marketing of existing products (121).

Many social benefits of CBRM are less tangible and more difficult to measure, such as improved access to information, knowledge exchange, learning, trust building, and stronger and wider social networks. However, these soft outcomes may also be more readily achieved, though sometimes difficult to sustain, and may support the achievement of other more tangible outcomes. Social outcomes are often undervalued in favor of plans or restoration projects, or measurable environmental or economic outcomes (121, 122). Although evidence-based policy making is needed for CBRM, undervaluing changes in attitudes, knowledge, and social capital may cause policy makers and funders to overlook the important contributions of community-based institutions to adaptive capacity (see **Figure 1**), which depends critically on knowledge exchange, learning, and social networks (123). Indeed, some of the recent CBRM successes relate directly to the development and application of these capacities in the context of collaborative adaptive management of western rangelands (99), Landcare in Australia (124), disaster preparation and response in Mongolia (83), and water point management in Kenyan rangelands (103).

We close this section by highlighting three emerging contradictions, which point to the ongoing challenges of CBRM design, implementation, and evaluation. First, CBRM must be responsive to local social and ecological conditions, yet the adoption of CBRM as the new paradigm for pastoral development and rangeland conservation demands that the approach be scaled out and replicated across social-ecological landscapes. Second, pastoral institutions and their membership are often inherently flexible, subject to negotiation and contingent on context, and thus are not easily formalized. Yet securing access and management rights to pastoral resources, and ensuring equitable participation in decision making and benefit sharing may require formalizing previously malleable, norm-based systems. Finally, although CBRM is inherently local, pastoral systems in arid rangelands are spatially extensive, and their sustainable use often depends on herd mobility and dispersed social networks. Local institutions alone are insufficient to coordinate such movements and to monitor and respond to the aggregate environmental impacts of many mobile groups across large landscapes. Thus, CBRM, even at its most successful, is insufficient to address the institutional challenges of managing pastoral land use, so multiscale transboundary governance institutions are required.

The shimmer has worn off, but CBRM remains one of the most promising alternatives for achieving socially just, economically viable, and environmentally sustainable management of rangelands and the biodiversity they support (106, 107). As with many institutional innovations, the expectations for what CBRM could deliver were set too high, and the challenges of meeting them were underestimated. We share the hope that scientists, practitioners, and policy makers can together learn to improve the potential for next-generation CBRM institutions to achieve the elusive triple bottom line.

Market-Based Payment Schemes

Another institutional innovation is a market mechanism that explicitly connects the people who benefit from rangeland environmental services, such as clean water or wildlife habitat, with the pastoralists who produce those services. Many rangeland services, beyond agricultural products and

tourism, are treated as free goods without monetary value. When rangeland ecosystem services are undervalued (and nonrangeland services overvalued), people have the incentive to convert rangelands to higher value uses, such as cropping or settlement. To recognize the invisible values of rangelands, these services first need to be identified and measured, then valued in a common way (often economically), and finally used in decisions about how to improve the use of rangeland ecosystems (125). Creating this new value, through payments for ecosystem services or other methods (125), first began in forested systems but is now spreading to rangelands (126).

Payments for ecosystem service schemes aim to provide economic returns to pastoralists (the sellers) in exchange for improved environmental returns on investment for service users (the buyers). This occurs, for example, when pastoralists provide cleaner source drinking water by moving livestock corrals from streamsides, allowing municipal water utilities to reduce their investment in water treatment infrastructure. Increased profits can encourage pastoralists to stay on the land, which sometimes reduces their incentive to sell land for subdivision and development. Or improved profits may also attract young ranchers to continue ranching, strengthening the ranks of next-generation ranchers.

A whole suite of incentives is now being tried in rangelands, such as schemes for ecosystem or biodiversity payments, improved stewardship payments, conservation-friendly livestock products, and public-private conservation investment partnerships. In Kitengela, Kenya, for example, local landowners receive payments to keep the land open so that livestock and wildlife can continue to move freely, and these payments double the incomes of the poorest households in the dry season (64). In the United States, a wide range of government payments for improved rangeland stewardship exists, including prescribed grazing, prescribed burning, brush management, wildlife habitat management, and weed control (72). Efforts to market environmentally friendly livestock products (like conservation beef) are growing but are challenging to monitor (127). Public-private partnerships, like some in Africa, pay pastoral landowners to preserve wildlife habitat for tourism through development of joint business ventures between pastoralists and private safari enterprises (79). In our view, the best schemes not only provide positive monetary incentives but also aim to build the resilience of local communities through collaborative action and devolution of power.

Market-based schemes in rangelands share the same challenges as those elsewhere but also have unique features. All market-based initiatives share the difficulties of clearly linking improvements in stewardship with improvements in ecosystem services, valuing services in monetary and nonmonetary ways, monitoring changes in a transparent and frequent manner, and evaluating who does and does not benefit from payments (125, 126). On a Hawaiian forested ranch, for example, participants in a payment scheme used monetary gain but also cultural access to traditional plants and education access as key measures of success (125). But in drier rangelands, pastoralists using common land often move, making it difficult to link stewards, their practices, and provision of improved ecosystem services (126). In this case, leakage is a problem, where improved stewardship in one place may increase use on other lands, causing a loss of ecosystem services elsewhere. These challenges make monitoring and verification, already expensive and time-consuming, both more important and more difficult.

Ways of Knowing and Knowledge Integration

Cultural memory and innovation are both needed to adapt to change (128), and this insight has spawned growing interest in documenting TEK, IK, and LK (129) and in integrating experiential knowledge and science. TEK, IK, and LK are particular to specific people and places; are grounded in direct experience and observation of social-ecological systems; and are dynamic, evolving, and socially transmitted. TEK and IK develop over many generations, are socially and culturally

embedded, and are intergenerationally transmitted. Here we use TEK to encompass all these ways of knowing, which include not only information about the natural world but also the technologies, skills, and practices through which knowledge is applied and the values and institutions in which it is embedded (129).

Pastoralist TEK is important because rangelands cover extensive areas of Earth's surface that are difficult or impossible to scientifically monitor at the spatial and temporal scales relevant to management. TEK provides insights into the ecological dynamics of these systems (130, 131) and observations of changes over time and space (132), as well as traditional systems of management adapted to the inherent variability of these systems (133). Recent studies of pastoralist TEK have also documented herder observations of climate change (46, 47) and knowledge of conservation of plant populations (134) and fire management (132, 135). TEK has been used to identify monitoring objectives and indicators, and pastoralists have been trained to carry out formal rangeland monitoring (131, 136, 137).

Despite advances in the stature of TEK and its recognized value, challenges remain. These include rapid loss of TEK (134, 135), top-down or misguided conservation policy (132, 134–136), monitoring methods driven by Western science in isolation from other knowledge sources (131, 137, 138), and failure to apply TEK to development (138).

Socioeconomic, demographic, and cultural changes contribute to loss of pastoralist TEK (132), as do government policies that prevent its active use, development, and transmission by forcing mobile herders to settle (133), removing pastoralists from protected areas (134), or prohibiting traditional management practices, such as burning (132, 135). Controversy lingers over appropriate use of TEK and over the power imbalances between TEK and science, calling into question whether different types of knowledge should be compared or combined (139). Others contend that TEK scholarship overemphasizes knowledge content at the expense of understanding the process and context of knowledge creation and use (138).

Integrating TEK with science has obvious value. Despite power imbalances and occasionally conflicting knowledge claims, TEK and science are largely complementary (137). Furthermore, when local people help identify locally salient indicators and carry out assessments, monitoring is more likely to lead to prompt action (140). Although initial lessons for knowledge exchange, integration, and management have been harvested (139, 141), additional research is needed to inform best practices for knowledge integration and application (142). CBRM institutions can play an important role in facilitating knowledge coproduction, integration, and application. However, community-level participatory monitoring alone cannot detect the cumulative impacts of local changes at a regional scale. Thus, there remains a need for multiscale monitoring coupled with multilevel rangeland governance institutions. Finally, TEK can be maintained only through active use and communication (132, 141). This requires greater resource access and management autonomy for pastoralists, as well as rethinking policies that exclude herders from protected areas, force them to settle, or limit traditional management practices that maintain biodiversity.

Innovations by Scientists, Linking Knowledge with Action

In addition to efforts to integrate indigenous and scientific knowledge, scientists have made progress in making their science more relevant to pastoral practice and management. Science that starts, continues, and ends with the linked needs of pastoralists and rangelands will be more relevant, legitimate, and credible to diverse stakeholders (36). This varies from citizen science approaches, where the public participates in data collection, to coresearch partnerships, where diverse stakeholders are part of the entire science process from question generation to data interpretation. Like TEK, coproduced knowledge derived when diverse stakeholders work collaboratively leads

to action that is much more likely to be useful and used (140). In Kenya, for example, pastoral community facilitators were boundary spanners among communities, policy makers, and scientists, coproducing science that directly addressed the joint needs of pastoralism and wildlife conservation (143). Such arrangements have been called translational science partnerships, which have significant challenges—including competing interests slowing development of trust, integrating scientific and experiential knowledge, and the need for truly transdisciplinary science (144). When these challenges are overcome, they promote social learning through experimentation by diverse stakeholders, which builds the capacity of people to adapt to change and strengthens the resilience of these linked social-ecological systems (145). Collaborative adaptive management, whereby diverse stakeholders both learn and experiment through management together, is also a growing approach to linking science and action (99).

USDA Natural Resources Conservation Service: US federal agency that works with private landowners on resource management

Another insight is the need for new science that integrates the past focus on developing generalizations for wide application based on experimentation conducted at a limited scale with science conducted at a management scale (whole properties or watersheds, for example) (35, 146). The Conservation Effects Assessment Project of the USDA Natural Resources Conservation Service, for example, is an effort to understand how well policy-initiated conservation practices on farmland deliver environmental benefits (72). This larger-scale science needs to link the historical, social, and ecological information directly and have longer timescales (35, 144).

RESPONDING TO FUTURE CHANGE

We can see how pastoral peoples, and their supporters, are building the foundation to respond to these changes today by building new collaborative, place-based institutions (rules, organizations) that tackle rangeland people's issues at an appropriate management scale, such as the landscape or watershed. Often these efforts include community- or market-based institutions to connect urban users of rangeland ecosystem services to the pastoralist stewards of those services. New institutions often include landowners, land users, government agencies, nonprofits, and the private sector. Many use new ways of coproducing and cointerpreting traditional and scientific knowledge about these places at a scale appropriate for management.

All of these approaches have weaknesses that need to be addressed as we move forward. Market-based approaches need to address the trade-offs in managing different ecosystem services, such as forage production, water quality, and wildlife habitat (35), partly because improvements in one service may cause a decline in another. To better understand the dynamics and effects of management, we need better linked social and ecological models, coproduced with different knowledge sources, to create different scenarios about future conditions in response to alternative management and policy decisions, accessible to all stakeholders to support faster social learning (147). We have to use all our sources of knowledge, from experiential knowledge to mathematical modeling, to develop ways to forecast bad and rapid changes (148) and avoid or escape unsustainable social-ecological traps (145) in the future.

SUMMARY POINTS

1. Rangelands are at a crossroads: Although traditionally defined as lands for grazing wildlife and livestock, some scholars are expanding the way they define this term to include the diverse ways people use rangelands and the varied ecosystem services they provide.

2. Rangelands are now thought of as linked social-ecological systems, each with a unique ecological, historical, political, and cultural context, where the social system and ecosystem adapt to each other, and the resilience of this coupled system depends, in part, on this capacity to change.
3. Most global rangelands are still used (and sometimes owned) in common, even in countries with widespread private rangeland, and this communal use can be and often is sustainable, provided that strong local institutions that govern use are in place.
4. Herders around the world solve the pastoral paradox (need for both secure but flexible access to land) with institutions that regulate common, quasi-private, and private ownership or use to avoid both the tragedy of open access (misnamed the tragedy of the commons) where there are no rules of use and the tragedy of enclosure on privatized and fragmented land.
5. Growth of populations and consumption, the spread of markets, the commodification of nature, globalization, and climate changes are all accelerating the transformation of land use and land tenure in rangelands around the world, causing loss, expansion, fragmentation, and reaggregation of rangelands as pastoralists solve the pastoral paradox in different ways.
6. Rangeland degradation is not as widespread as previously thought, but it does occur, particularly in wetter rangelands. Only more long-term and broad-scale coresearch, integrating experiential and scientific knowledge, will allow us to clearly distinguish the effects of grazing, climate, and land use, as well as when and where degradation is fleeting or permanent.
7. Recent learning and experimentation with both community- and market-based institutions are moving us closer to achieving socially just, economically viable, and environmentally sustainable management of rangelands and the biodiversity they support.
8. Challenges remain, particularly how to ensure that new institutions share benefits equitably, how to manage and monitor spatially extensive systems that often require herd mobility across scales, and how to determine the environmental returns of investing in conservation stewardship practices.

FUTURE ISSUES

1. As the future brings changes in climate, landownership, new uses (mining, energy), and ranching populations, who are the winners and losers? This applies to pastoral peoples and also to nonhuman species in rangelands.
2. What is driving rangeland degradation—livestock, climate change, or other land use(s)? Where and when do these causes of change operate most strongly and why?
3. What will rangelands look like in the future? Will they replace drying cropland, be full of windmills, be empty of people, or be in some other configuration/combination? How can our current rangeland knowledge be applied to new land uses?
4. What are the best ways to reaggregate fragmented lands and in which situations?

5. How do local and nested multilevel resource management institutions influence the adaptive capacity of rangeland social-ecological systems? How do we scale out community-based management in extensive and mobile herding systems that require flexible, norm-based management institutions that go beyond the principles of common pool resource governance theory?
6. What are the most effective ways to integrate local and scientific knowledge to support good collaborative decisions and create strong institutions?
7. What innovations and institutions best support the resilience and sustainability of rangelands and pastoral peoples in an equitable way?
8. Do we need a new kind of science to answer these questions in a useful way?

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