Transforming ruminant livestock systems for nature, human wellbeing, and climate: Diverse systems require nuanced solutions

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Abstract

Ruminant livestock production is among the most controversial land uses and sectors of our global food system today. It also may be the most consequential, impacting half the land on earth, supporting over one billion people directly, and contributing significant greenhouse gas emissions. This sector must be part of food systems transformation to support nature, tackle climate change, and improve human wellbeing. However, the environmental, economic, and social context and outcomes from these systems varies enormously. Silver bullet solutions or misapplication of scientific findings can lead to trade-offs and inefficiencies. We developed case studies from a range of biomes, production system types, socio-political and economic contexts around the world. We then did a comparative qualitative analysis to identify patterns in contextual factors that enable or create barriers to implementation of a range of management practices, and can be used to inform policy or other interventions. In this paper, we describe the contextual factors that influence uptake of different practices in three rangeland-based case studies which we chose to exemplify the three major production system types, and a cross-section of climatic and socio-economic settings – Eastern Africa, the Tibetan Plateau of China, and the Great Plains of the United States. We highlight that research and resulting policy to improve climate, biodiversity, and human wellbeing outcomes must be better tailored to the unique, often-changing local conditions than they have been in the past.

Introduction

Grazing lands make up over a quarter of ice-free land (FAO 2023) and can provide wildlife habitat, soil carbon stocks, livelihoods and cultural value in addition to livestock production (Sala et al. 2017). Globally, livestock production systems based in grazing lands exist across diverse ecological, economic, social and cultural contexts, (Rivera-Ferre et al. 2016) and outcomes (Poore and Nemecek 2018). To meet calls for greater environmental sustainability in livestock production, there is a need to understand how context – both historical and current – informs potential practice change and related outcomes. Here, we used a case-study approach to identify patterns in: 1) the key contextual factors that influence systems; 2) use of different management practices; and 3) enabling conditions and barriers for change towards improved sustainability. Our aim is to highlight how context can inform effective policy and investments to encourage sustainable livestock practices that maximize benefits and reduce harms for people, climate, and nature.

Methods

We conducted a qualitative, comparative thematic analysis of case studies from diverse livestock production systems and agroecological regions around the world (Kazanski et al. *in review*). Case studies were developed based on region-specific knowledge and experience, published literature, and input from local and regional practitioners or experts in livestock production. The case studies and the comparative analysis enabled us to explore the relative weights of the impacts of contextual factors on current practices and potential to change. Here we focus on rangeland cases from Eastern Africa, the Tibetan Plateau in China, and the cow-calf phase of cattle production in the Great Plains of the United States, which provide a cross-section of common economic/market and ecosystem contexts (Kazanski et al. *in review*). We also focus on the practice categories of agroforestry, animal management, technology and information within these case studies.

Results

Numerous environmental, economic, social and cultural characteristics shape livestock production systems (Kazanski et al. *in review*). The rangeland-based cases explored here highlight the diversity of production systems when all these elements are taken into consideration (Table 1). The case studies are predominantly based in semi-arid to arid rangelands where precipitation is the primary constraint on forage production. In Eastern African systems, livestock and wildlife coexist, introducing conflict and considerations on forage use. In the Great Plains, ranching with sound management can support wildlife by maintaining intactness of grazing lands that could otherwise be converted to crop production or developments that could reduce habitat (Cameron et al. 2014). Management and land tenure also varies: in Eastern Africa, communal grazing is predominant; in the Tibetan Plateau land was historically communally managed but has shifted to more individualized allotments; and in the Great Plains land is individually managed. In both the Eastern African and Tibetan Plateau pastoralist systems, livestock are a primary source of livelihoods (Lind et al. 2020), although tourism is an increasing source in the Tibetan Plateau (Gongbuzeren et al. 2024). Livestock also predominantly support hyper-local markets. In contrast, in the Great Plains, while ranching is core to many livelihoods, ranching families increasingly have additional jobs to diversify incomes (Wulfhorst et al. 2022) and production is linked with intensive row crop farming in service of commercial, national and global markets.

The case studies highlight that livestock production "best" practices depend on context and should not be universally applied. For example, in settings with a history of some tree canopy (e.g. in some systems across Eastern Africa), agroforestry offers benefits like improved feed and nutrition and adaptation to climate change (Balehegn et al. 2015; Balehegn et al. 2017). However, in systems that did not evolve with trees (e.g. the Great Plains or Tibetan Plateau), agroforestry practices could jeopardize biodiversity and ecosystem services (Veldman et al 2015) or fail due to soil and rainfall constraints (Briske et al. 2024). We find that even categories of practices that are generally beneficial tend to have important specific considerations depending on context (e.g. technology and information services and animal management). For example, technical services are identified as a

gap/opportunity in both the Tibetan Plateau and Great Plains cases. Yet, agricultural "innovations" might look different across contexts. While ag-tech and innovation is often about robotics, precision agriculture, or new varieties, well established or traditional practices with multiple benefits may be a missed opportunity that could be bridged, e.g., through use of mobile phones with chat or video features for veterinary telehealth. Similarly, while animal management is broadly applicable, the specific goals of genetic selection and breeding, for example, can differ by context. In some cases, breeding aims for larger and faster growing animals (e.g. the commercial systems in the Great Plains). However, these breeds tend to require high nutrition, which may be limiting in low-input extensive rangeland systems. In contrast, animals with smaller mature size can be better adapted to harsh conditions (e.g., poor nutrition, extreme temperatures), and could be increasingly valued across systems as the impacts of climate change intensify. Taking context into consideration when identifying practices or system change to support sustainability is therefore critical.

We also find that the primary barriers and enabling conditions for practice implementation strongly differ by contexts (Table 1). In the analysis, economic and market settings emerged as primary drivers of change: in the Great Plains case study (an example of commercial production in a high-income country), consumer and market demands, regulatory enhancement, investment in technology research and development, and safe-to-fail trials are promising enablers for change. In contrast, in Eastern Africa and the Tibetan Plateau (multipurpose systems in low- and middle-income countries), capacity building and investment in technical assistance, culturally appropriate training on herd management, and climate investments for inputs or technology are more likely to facilitate change. We find the ability to change practices or systems is also often constrained by environmental factors, like precipitation, which is becoming increasingly variable (Sloat et al 2018). Cultural tradition and history also appeared to ossify behaviors, greatly informing future practices and systems, and what change might be possible.

Table 1. Livestock production system case study summaries. Case study details were compiled by regional experts based on the literature and additional expert input as described in a prior study (Kazanski et al. *in review*).

	Eastern Africa	Tibetan Plateau of China	Great Plains of the U.S.
Dominant production systems	**Pastoralism.** Mobile pastoral systems of diversified herds (cattle, sheep, goats). Livestock are multipurpose, providing meat, milk, and blood[1]. Many people and their livestock are located far from urban market centers.	**Pastoralism**. Yak and sheep graze high-altitude pastures for the provision of food, fuel (manure) and socio-cultural purposes. There is a history of communal land and animal management, but this is changing[9].	**Ranching**. Mostly cattle grazed in arid rangelands during cow-calf phase, then fattened/finished on grain. The system is entirely integrated into the global economy with some local and regional market opportunities.
Dominant ecosystem	Tropical and subtropical grasslands, savannas and shrublands	Montane grasslands and shrublands	Temperate grasslands, savannas and shrublands
Environmental context	Degradation of grazing lands, characterised by soil erosion, encroachment of woody	Fragile alpine soils	Climate change impacts threaten economic viability of this system[12, 13].

	species, loss of biodiversity[2].	Increased stocking rates have negative impacts on vegetation and soils[10].	
Economic context	Livestock production is core to community livelihoods[3].	Livestock products are sold into domestic markets; tourism presents opportunities to diversify livelihoods[11.]	Global market integration; beef is sold into both domestic and export markets, especially Asia[14]. Profit margins are tight.
Social and cultural context	Deep cultural value of livestock[4, 5]; pastoralism has a 10,000+ year-history in the region[6].	Deep cultural history and tradition	Rural community livelihoods Ranching and cowboy culture are culturally significant
Barriers	Difficult for vulnerable communities and households to take risks on new practices[7].	Little opportunity to improve or diversify production within this ecosystem.	Consumers driven by price Capital improvements are unaffordable
Enabling conditions	Commitment to adapting livestock systems to keep them central to livelihoods[8]	Livestock production and tourism are being explored for further integration and diversified marketing strategies. Government policy is encouraging community-level grazing land management and reaggregation of livestock.	Tax breaks, insurance and subsidies can facilitate practice change

[1]Lind et al., 2020; [2]Gil-Romera et al., 2010; [3]Lind et al. 2020; [4]Dabasso et al. 2022; [5]Galaty 2021; [6]Learn, 2018; [7]Boruru et al., 2011; [8]Mahdavi et al., 2023; [9]Gongbuzeren et al., 2016; [10]Zhuang et al., 2019; [11]Gongbuzeren et al., 2024; [12]Klemm et al., 2020; [13]Briske et al., 2021; [14]USDA, 2024

Discussion

The three case studies highlight how context informs current and potential production systems and practices. Economic and market setting, the role of livestock in culture and livelihoods, and ecological setting all interact to inform what might be considered best practices. We also see that environmental constraints, history, and cultural tradition inform what future practices or systems might be possible. It is clear that environmental, economic, and social and cultural elements are key to understanding production systems and opportunities for change. The inclusion of additional perspectives could shift the picture of these systems.

The observation that context is important is not new, but worth emphasizing, particularly to inform policy and investment. In global fora and multilateral policy efforts, there is increasing attention on livestock systems and rangelands (e.g. at recent climate COPs; the upcoming International Year of Rangelands, 2026; and FAO's recent Global Conference on Sustainable Livestock Transformation, 2023). For an equitable and just food system transformation, decision makers must incorporate understanding of context into policy and investment approaches.

Doing this, while considering multiple outcomes from livestock systems for people, climate, and nature, will be critical to crafting policies that maximize benefits and reduce harms (Harrison et al. 2021).

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References

Balehegn M, Eik LO, Tesfay Y (2015) Silvopastoral system based on Ficus thonningii: An adaptation to climate change in northern Ethiopia. African Journal of Range & Forage Science, 32(3), 183–191.

Balehegn M (2017) Silvopasture using indigenous fodder trees and shrubs: The underexploited synergy between climate change adaptation and mitigation in the livestock sector. Climate Change Adaptation in Africa: Fostering Resilience and Capacity to Adapt, 493–510.

Boruru EO, Ontita E, Ogara WO, Oguge NO (2011) Climate Change and the Emergence of Helter-Skelter Livelihoods Among the Pastoralists of Samburu East District, Kenya. In: Leal Filho, W. (eds) Experiences of Climate Change Adaptation in Africa. Climate Change Management. Springer, Berlin, Heidelberg.

Briske DD, Vetter S, Coetsee C, Turner MD (2024) Rangeland afforestation is not a natural climate solution. Frontiers in Ecology and the Environment.

Cameron DR, Marty J, Holland RF (2014) Whither the Rangeland?: Protection and Conversion in California's Rangeland Ecosystems. PLOS ONE, 9(8), e103468.

FAO (2023) Global Conference on Sustainable Livestock Transformation; September 25-27, 2023: https://www.wfo-oma.org/calendar-news/fao-global-conference-on-sustainable-livestock-transformation/

FAO (2023) "Total meat production – FAO" [dataset]. Food and Agriculture Organization of the United Nations, "Production: Crops and livestock products" [original data].

Gil-Romera G, Lamb HF, Turton D, et al (2010) Long-term resilience, bush encroachment patterns and local knowledge in a Northeast African savanna, Global Environmental Change, 20(4): 612-626.

Gongbuzeren, Zhuang M, Li W (2016) Market-based grazing land transfers and customary institutions in the management of rangelands: Two case studies on the Qinghai-Tibetan Plateau. Land Use Policy, 57:287-295.

Gongbuzeren, Lu J, Kerven C, Rang G (2024) Exploring the role of nested institutions in community-based tourism development: Two case studies from China's Tibetan pastoral region. Journal of Sustainable Tourism, 32(4), 677–694.

Harrison MT, Cullen BR, Mayberry DE, et al (2021) Carbon myopia: The urgent need for integrated social, economic and environmental action in the livestock sector. Global Change Biology, 27(22), 5726–5761.

Klemm T, Briske DD, Reeves MC (2020) Vulnerability of rangeland beef cattle production to climate-induced NPP fluctuations in the US Great Plains. Global Change Biology, 26: 4841-4853.

Learn JR (2018) Ritual cemeteries – for cows and then humans – plot pastoralist expansion across Africa. Smithsonian Magazine. Available at: https://www.smithsonianmag.com/science-nature/ritual-cemeteries-cows-humans-pastoralist-expansion-across-africa-180970683/ (Accessed 01 11 2024).

Lind J, Sabates-Wheeler R, Caravani M, et al (2020) Newly evolving pastoral and post-pastoral rangelands of Eastern Africa. Pastoralism 10, 24 (2020).

Mahdavi S, Shahraki M, Sharafatmandrad M (2023) The mechanism of knowledge-based behavior of pastoralists for rangeland management: exploitation, restoration and conservation. Scientific Reports 13, 16296.

Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science, 360, 987-992.

Rivera-Ferre MG, López-i-Gelats F, Howden M, et al (2016) Re-framing the climate change debate in the livestock sector: Mitigation and adaptation options. Wiley Interdisciplinary Reviews: Climate Change, 7(6), 869–892.

Sala OE, Yahdjian L, Havstad K, Aguiar MR (2017) Rangeland Ecosystem Services: Nature's Supply and Humans' Demand. In DD Briske (Ed.), Rangeland Systems: Processes, Management and Challenges (pp. 467-489). Springer International Publishing.

Sloat LL, Gerber JS, Samberg LH, et al (2018) Increasing importance of precipitation variability on global livestock grazing lands. Nature Climate Change, 8(3), 214-218.

USDA (2024) Beef & beef products. United States Department of Agriculture (USDA). https://fas.usda.gov/data/commodities/beef-beef-products

Wulfhorst JD, Fancher H, Ritten J, Nagler A (2022) Community security in beef production sustainability.

Zhuang M, Gongbuzeren, Zhang J, Li W (2019) Community-based seasonal movement grazing maintains lower greenhouse gas emission intensity on Qinghai Tibet Plateau of China. Land Use Policy, 85:155-160.