

Review:

Rangeland management in Tanzania: Opportunities, challenges, and prospects for sustainability

BASHIRI IDDY MUZZO^{1,*}, DAVID DAWSON MALEKO², ERIC THACKER¹, FRED D PROVENZA¹

¹Department of Wildland Resources, Utah State University. 5200 Old Main Hill, Logan, UT 84322, USA. Tel.: +1-435-797-0242,

*email: iddy.muzzo@usu.edu

²Department of Animal, Aquaculture and Range Sciences, Sokoine University of Agriculture. P.O. Box 3004 Morogoro, Tanzania

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Abstract. Muzzo BI, Maleko DD, Thacker E, Provenza FD. 2023. Review: Rangeland management in Tanzania: Opportunities, challenges, and prospects for sustainability. *Intl J Trop Drylands* 7: 83-102. Rangelands in Tanzania play a crucial role in supporting local livelihoods and the country's economic development. However, their long-term sustainability is threatened. This review paper identifies challenges and explores opportunities to ensure their continued sustainability. Opportunities include implementing dedicated policies and regulations, using expertise in range science, leveraging technological advancements, investing in land for private ranches, using ample bushes and shrub resources for small ruminant production, and responding appropriately to high market demand for milk and meat from ruminants. Major challenges include insufficient technology and limited technical know-how, low and erratic rains leading to dry season pasture scarcity, infectious diseases and the spread of invasive species. Other challenges include conflicting interests from other land users that have led to the massive conversion of communal rangelands to croplands, and the need for areas to protect wildlife and human settlements. These challenges can be addressed by policy enforcement, strengthening pastoral organizations, fostering the growth of experts in climate-adapted forage and livestock breeding, and embracing advanced technology. Active involvement of local communities in decision-making processes and facilitating rangeland restoration can ensure the sustainable management of rangelands in Tanzania. Another promising avenue is the strategic use of locally adapted livestock species to control invasive plants, complemented by governmental enforcement of a grading system for meat and establishing a price-based quality meat market. Incorporating these prospects into rangeland management strategies can enhance the ecological sustainability and resilience of rangelands while supporting local livelihoods. Future research should focus on evaluating and implementing these strategies to promote sustainable rangeland management practices in Tanzania and elsewhere with similar environment.

Keywords: Invasive species, nomadism, rangeland improvement, shrubs and bushes, Tanzania

INTRODUCTION

Rangelands are extensive natural landscapes, covering approximately 40-50% of the Earth's terrestrial surface (Robinson et al. 2019). These landscapes include grasslands, shrublands, savannahs, woodlands, deserts, tundra, and riparian and wetland areas. These lands are unsuitable for cultivation but revegetate naturally or artificially and managed like native vegetation. The predominant vegetation in rangelands are grasses, forbs, shrubs, and fodder trees, proving suitable forage for wildlife and livestock through extensive grazing or browsing. Rangelands play a significant role in environmental, economic, and cultural functions supporting millions of peoples livelihoods worldwide (Bremer et al. 2021). In Tanzania, rangelands, which receive an annual rainfall of less than 700 mm, are mostly allocated in the country's Central and Northern regions (Figure 1). They provide several ecosystem services including habitat for wild flora and fauna, carbon sequestration and catchments for watersheds. They also provide forage for ruminant livestock production systems. Tanzania has 35.3 million cattle, 25.6 million goats, and 8.8 million sheep, mostly raised in rangelands (URT 2022). According to the NAFORMA (2015), grazing and wildlife areas cover 10.5% and 22% of the Tanzanian mainland, respectively.

This provides an estimated 9,923,414 ha for grazing and 20,791,914 ha for wildlife, with nearly half of these areas managed as private or protected areas and ranches, while the remaining acreage is village or public land (Figure 2). Tanzanian livestock production is sustained by rangelands dominated by native pastures, contributing 7.4% of the national GDP (Nandonde et al. 2017). Most communal lands are dominated by miombo woodlands that receive less than 700 mm of precipitation per year (Ruvuga et al. 2021), followed by grassland (800-1200 mm), forest grassland, gallery forest (1,200 to 2,000 mm), and thick bush lands (600 to 800 mm). The major Tanzanian rangeland products and services are potable water for human use, irrigation for forage crops for livestock, and various products such as meat, milk, wool, leather, and medicinal plants.

In 2022, the government of Tanzania officiated communal rangelands into land statutes as a strategy for authorizing the community to use available resources properly. Kamwenda (2002) suggested that closely tracking resource utilization by village guards (*sungusungu*) and village assemblies (*dagashida*) in the north-western semi-arid regions among the Sukuma People of Tanzania could protect resources. However, these areas are degraded, and some cannot support grazing because of seasonal variations in the quantity and quality of forages (Selemani 2014).

Rotational grazing systems are often used to promote recovery of diverse plant richness (Muzzo and Provenza 2018; Harmel et al. 2021). However, Tanzania's human population was 61.7 million by 2022 (NBS 2022), with an estimated annual average growth rate of 3.1% since 2012. This has led to the conversion of rangelands into settlements and croplands (Table 1) to increase food security. Although Participatory Rangeland Management (PRM) projects have been implemented in some regions of Tanzania, management practices remain less adaptable, and benefits from common properties are not equally distributed, and as Flintan (2012) noted, common property decisions are often made irrationally due to self-interest. Numerous practices can enhance sustainable rangeland management in Tanzania. In their studies, Rainsford et al. (2021) and Rego et al. (2021) emphasized the significant contribution of fire to ecosystem health, highlighting the importance of accurate timing in the application of prescribed burning to effectively manage undesirable rangeland plants that can hinder livestock productivity. Fire and herbivory are natural ecological processes that drive the heterogeneity of rangeland ecosystems. Fires clear dead vegetation debris, promote fast regrowth of fire-tolerant plant species such as *Themeda triandra* grass and *Acacia nilotica* fodder trees, and create more open spaces (Lamont et al. 2019). The intensity and frequency of fires influence the type and structure of vegetation in a given area (Fernandez-Garcia et al. 2020), while excessive fires lead to massive death of plant communities and environmental degradation. Grazing by herbivores affects the composition and structure of plant communities (Lindén et al. 2021). Different species of herbivores may selectively graze specific plant species, which can impact vegetation

composition including grasses, legumes and forbs (Pauler et al. 2020). When fire and herbivory occur in the same spatial and temporal scales, they create heterogeneity that can attract wildlife and livestock to recently burned patches (Fuhlendorf et al. 2009). Pyric herbivory or patch-burning strategic practices can not only enhance livestock production and benefit wildlife but also increase habitat mosaics and heterogeneity, which in turn increases biodiversity, enhancing ecosystem services (Allred et al. 2014; Scasta et al. 2016; Scasta et al. 2023). In a changing climate associated with extended drought and variable rainfall, improved pasture and irrigated farm pastureland are essential for maintaining annual livestock production (Ndesanjo and Theodory 2021). Feed conservation in the form of dry crop residues, hay, silage and lopping practices offer alternative strategies to sustain livestock productivity during acute dry seasons (Muzzo and Provenza 2018).

In conclusion, proper range management practices can help sustain ecosystems and biodiversity, which can in-turn help reduce soil erosion, increase vegetation cover, and increase water infiltration, eventually increasing water flow into the soil, surface and ground water resources recharge. Conversely, a growing human population in Tanzania is increasing demands for water, food, and other rangeland resources. Tanzanian rangelands support unique wildlife species important for tourism and recreation. The future of these multi-benefits from Tanzanian rangelands is uncertain due to global climate change and increasingly variable weather patterns. Therefore, this review paper explores the challenges and opportunities within rangelands of Tanzania and fills some gaps in prospects to their sustainability.

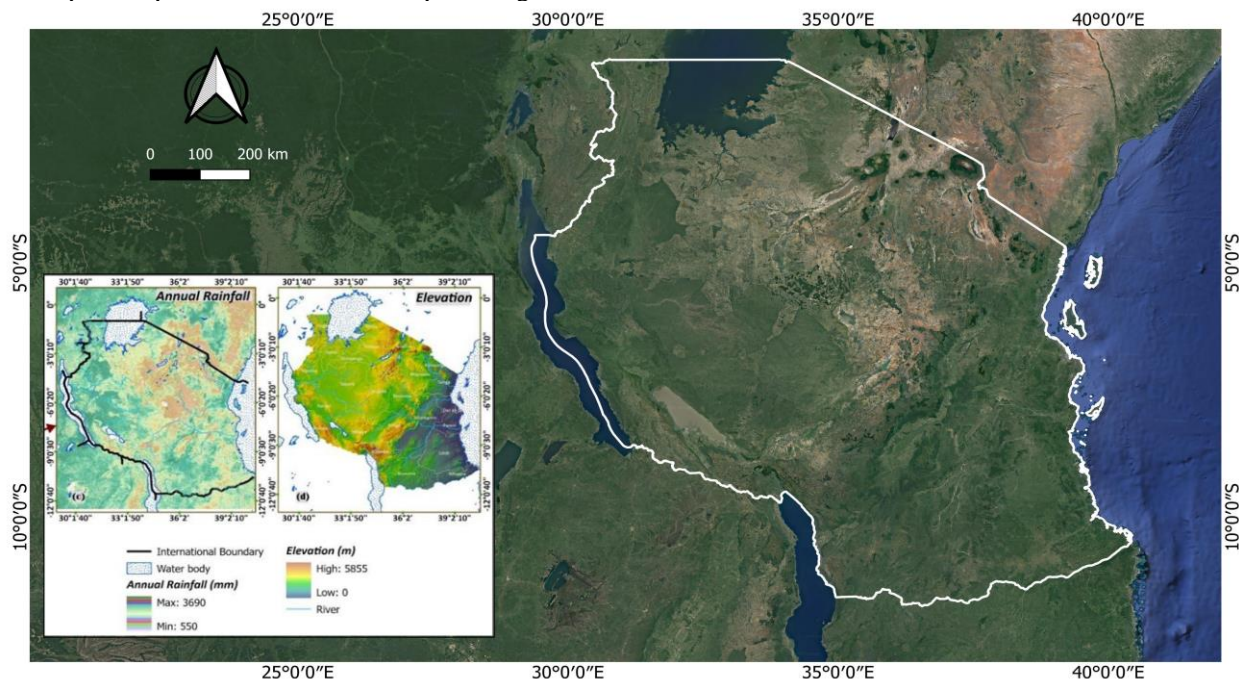


Figure 1. A map showing rangeland areas in Tanzania characterized by receiving less than 700 mm rainfall per annum (brown color in (c) and elevation in (d).

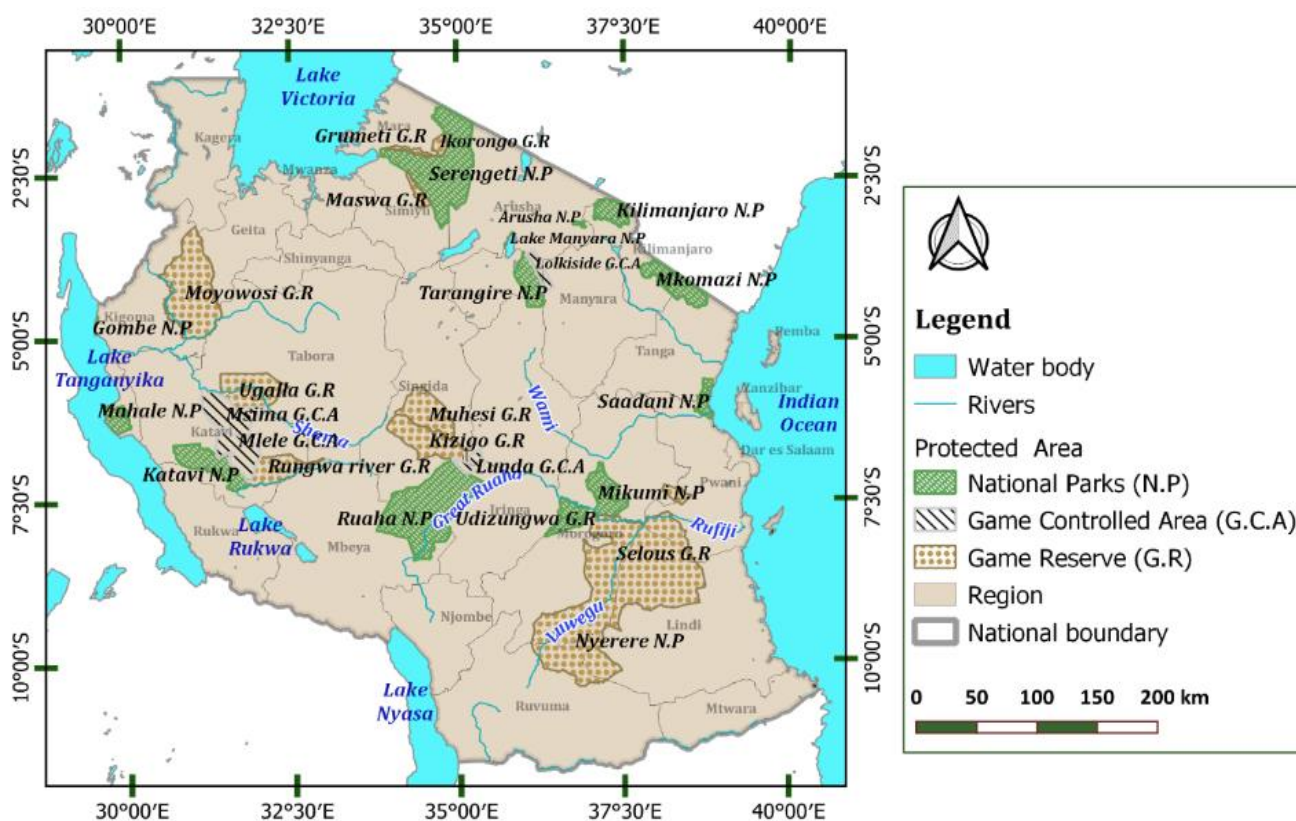


Figure 2. Map of Tanzania showing the distribution of different wildlife protected areas in the rangelands

Table 1. Land use area and rate of change in cover classification according to Nzunda and Midtgaard (2019)

Cover class and land use	Area (ha) ^a		Total changed area 2010–1995 (ha)	Changed area per year (ha/yr)	2010 Area as a percentage of 1995 area	% Annual rate of change ^b
	1995	2010				
Bushland	17,372,207	12,666,025	-4,706,182	-313,745	72.90	-2.10
Cultivation	9,764,073	31,967,393	22,203,320	1,480,221	327.40	7.90
Grassland	20,606,711	6,056,976	-14,549,735	-969,982	29.40	-8.20
Forest	38,097,662	33,296,651	-4,801,010	-320,067	87.40	-0.90
Cover and other land uses	1,715,590	3,569,198	1,853,608	123,574	208.00	4.90

Note: The 2010 land cover map did not include 514,594 ha of unclassified area, and rate annual changes was calculated according to Puyravaud (2003)

OPPORTUNITIES FOR PROPER MANAGEMENT

Availability of experts, institutions for rangeland management and research

Experts in range science, such as graduates from Sokoine University of Agriculture (SUA), the Tanzanian Vice Presidents’ environment division Office in the Mainland, Ministry of Agriculture (MOA), Ministry of Livestock and Fisheries (MLF), Ministry of Regional Administration, and Local Government Tanzania (PO-RALG), along with institutions like the Tanzania Livestock Research Institute (TALIRI) and Livestock Training Agency (LITA), and the Rangeland Society of Tanzania (RST) an NGO, can make significant contributions to managing rangelands. Moreover, the Tanzania Wildlife Authority (TAWA) and Tanzania Wildlife Research Institute (TAWIRI) are other key stakeholders in addressing the

various challenges of human, wildlife, and livestock interactions in the rangelands. The number of SUA graduates in range management averaged 60 students per academic year from 2011 to 2022. The first B.Sc. Range Management students was enrolled in 2008; since 2011, students have continuously graduated, resulting in 664 graduates by 2022 (Figure 3). They possess the essential knowledge and skills required to sustainably manage rangelands. Regarding gender, between 2011 and 2022, SUA graduated 193 females and 471 males with a B.Sc. in Range Management (Figure 4). This underscores the institution’s commitment to promoting gender diversity in this field, ensuring that Tanzania’s livestock keepers benefit from a diverse and well-trained pool of graduates. However, there is a challenge in securing relevant employment for these graduates, as there are limited job opportunities in government rangeland management

sections and private companies. This is due to lower government budget allocations, policies, and sectoral prioritization. Additionally, there may be a scarcity of companies specifically dealing with the graduates' specialty. Within MLF and PO-RALG, leading heads of the sector employ range/livestock officers to oversee and facilitate sustainable rangeland management practices. Their roles are instrumental for effectively implementing policies and practices essential for rangeland management. TALIRI operates seven research centers strategically located in seven agro-ecological zones of the Tanzania Mainland. These centers, which include Kongwa (Dodoma) and TALIRI Mpwapwa, TALIRI Naliendeke (Mtwara), TALIRI Mabuki (Mwanza), TALIRI Tanga, TALIRI West Kilimanjaro (Kilimanjaro) and TALIRI Uyole (Mbeya), conduct valuable research on rangelands in diverse environments, significantly advancing understanding of rangeland dynamics and serving as vital sources of guidance for sustainable use and conservation. TAWIRI comprises four Research Centers, including Kingupira Wildlife Research Centre (Selous Game Reserve-Southern Tanzania), Njiro Wildlife Research Centre (Njiro in Arusha – Northern Tanzania), Mahale-Gombe Wildlife Research Centre (Gombe National Park –South-Western Tanzania), and Serengeti Wildlife Research Centre (Serengeti National

Park- North-Western Tanzania). These research centers provide valuable efforts towards sustainable management of wildlife resources in rangelands. They offer essential research, extension services, and capacity-building initiatives that are fundamental for harmonizing rangeland conservation with wildlife habitat preservation. In addition to these government institutions and academic establishments, the Rangeland Society of Tanzania (RST) unites professionals and experts in range science. This collaborative platform fosters knowledge exchange and advocates adopting sustainable rangeland management practices. Moreover, the active engagement of non-governmental organizations (NGOs) is pivotal in this holistic approach. Numerous NGOs, both national, such as Tanzania Natural Resources Forum (TNRF), and international, such as The Nature Conservancy (TNC), Wildlife Conservation Society (WCS), and International Livestock Research Institute (ILRI), are working to promote sustainable rangeland Management in Tanzania. These organizations work in synergy with governmental bodies, academic institutions, and local communities to implement projects and initiatives aimed at rangeland conservation and supporting community livelihoods. Their involvement enhances the collective impact on the sustainable management of Tanzania’s rangelands.

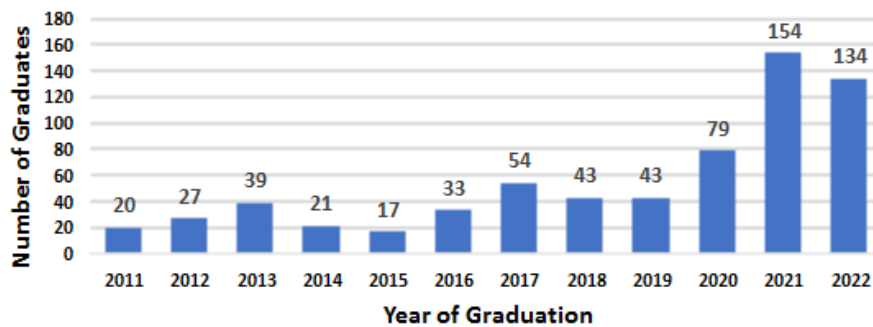


Figure 3. Number of individuals who graduated with B.Sc. Range Management at SUA between year 2011 and 2022 (Source: Sokoine University of Agriculture, 2022)

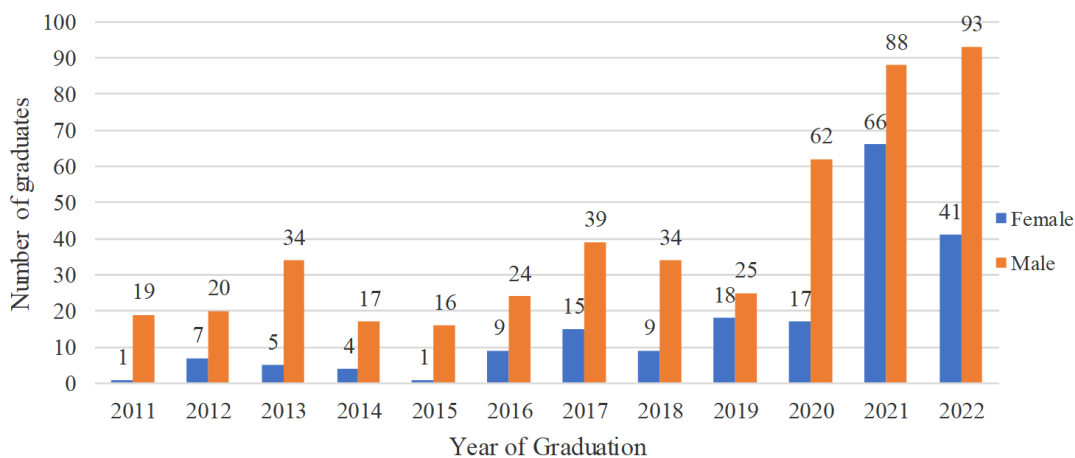


Figure 4. Number of individuals who graduated with B.Sc. Range Management at SUA between 2011 and 2022 by gender (Source: Sokoine University of Agriculture, 2022)

Availability of policy and regulations for rangeland management

The Grazing land and Animal Feed Resources Tanzania Act, 2010 (No. 13) provides legal frameworks for managing rangelands in Tanzania. The act promotes community participation in rangeland management, allowing for the involvement of local communities in decision-making processes. That promotes a sense of ownership and responsibility among the communities towards the sustainable management of rangelands. The act also regulates grazing activities, specifying the number of animals that can be grazed on a particular area of rangeland, the duration of grazing periods, and the use of rotational grazing systems. This helps to prevent overgrazing, soil erosion, and degradation of rangelands. In addition, the act promotes the conservation of rangelands and their biodiversity by providing guidelines for demarcating and safeguarding grazing lands. It recognizes the importance of rangelands in supporting wildlife, particularly in areas designated for conservation, while providing guidelines for managing rangelands in ways that balance the needs of livestock and wildlife. Finally, the act penalizes illegal activities that damage rangelands, such as logging, charcoal production, and mining. This helps to deter illegal activities that can destroy rangeland ecosystems.

Technological advancement for range improvement

Tanzania has recently achieved major technological strides in range improvement with the goal of enhancing the management, sustainability, and production of rangelands. Remote sensing technology, such as satellite imagery, is used to monitor and map rangeland conditions, including vegetation cover, soil moisture, and land use changes (Jamali et al. 2023). According to a systematic review by Nzunda and Yusuph (2022), Geographic Information Systems (GIS) and Remote Sensing are used in rangeland management in Tanzania to analyze and visualize spatial data, assess land use changes, and monitor grazing patterns. GIS is also used to map the distribution of rangeland resources, identify areas of degradation and the potential distribution of invasive alien species (Sutomo et al. 2016). This technology has effectively identified potential areas for sustainable grazing and improved pasture management. Thus, GIS is a useful tool for rangeland managers in Tanzania to make informed decisions and develop effective management plans. Wiethase et al. (2023) found remote sensing and ecological modeling methods were used to investigate degradation of rangelands in Northern Tanzania. By integrating remote sensing and ecological modeling, researchers have identified pathways of degradation in rangelands, and assessed the potential for recovery (Donovan and Monaghan 2021). They found degradation was driven by overgrazing, bush encroachment, and soil erosion and that these pathways led to a loss of vegetation cover and soil fertility. However, they also found with proper management practices, such as rotational grazing and bush thinning, rangelands can recover and regain their productivity and ecological functions. In addition,

integrated ecological modeling has been used to map the potential distribution of invasive species under current and future climatic conditions, providing valuable insights for managing *A. nilotica* invasive species in Central-Eastern Indonesia (Sutomo and Van Etten 2017). Mobile-based applications, such as the Tanzania Livestock Market Information System (TL-MIS), provide information on market prices, livestock diseases, and other relevant information to livestock farmers. This helps people make informed decisions on livestock production and marketing. Tanzania has developed and distributed improved pasture seeds, such as *Brachiaria* grass and *Napier* grass, that are more resistant to drought and pests and have higher nutritional value. According to a study by Tenga and Mramba (2015), adopting improved forage varieties has improved livestock production, reduced pressure on natural rangelands, and enhanced soil fertility. For example, the Tanzania shorthorn zebu cattle breed is known for its high disease resistance and adaptability to harsh environmental conditions. According to a study by Yonas (2020), crossbreeding of local and exotic breeds has improved breeds with higher productivity and resilience to the adverse effects of climate change. Water harvesting techniques, such as constructing water ponds and dams, are used to store water for livestock and wildlife during the dry season. This helps to reduce pressure on natural water sources and supports the sustainable use of rangelands. Tanzania has also implemented community-based management systems, such as village land use planning and joint forest management, to promote community participation in rangeland management. Collectively, these practices help to ensure the sustainable use of rangelands and reduce conflicts over natural resources.

Investment land for opening private ranches

Achieving the sustainable use and management of rangeland resources in Tanzania requires a multifaceted approach considering ecological, social, and economic factors. The country's rangelands are critical to its economy, providing grazing areas for livestock, which is a key source of income for many rural communities. According to Yanda et al. (2021), private ranching provides an alternative land-use option for rangelands in Tanzania, especially in areas where communal grazing can lead to overgrazing, land degradation, and encroachment. Private ranching can provide incentives for proper land management, as the owners have a financial interest in maintaining the health and productivity of their land in ways that lead to better grazing management, reduced overgrazing, and improved rangeland health. The Mwiba Wildlife Reserve is one example of a successful private ranch in Tanzania. This 125,000-acre reserve was established in 2006 and is managed by the Friedkin Conservation Fund. The reserve provides more diverse habitats for wildlife, such as elephants, lions, and giraffes. It also generates revenue through ecotourism, with visitors paying to stay at the reserve's luxury lodges. Also, the Manyara Ranch Conservancy, spanning 45,000 acres and managed by the African Wildlife Foundation, offers another compelling illustration of private ranching's

potential. This conservancy provides a sanctuary for wildlife such as elephants, zebras, and wildebeests and serves as an income source for the local Maasai community through ecotourism and grazing fees. Furthermore, the Mako Farm, situated in the southern highlands of Tanzania, demonstrates the efficacy of private ranching practices that integrate livestock production and wildlife conservation over approximately 3,707 acres. The farm embraces holistic management principles, incorporating planned grazing, water resource management, and soil conservation to rejuvenate rangeland health. This approach has yielded tangible benefits, including increased livestock production, enhanced soil health, and restoration of previously degraded rangelands.

Availability of ample bush and shrub resources for small ruminants' production

Tanzanian rangelands have a high diversity of plant species, which include a variety of shrubs and woodlands over 33 million ha that provide valuable forage for small ruminants such as goats and sheep (Nzunda and Midtgaard 2019) (Figure 2). These shrubs and woodlands have high nutritional quality and palatability for small ruminants, making them a valuable source of protein, minerals, and vitamins. Browse species such as *Acacia*, *Commiphora*, *Grewia*, *Ficus*, *Combretum* and *Terminalia* spp contain high levels of crude protein and minerals in their leaves, making them highly preferred by goats and sheep (Kideghesho 2016). Furthermore, the fruit pulp and leaves of *Tamarindus indica* contain secondary compounds with potential medicinal properties, aiding in the treatment of digestive issues and acting as a natural anthelmintic. *Azadirachta indica*, commonly known as neem tree, represents another valuable resource for managing various livestock ailments, particularly external parasites (Landau et al. 2009). Certain *Acacia* shrub species, like *Acacia angustissima*, have condensed tannins that can reduce enteric methane emissions (Naumann et al. 2018). Moreover, *Acacia* species are renowned as nitrogen-fixing legumes, offering valuable forage for animals and contributing to soil fertility.

The abundance of shrubs in Tanzania's rangelands presents a valuable opportunity for raising small ruminants, allowing them to benefit from a wide range of nutritious forages that benefit their health and human health. The selective grazing behavior of small ruminants, which enables them to target the most nutritious portions of vegetation, maximizes their nutritional intake and growth potential, enhancing the productivity and market value of small ruminants raised in rangelands (Claps et al. 2020). Shrubs within the grazing landscape offer small ruminants access to a more diverse diet, ensuring a balanced intake of nutrients and other health-promoting phytochemicals (Villalba et al. 2019). Goats raised in rangelands exhibit higher body weights and market values than those raised on farm-based diets (Dieters et al. 2021). In turn, the health of humans is promoted by eating meat and dairy products from livestock that consume diverse mixtures of phytochemically rich plants (Provenza et al. 2019; Van Vliet et al. 2021). Tanzanian pastoralists have historically

relied on various shrubs as remedies for their animals nutritional and medicinal needs. Further research is needed to identify secondary compounds within the most common shrubs that may benefit animal health and production while reducing environmental impacts. Muzzo and Provenza (2018) have proposed exploring ethno-veterinary pharmacopeia and plant usage as alternatives to costly veterinary medications. Thus, incorporating shrubs into the ecosystem can benefit soil health, promote plant growth, and enhance animal and human well-being.

High market demand for milk and meat from rangeland ruminants

The demand for a range of products is a significant driver for managing rangelands in Tanzania. According to the Tanzania Livestock Modernization Initiative, the country has an estimated 34 million cattle, which provide a valuable source of meat for the local and export markets (Nandonde et al. 2017). Over the last decade, milk production has increased significantly, but the need for improved breeds and specialized feed has resulted in poor milk yields (CSIRO 2022). In recent years, the milk demand has surged owing to population growth and the economy. This has widened the gap between the demand and the local milk supply (Blackmore et al. 2022; Maleko 2022). According to MLF's report in 2017, the projected increase in beef meat production by 52% will not meet demands of the expected 71% growth in consumption by 2022, resulting in a 17% deficit (124,778 tons) in beef production and consumption (MLF 2017). Additionally, the Livestock Analysis (LSA) estimates a significant red meat (beef) supply gap of 1.7 million tons by 2031-32 under the business as usual investment scenario. This suggests that by 2031, the anticipated domestic beef production will only meet 15% of domestic consumption (MLF 2017). The resulting deficit will likely increase meat prices, impacting consumers in Tanzania. This may increase pressures on rangelands and lead to overgrazing, soil erosion, and land degradation, which will decrease productivity, posing a threat to the industry's long-term sustainability. Therefore, managing rangelands sustainably presents an opportunity to improve the productivity and health of the land, thus increasing the supply and market value of range products. Sustainable management practices can improve the quality and quantity of pasture, leading to higher meat yields and better prices for farmers. Rotational grazing, where livestock are moved between pastures to allow for vegetation recovery, can increase the weight gain of livestock, resulting in higher meat yields (Msofe et al. 2019; Munson et al. 2020). Similarly, sustainable management of rangelands can enhance the availability and quality of pasture seeds and milk for sale, thus increasing the industry's profitability.

In addition to livestock, wildlife can become a valuable source of income. Wildlife can add value through utilitarian uses such as hunting or harvesting wild game meat for local use or as part of an ecotourism operation for international markets. However, unregulated hunting practices can lead to exploitation of wildlife, resulting in population declines and loss of biodiversity. When wildlife

species have economic value, and their use is regulated, they help promote conservation and provide opportunities for conservation practices. However, caution should be used when creating or supporting wildlife markets, as that can lead to the exploitation of wildlife resources. While some argue that hunting operations have increased conservation efforts in places like Tanzania, others have questioned this approach's effectiveness, ethics, and social considerations (Lindsey et al. 2007). In North America, the elimination of wildlife markets that sold wild game meats is partially credited with reducing the illegal taking of game in the US in the late 19th and early 20th century (Trefethen 1975). Regulating hunting and harvesting is essential to the long-term sustainability of game species (Trefethen 1975; Thacker et al. 2023). Sustainable hunting practices, such as regulated quotas and hunting seasons, can provide a source of wild game meat for sale while ensuring the long-term conservation of wildlife (Ingram 2020; Ingram et al. 2021). Therefore, Tanzania needs a coordinated effort among stakeholders, including government agencies, farmers, and local communities, to implement sustainable management practices and meet the marketing demand for a range of products in Tanzania. Sustainable rangeland management practices can improve livestock and wildlife productivity and land health while reducing the industry's environmental impact.

RANGELANDS MANAGEMENT CHALLENGES IN TANZANIA

Limited knowledge of sustainable rangeland management

Limited knowledge and skills in rangeland management in Tanzania have led to degradation and desertification, with significant economic, social, and environmental consequences. Overgrazing, inadequate control of invasive species and unsustainable grazing practices are prevalent issues, resulting in soil fertility loss and declining vegetation cover (Beever et al. 2006; Middleton 2018; Wassie 2020). Increased investment in education and training programs is essential to address this challenge. Capacity-building initiatives should focus on soil and water conservation, range ecology, and livestock management (Cullen et al. 2014). Collaborative efforts involving research institutions, government agencies, and stakeholders can promote innovative approaches like precision livestock management techniques, using GPS tracking, and remote sensing to optimize grazing patterns and reduce overgrazing (Bailey et al. 2021). Other countries have improved rangeland management through technological advancements and research. Satellite technology in Australia aids in mapping rangeland vegetation, facilitating targeted management interventions (Ward et al. 2016). Incorporating indigenous knowledge and practices, such as rotational grazing and controlled burning, can also promote rangeland health and productivity (Finca et al. 2023). Similarly, shepherding practices, as adeptly employed by the Maasai, have been successfully harnessed for enhancing rangeland conditions

and reducing predation pressures. By addressing knowledge gaps and applying successful strategies from other countries, Tanzania can improve rangeland management, mitigate degradation, and preserve these valuable resources.

Tanzania's rangelands are a critical resource for the country's economy, supporting livestock production and wildlife conservation and providing vital ecosystem services (URT 2022). Multisectoral competition among agriculture, forestry, mining, urbanization, and wildlife conservation is a significant challenge facing rangeland management in Tanzania (Kivelia 2007; Msoffe 2010; Nuhu 2019; Mahajan et al. 2021; Anthony et al. 2023). These sectors have different objectives and priorities, which can sometimes conflict, leading to unsustainable land use practices that degrade rangeland ecosystems. For instance, the expansion of agriculture and settlement has resulted in the conversion of Maasailand rangelands to croplands and urban areas, which has led to habitat loss and fragmentation, reducing the carrying capacity of rangelands (Kivelia 2007; Msoffe 2010; Anthony et al. 2023). Similarly, mining activities in the Mara region have led to soil disturbance, land degradation, and water pollution, affecting the quality of rangelands (Matano et al. 2015). Establishing Wildlife Management Areas (WMAs) in Tanzania was intended to involve local communities in wildlife management on village lands and promote wildlife conservation. However, implementing WMAs have not yielded the expected socioeconomic benefits due to top-down approaches that overlook the meaningful participation of local communities and led to conflicts and disengagement from local communities. WMAs have been converting community grazing land, leading to conflicts between local communities in the Maasai Steppe and the Eastern Arc Mountains and conservation authorities. Nelson et al. (2016) found that WMAs converted over 160,000 hectares of community grazing land between 2009 and 2014, negatively impacting local communities, particularly pastoralists. Similarly, Moyo et al. (2016) and Kicheleri et al. (2018) reported that establishing a WMA in the Burunge Wildlife Management Area resulted in conflicts between conservation authorities and local pastoralists due to the enclosure of communal grazing lands. Involving local communities in the WMA process and respecting their customary rights and practices is essential for successful conservation and sustainable livelihoods in Tanzania.

The government's budget allocation to rangeland management has been insufficient despite the importance of these lands to the national economy. Eilola et al. (2021) found that funding for rangeland management in Tanzania is limited and often fragmented across different government departments, leading to ineffective management and conservation of these lands. Additionally, a lack of coordination and collaboration among government departments, stakeholders, and communities involved in rangeland management can lead to conflicts over land use and cooperation in implementing conservation and management strategies. For instance, Mairomi and Kimengsi (2021) found limited coordination

and communication among government agencies responsible for rangeland management, leading to conflicting policies and ineffective management strategies. The absence of a specific National Rangeland Policy also contributes to the challenges in managing Tanzania's rangelands. While the National Land Use Policy provides guidelines for the sustainable use and management of land, including rangelands, the absence of a dedicated policy makes it difficult to address these lands' unique needs and issues (Robinson et al. 2019). Tanzania's rangelands are not the only ones facing challenges in effective management. For example, despite having a national rangeland policy, Ethiopia has limited implementation of practices due to a lack of funding and weak enforcement mechanisms (Gelan 2014). Similarly, in Nigeria, the government's focus on other sectors, such as oil and gas, has resulted in the neglect of rangelands, leading to their degradation and loss of biodiversity, despite having a national policy on sustainable rangeland management (Leke and Leke 2019; Olayide 2021).

Communal grazing land is state-owned

State-owned communal lands are a key issue in Tanzanian rangeland management. Traditionally, rural communities managed lands communally under customary laws (Yanda and Mung'ong'o 2018). However, state ownership results in conflicts over land use and limited community involvement (Haller 2019; Robinson et al. 2019). This hampers effective strategies and conservation support, however, the government is promoting formulation and implementation of village land use plans together with access to individual ownership of Certificate of Customary Land Occupancy Rights (CLCORs) for enhancing land secured tenure among rural poor (John and Kabote 2017). Neglecting customary practices causes conflicts and weakens community cohesion (Sulle and Nelson 2009). This challenge is also evident in countries like Ethiopia and Kenya. In Ethiopia, converting communal lands into state-owned lands has sparked conflicts and undermined community involvement in land management (Atmadja et al. 2019; Sulle 2021). Similarly, Kenya's nationalization of communal lands has led to conflicts over land use and the neglect of customary land tenure systems (Little 2019). Recognizing and involving local communities in decision-making is essential (Atmadja et al. 2019; Little 2019). The National Land Policy in Tanzania acknowledges customary tenure, but implementation is limited (Biddulph and Hillbom 2020). Addressing state-owned communal lands necessitates a reverence for customary practices, community involvement in decision-making, and the establishment of robust legal and institutional frameworks. Strengthening community participation through capacity building empowers involvement, with transparent land tenure systems reinforcing equitable rights. Inclusive policies harmonizing land use with livelihoods and culturally sensitive conflict resolution mechanisms are vital for promoting effective rangeland management in Tanzania (John and Kabote 2017; Little 2019).

Poor cattle breeds

Effective rangeland management in Tanzania is challenged by the need to improve the performance of local animal breeds. According to Abdurehman (2019), most of Tanzania's livestock are local breeds including the dominant Tanzania Short-Horned-Zebu cattle generally well adapted to the harsh rangeland conditions. However, improving their growth, milk and meat production is essential to enhanced rangeland productivity and sustainability. These breeds are often small, have low productivity, and are resistant to most diseases and parasites, and extreme climates including droughts (Kangalawe et al. 2017). As a result, livestock production is low, and livestock keepers must graze their animals on larger areas of rangelands to meet their needs, leading to overgrazing and degradation of rangelands. Access to improved animal breeds has been challenging in Tanzania (Armson et al. 2020). The government's efforts to introduce improved breeds, such as the Mpwapwa breed, have been limited (Wilson 2021), and the private sector has not invested enough in breeding and distributing improved breeds to livestock keepers in rangeland areas. According to Baker et al. (2015), the lack of access to improved breeds has significantly constrained livestock production in Tanzania, particularly in rangeland areas. Other countries face similar challenges in improving animal breeds in rangeland areas. For instance, in Ethiopia, the low productivity of livestock breeds has been identified as a significant constraint to rangeland management (Ma'alin et al. 2021). Ethiopia has tried introducing improved breeds with higher production and performance than local breeds (Table 2). However, the adoption rates by livestock keepers have been low due to the high cost of purchasing and maintaining improved breeds (Gebreyohanes et al. 2021). Kenya has a long history of importing high-yielding animal breeds, such as Friesian, Ayrshire, Guernsey, and Jersey dairy cattle breeds from Europe and North America (Aliloo et al. 2020). These breeds were introduced to improve milk production and meet the growing demand for dairy products. However, these breeds have negative impacts on rangeland management, as they require more water and forage (Kelio 2022; Oloo et al. 2022) than local breeds, which are adapted to the arid and semi-arid conditions of these rangelands (Mudavadi et al. 2020).

Clearly, the trade-off between exotic and local breeds is a complex issue involving social, economic, and ecological factors. While exotic breeds may have advantages in terms of productivity and marketability, they may not be suitable for all environments because they require more inputs, such as feed and veterinary care. On the other hand, local breeds adapted to local conditions require fewer inputs, making them more sustainable and resilient in the face of environmental and economic shocks (Gerber et al. 2015; Ragkos et al. 2017; Tribaldos 2021). However, people's desire for higher performance and potentially better economic gain has triggered the adoption of exotic breeds (Opiyo et al. 2015; Snaibi and Mezrhhab 2020), leading to the loss of local breeds and a decline in genetic diversity. This trend has also resulted in losing traditional knowledge and cultural practices associated with animal husbandry in

pastoralist communities (Ayantunde et al. 2007; Njisane et al. 2020; Hailemariam et al. 2021). Crossbreeding with locally adapted and improved breeds can be a viable solution to enhance Tanzanian rangeland productivity and sustainability while preserving genetic diversity and traditional knowledge. Castaño-Sánchez et al. (2023) conducted a study involving Hispanic heritage cattle (e.g., Criollo) and crossbreeds (Criollo × Angus), comparing them with traditional Angus cattle in the southwestern US. Crossbreed cattle exhibited lower water use, fuel consumption, nitrogen footprint, and production costs regardless of the finishing diet. Crossbreeding can produce offspring with desirable traits such as higher productivity, disease resistance, and adaptability to local conditions. However, crossbreeding has risks, such as unintended consequences on genetic diversity (Kitole and Sesabo 2022) and negative impacts on traditional knowledge and cultural practices. To improve the livelihoods of Tanzanian pastoral communities, local communities must be involved in the decision-making process while carefully evaluating the potential benefits and risks of crossbreeding.

Infectious diseases

Diseases in Tanzania's rangelands, such as East Coast Fever (ECF), Foot-and-Mouth Disease (FMD), Contagious Bovine Pleuropneumonia (CBPP), and Rift Valley Fever (RVF), significantly impact livestock productivity and human health. Annual outbreaks of FMD and CBPP across the country lead to losses (Swai et al. 2021), with CBPP outbreaks causing about 55% of cattle deaths in the southern highlands region (Msami et al. 2001). Rift Valley Fever (RVF), an important viral disease affecting ruminants in Tanzania, causes significant economic losses in the livestock industry (Sindato et al. 2011; Olovsson 2019; De Glanville et al. 2022;). Mosquitoes transmit the RVF virus, and outbreaks in Tanzania have been reported since the 1930s, with the most recent outbreaks occurring in 2007 and 2018 resulting in significant human and livestock losses, highlighting the need for effective disease control strategies and interventions (Sindato et al. 2011, 2022). RVF is an emerging and re-emerging disease in Tanzania, with the potential to cause significant impacts. Poor animal husbandry practices, inadequate vaccination, and lack of quarantine measures contribute to disease transmission, and the movement of livestock between regions and countries exacerbates the issue and the spread of diseases in rangeland areas (Sindato et al. 2022). Limited access to veterinary services in remote rangeland areas also hampers effective disease control efforts (Kimaro et al. 2018). Mitigating the effects of these endemic diseases is crucial for ruminant health, farmer livelihoods, and the livestock industry. Disease control strategies should include surveillance, vaccination, and biosecurity measures to prevent disease spread (Sargison 2020). A comprehensive approach is needed to address the challenge of diseases in Tanzania's rangelands, focusing on improved animal husbandry, expanded vaccination and treatment programs, and strengthened veterinary services in remote areas. Community-based animal health programs can enhance disease control measures and access to

veterinary services in rural regions (Auty et al. 2021; Enahoro et al. 2021). Additionally, improving surveillance and early warning systems can help detect and control disease outbreaks in rangeland areas. Species Distribution Models (SDMs) can be employed to predict the potential distribution of livestock disease vectors and assess the risk of outbreaks (Lippi et al. 2023), providing valuable insights for proactive disease management and control. Khwarahm (2023) showed how SDMs can also be applied to understand changing species' geographical distribution and abundance patterns, considering dynamic environmental conditions. These models have been used to create high-resolution maps of host distribution, reflecting the baseline risk of disease (Singleton et al. 2023). By using SDM such as MaxEnt (Maximum Entropy Modeling), one can accurately predict species distribution and identify the relevant environmental and bioclimatic determinants of disease risk (Gwaka et al. 2023; Rathore and Sharma 2023; Saputra et al. 2023; Singleton et al. 2023). Additionally, they can consider the temporal dimension, accounting for changes in species distributions over time (Karger et al. 2023). For instance, MaxEnt modeling has been used to estimate and predict zoonotic animal diseases under climate change in China (Cao et al. 2023) and to predict the spatial distribution of vector ticks of Crimean–Congo Haemorrhagic Fever in Iraq (Khwarahm 2023). Therefore, implementing SDMs, especially using MaxEnt in Tanzania rangelands, can contribute to a more effective and informed approach to addressing livestock diseases by predicting disease occurrence and identifying areas at high risk of outbreaks.

Acidic and infertile soils

Tanzania's rangelands face a significant challenge due to acidic and infertile soils. Mdegela et al. (2022) found a significant proportion of Tanzania's rangelands are in areas with soils that are acidic and low in essential nutrients, such as nitrogen and phosphorus. These soils are also susceptible to erosion. The acidic nature of the soil, ranging from pH 5.0-6.5 (Zarekia et al. 2012; Selemani 2015; Mdegela et al. 2022), affects the growth of vegetation, which is a critical resource for livestock production and wildlife conservation. The effect of acid pH on plant biomass production in rangeland was clearly observed in the study by Werner et al. (2016) (Table 3). Poor rangeland management practices, such as overgrazing and deforestation, further compound the challenge, leading to soil erosion and degradation. The problem of acidic or alkaline and infertile soils is not unique to Tanzania's rangelands. For example, in Ethiopia, rangelands located in areas with acidic and low-fertility soils are less productive than those in areas with more fertile soils (Mesfin et al. 2018; Getabalew and Alemneh 2019; Hailu and Mehari 2021; Milisha 2021). In Kenya, soil acidity is a significant problem in rangelands, particularly in areas with high rainfall, which can leach essential nutrients from the soil (Jawuoro et al. 2017; Bolo et al. 2019). In South Africa, many rangelands suffer from highly acidic soils due to years of overgrazing, which affects plant growth and reduces biodiversity (Kotzé et al. 2013; Ntalo et al. 2022).

Similarly, in Egypt, rangelands are also affected by highly saline and alkaline soils, which limit vegetation growth and reduce forage availability for livestock (El Shaer and Al Dakheel 2016; Deshesh 2021; Tahir et al. 2022). A multifaceted approach is necessary to address this issue. Conservation measures like terracing, soil bunds, and agroforestry can reduce erosion and improve fertility. Promoting appropriate soil amendments and fertilizers can address acidity and nutrient deficiencies, improving soil structure and fertility (Horák et al. 2021). Lime and organic matter amendments help raise soil pH and increase nutrient availability (Bossolani et al. 2020). Sustainable land management practices, like rotational grazing, further enhance soil quality and reduce erosion. Therefore, a comprehensive approach that includes soil conservation practices, suitable soil amendments, and sustainable land management strategies is essential to improve Tanzania's rangeland health, productivity, and ecological sustainability.

Alien invasive species

Invasive plants pose a significant challenge to Tanzania's rangelands, impacting native species and reducing productivity. Studies by Ngondya and Munishi (2022) and Muzzo et al. (2023) reveal how invasive weeds decrease plant diversity and constrain ecosystem services. Improper rangeland management practices such as overgrazing and nomadism have also contributed to the spread of invasive plant species, further exacerbating the degradation of rangelands (Leroy et al. 2020). Invasive species, such as *Prosopis juliflora* (mesquite), *Parthenium hysterophorus* (carrot weed), *Astripomoea lachnosperma* (choisy), *Hygrophila auriculata* (marsh barbell), *Trichodesma zeylanicum* (cattle bush) and *Gutenbergia cordifolia*, have taken over large areas of rangelands in Tanzania (Adkins et al. 2019). The *P. juliflora* and *Chromolaena odorata* are notable invasive species in Tanzania, negatively affecting rangelands near the Serengeti National Park (Muzzo et al. 2023), reducing forage quality and livestock productivity (Muzzo and Provenza 2018). Similarly, other countries like South Africa, Egypt, and the US face invasive plant challenges. In South Africa, *Acacia* and *Eucalyptus* species cover over 10% of the land, including rangelands, adversely impacting water resources and biodiversity (O'Connor and van Wilgen 2020). In Egypt, *P. juliflora* reduces rangeland biodiversity and productivity (Dakhil et al. 2021). The US grapples with invasive plants such as *Bromus tectorum* (cheatgrass), *Taeniatherum caput-medusae* (medusahead), and *Centaurea solstitialis* (yellow star thistle), which alter ecosystem functions and hamper livestock production (USDA 2017). Managing invasive plants requires prevention, early detection, and integrated approaches (Van Beek et al. 2017). Ngondya and Munishi (2022) recommend Nature-based Solutions (NbS) like tree planting and promoting native species to control *G. cordifolia*. Integrated Weed Management (IWM) can also restore ecosystem composition and function. Effective management of invasive plants improves rangeland productivity and ecological health and provides economic

benefits through increased livestock production. Innovative grazing management programs should also be implemented to increase the use of invasive species by livestock.

Climate change and variability

Climate change is a major challenge, increasing temperatures while decreasing the amount of rainfall on rangelands in Tanzania (Figures 5 and 6). Prolonged droughts have become more frequent and severe, resulting in the loss of vegetation cover and reduced productivity of rangelands (Wiethase et al. 2023). The effects of climate change are exacerbated by overgrazing and the continued expansion of human populations, which increase pressure on the limited grazing resources available in rangelands (Louhaichi et al. 2019). As a result, the loss of grazing land has become a major issue for many communities in Tanzania, as they struggle to maintain their livelihoods and feed their livestock (Sangeda and Maleko 2018). The situation is similar in South Africa, where prolonged droughts have led to the loss of grazing land and reduced productivity of rangelands (Vetter et al. 2020). In response, some communities have established community ranches, where grazing land is managed collectively and sustainably to ensure long-term productivity and livelihoods (Hall and Cousins 2013). These ranches are often managed through traditional governance structures that benefit local communities economically through increased livestock production and ecotourism activities (Taylor et al. 2016). Similarly, in Kenya, community ranches have been established to address the challenges of overgrazing, climate change, and the loss of grazing land (Maoncha 2021). These ranches are managed through participatory decision-making processes and often incorporate innovative practices, such as rotational grazing and the restoration of degraded rangelands (Niamir-Fuller 2005). As a result, these community ranches have successfully improved rangeland productivity and ecological health while providing economic benefits to local communities (Kimiti et al. 2018). However, climate change exacerbates other challenges beyond rangeland productivity. For example, changing climates increase the frequency and intensity of wildfires, diseases, and invasive species (IPCC 2014; Gomez-Casanovas et al. 2021). Wildfires have increased in many parts of the world due to climate change, with the total number of large wildfires and the area burned increasing by 4.2% and 2.5% per year on average between 1984 and 2015, respectively (Mueller et al. 2020). Similarly, climate change has contributed to the spread of infectious diseases, such as Lyme disease and West Nile virus, into higher latitudes and altitudes since the 1980s (Semenza and Menne 2009). The rise in temperatures and changing precipitation patterns are creating more favorable conditions for invasive species to thrive, potentially exacerbating ecosystem degradation (IPCC 2014; Turbelin and Cafford 2021).

Table 2. Livestock breeds in Tanzania and their performance parameters (Ministry of Livestock and Fisheries 2017)

Species	Breed	Total population	Parturition rate	Prolificacy rates	Parameters				
					Mortality rates	Weight adults	Dressing %	Milk yield	Loin Length
Cattle									
Local breeds	Tanzania Short-Horned Zebu (TSZ)	24,014,360	61%	1.00	2%-20%	260-380 kg	51-53%	270-1,200	250
	Sanga	1,062,440							
	Mpwapwa	800							
	Boran	103,200							
Exotic breeds	Ayrshire	61,920	67%	1.00	2%-10%	350-400kg		155-2,200	305
	Friesian	133,840							
	Jersey	9,536							
	Sahiwal	2,384							
	crossbreeds	411,500							
Total cattle		25,799,980							
Sheep									
Local	East African Blackheaded	1,979,952	1.50	1.20	2-7%	38-40kg	45-47%		
	Tanganyika	5,182,627						NA	NA
	Long-legged Red Maasai	1,522,182							
Exotics	Black Head Persian	15,239	1.60	1.10	2-6%	47-50kg	50%		
Total sheep		8,700,000							
Goats									
Local	Small East African	16,196,201	1.50	1.30	2-20%	38-65%	48%	NA	NA
	Malya	1,984		1.50			50%	90	180
Exotics	Anglo-Nubian	672		1.50	2-12%	49-70%	50%	500	187
	Boer	1,680					53%		
	Norwegian	1,903					50%		
	Saanen	1,680							
	Toggenburg	3,359							
	Crossbreeds	492,521							
Total goats		16,700,00							
Pigs									
local	Local Tanzanian	475,000	2	6.00	2-30%	55-60kg	60%	NA	NA
Exotics	Hampshire	19,000		8-10	2-15%	72-90kg	70%	NA	NA
	Landrace	95,000							
	Large white	133,000							
	Saddleback	38,000							
	Crossbreeds	1,140,000							
Total pigs		1,900,000							
Poultry									
Local	local	42,000,000	Not Established	Not Established	8-40%	1.2-1.5kg	80%	NA	NA
Exotics	Layers	12,000,000			2-5%	1.2-1.6kg	85.5%	NA	NA
	Broilers	22,500,000							
Total poultry		76,500,000							

Table 3. Soil pH and forage biomass in different range management systems

Treatment	Plant biomass			Composition of grazing material		
	Grazing materials	Weeds	Total (kg ha ⁻¹)	Grasses	Leguminous	pH
BR	465.50b	601.70a	1,067.20b	465.30b	0.20b	5.40a
NR	2,664.90a	330.50ab	2,995.30a	2,664.60a	0.30b	4.10b
IH	2,820.50a	204.90b	305.40a	2,690.90a	129.60b	4.00c
IC	1,640.00ab	198.80b	1,838.80ab	1,507.20ab	132.80a	5.00d
CV (%)	50.40	66.70	37.00	50.20	62.00	4.80

Note: NR: Natural rangeland; BR: Burned natural rangeland; IH: Natural rangeland improved with harrowing; IC: Natural rangeland improved with chisel plowing (Werner et al. 2016). Values followed by same letter(s) within a column did not differ significantly at 0.05 level

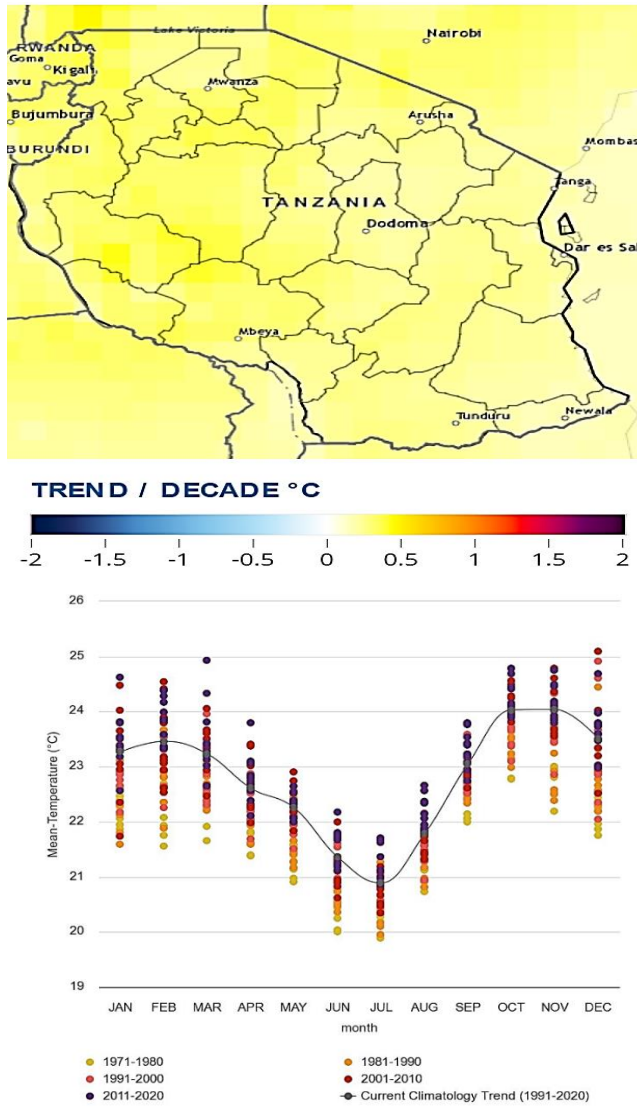


Figure 5. Tanzania mean temperature trend and variability across seasonal cycle per decade 1971-2020 (Source: World Bank group data).

PROSPECTS FOR SUSTAINABILITY OF RANGELANDS IN TANZANIA

Policy enforcement on rangeland resource use and management

Tanzania has policies and laws governing rangeland resource use and management, such as the Grazing-land and Animal Feed Resources Act of 2010 and the Wildlife Conservation Act of 2009. These legal frameworks ensure the sustainable conservation of rangeland resources, including soils, water, plants, and animals. The Land Act of 1999 recognizes local communities' rights to use and manage land, including rangelands. However, enforcing these laws is challenging, especially at the local level, due to limited capacity and resources. Addressing these challenges and strengthening enforcement mechanisms is vital for sustainable rangeland management in Tanzania.

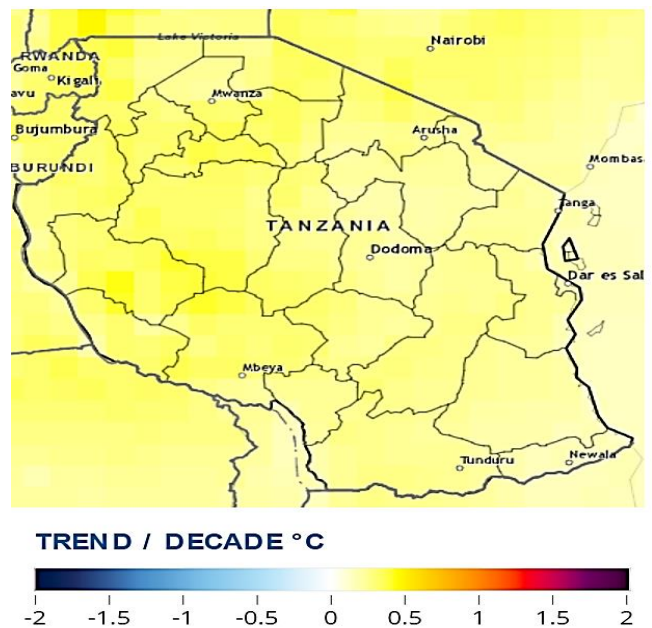
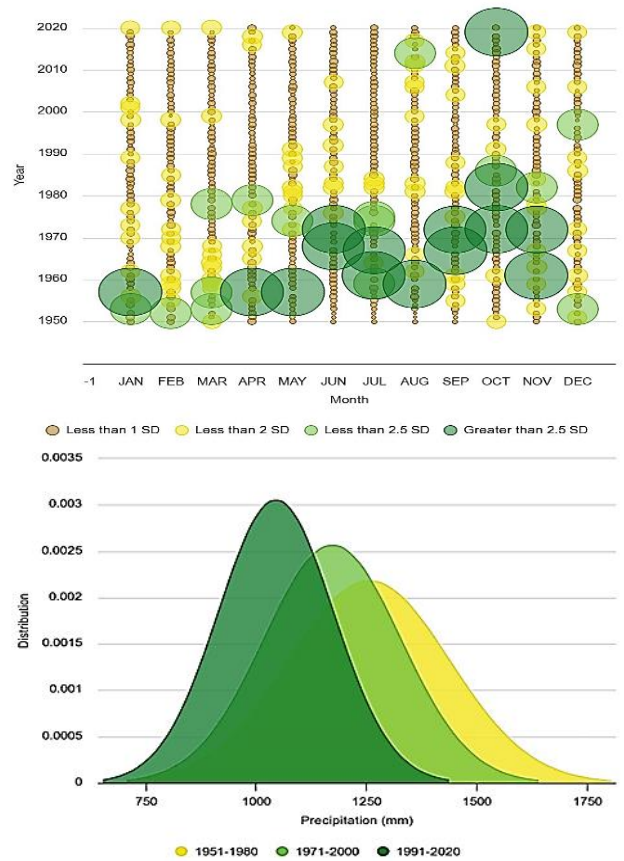


Figure 6. Tanzania's change in precipitation distribution and events intensity from 1971 – 2020 (World Bank group data)

Examples from other countries include Mongolia, where the National Rangeland Health Program, launched in 2003, addresses rangeland degradation through monitoring, training on sustainable grazing practices, and rehabilitating rangelands. The Forest Service and Bureau of Land Management manage vast rangelands in the US using

policies like rotational grazing and habitat restoration. These examples highlight the significance of policies and laws in governing rangeland use and management. Effective enforcement, through monitoring and community involvement, is crucial to ensuring the sustainability of rangeland ecosystems.

Pastoral organizations

Forming pastoral organizations in Tanzania promotes sustainable land use practices and community involvement (Nganga et al. 2019). Village-level organizations endorse practices like rotational grazing, preserving rangeland productivity and ecological integrity. They bridge local communities and government agencies, facilitating communication and collaboration in rangeland management. Organizations coordinate rangeland management across villages and stakeholders at district and regional levels. Likewise, the Tanzania Pastoralist Council (TPC) advocates for policies supporting pastoralists' livelihoods and sustainable land use. TPC collaborates with government agencies and NGOs for participatory rangeland management, ensuring community access to resources. The Forum for Pastoralists in Ethiopia (FPNE) promotes pastoralism and sustainable land use. FPNE influenced a national rangeland management policy supporting pastoralism (Gebeye 2016). The Maasai Mara Wildlife Conservancies Association (MMWCA) manages wildlife conservancies with holistic grazing and wildlife conservation, reducing conflicts and enhancing rangeland productivity (Weldemichel and Lein 2019). Pastoral organizations mobilize resources for research through the Pastoralist Knowledge Hub (PKH), led by the International Livestock Research Institute (ILRI), improving pastoral communities' well-being in East and West Africa (Nganga et al. 2019). Forming pastoral organizations is vital for rangeland management in Tanzania. They promote community-based practices, coordinate efforts, advocate for sustainable policies, mobilize research resources, and support local communities' livelihoods.

Advanced technology in rangeland restoration

Effective rangeland restoration in Tanzania relies on advanced technologies like re-seeding, bush control, remote sensing, mapping, and precision grazing management for sustainability. Strategic re-seeding involves planting resilient seeds in degraded areas to restore vegetation and biodiversity (Fertu et al. 2021). Mapping and remote sensing identify restoration areas and monitor progress through satellite imagery and drone sensors (Rhodes et al. 2022). Targeted re-seeding positively impacts vegetation cover and diversity, improving rangeland health (Fertu et al. 2021). Invasive species control and promoting native vegetation involve various methods, including herbicidal applications, mechanical removal, and biological interventions. Tebuthiuron herbicide has effectively controlled invasive species while facilitating native vegetation regrowth in weed-invaded rangelands, with minimal disruption to ecological balance and cost-effectiveness (Chambers et al.

2021). Tebuthiuron has been used in restoration initiatives in countries such as the US, Canada, and Australia.

Combining indigenous knowledge with modern tracking tools can safeguard vital rangeland environments and boost resilience in pastoralist livelihoods. Precision livestock management, exemplified by GPS tracking, prevents overgrazing, minimizing impacts on rangeland ecosystems (Bailey et al. 2021). Maasai shepherd practices, deeply rooted in cultural heritage, provide insights into localized grazing dynamics and animal behavior, merging indigenous wisdom with real-time data through GPS technology (Galvin et al. 2020). This integration enhances pastoralist livelihoods and preserves rangeland ecosystems (McKemey et al. 2020).

Finally, expanding climate-adapted forage breeding improves sustainability (Moorby and Fraser 2021). Recruiting more forage plant breeders mitigates climate impacts on livestock production, ensuring food supply and soil health (Gomez-Casanovas et al. 2021). Adopting climate-adapted forages enhances income and livelihoods and incorporates indigenous knowledge (Baker 2013). The fusion of tradition and technology promises a resilient and sustainable future.

Use of locally adapted livestock to utilize and control invasive species

Strategic utilization of locally adapted livestock species and breeds offers an effective approach to addressing invasive species in Tanzanian rangelands. The Ankole cattle, Small East African goats, Red Maasai sheep, and Short Horn Zebu are notable examples of breeds with evolved capabilities to thrive in harsh rangeland conditions (Sikiru et al. 2023). Ankole cattle have browsing behaviors that make them effective at consuming invasive plants. Small East African goats exhibit resilience and adaptability, allowing them to eat a variety of shrubs, as well as invasive species of grasses and forbs, efficiently. Red Maasai sheep possess grazing and browsing capabilities, selectively consuming invasive plants while preserving native vegetation. Short Horn Zebu cattle have evolved heat and drought tolerance, disease resistance, and efficient foraging abilities, making them adept at utilizing and controlling invasive species. Including these locally adapted livestock species in management strategies provides a scientifically supported approach to mitigate the spread and impact of invasive species in Tanzanian rangelands, leading to improved ecological sustainability and resilience. Further research and appropriate grazing management practices can optimize the effectiveness of this approach.

Enforcing grading system and quality meat market-based price

Implementing a meat grading system, standard prices, and meat inspectors holds potential in managing Tanzanian rangelands. However, the lack of necessary resources and law enforcement hinders the system's implementation outlined in the Meat Industry Act of 2006. Successful meat grading systems in South Africa and Egypt maximize quality meat production and resolve land use conflicts

(Muzzo and Provenza 2018). Adapting such practices in Tanzania could boost meat exports and address challenges beef producers face with high input costs and inadequate incentives for quality meat production. Enforcing meat grading systems and setting standard prices based on quality could transform Tanzania's beef industry. Consumers respond positively to quality meat even at higher prices. Short training courses and government certificates are necessary for successful implementation. This system improves beef production, encourages the meat processing industry, increases employment opportunities, and improves living standards. Reducing livestock numbers and optimizing use of pastures can mitigate farmer-pastoral conflicts (Benjaminsen et al. 2009; Neely et al. 2009). By embracing these measures, Tanzania can achieve sustainable rangeland management, economic growth, and improved community livelihoods, but collaboration among government agencies, local communities, researchers, and stakeholders is crucial for success.

Satellite, group, and family ranching initiatives in Tanzania

Tanzania, known for its vast rangelands and diverse landscapes, presents a lucrative investment opportunity in livestock and game farming. The concept of satellite ranches, smaller-scale livestock farming operations near central entities like NARCO, has gained attention in Tanzania. These satellite ranches are strategically designed to complement the objectives and activities of the central entities while addressing the specific needs and opportunities of local livestock keepers. However, the current state of satellite ranches often fails to fully utilize their potential, as they primarily serve as land for livestock keeping rather than integrated components of a comprehensive livestock production strategy. Therefore, to unlock the full potential of satellite ranches, it is crucial to reassess and align the goals of the government and the livestock industry towards profitability and sustainability. Well-established satellite ranches can facilitate structured and sustainable livestock management practices among local communities, optimizing the utilization of rangeland resources. This can be achieved by distributing grazing areas and reducing the risk of overgrazing and land degradation. Additionally, satellite ranches provide knowledge and skill transfer opportunities from central entities, fostering capacity building and enhancing local livestock management and land stewardship capabilities. These ranches also contribute to diversifying the income sources of local communities, potentially including ecotourism, which can enhance financial stability. The proliferation of satellite ranches collectively plays a pivotal role in supporting the growth of Tanzania's vital livestock sector and significantly contributes to its development and sustainability.

Group livestock ranching offers an alternative and accessible approach to sustainable rangeland management, particularly for individual pastoralists with limited resources (Boone et al. 2005; Kerven et al. 2021). By forming collaborative initiatives, pastoralists can pool their

livestock herds and resources, share responsibilities, and collectively manage rangelands (Undargaa 2017). This approach reduces the workload for individual members and enables more efficient land management (Hannus and Sauer 2021). Group ranching often attracts support from governmental and non-governmental organizations, providing training, access to veterinary services, and funding for sustainable practices (Pas et al. 2023). Furthermore, collective action enhances the bargaining power of pastoralist groups in markets, leading to better prices for livestock and related products. Moreover, group ranches can implement sustainable practices to reduce environmental impacts, such as overgrazing and land degradation (Zhang et al. 2021). Beyond economic benefits, group ranching fosters community, mutual support, and collaboration among members, contributing to improved livelihoods and the conservation of rangeland ecosystems (Nishi et al. 2023).

Promoting family ranches, exemplified by multi-generational family ranches like the King Ranch in Texas, stands out as a key strategy for enhancing the sustainability of rangeland management (Henderson 2021). These family ranches provide numerous advantages, including multigenerational stewardship, localized expertise in understanding rangeland ecosystems, economic resilience, community integration, and a strong commitment to conservation practices (Grelet et al. 2021). This commitment includes responsible land management techniques like rotational grazing and the preservation of native plant species, contributing to the overall health of rangeland ecosystems. Tanzania supports the establishment of family ranches among pastoralists with substantial herds, often exceeding 200 head of livestock. Like the multi-generational family ranches in the US that have often been in operation for many decades, these family ranches significantly contribute to improved rangeland management, economic stability, and biodiversity preservation (Wilmer et al. 2020; Biggs 2022). The long-term planning views held by multigenerational ranchers in Utah contributed to the ranches implementing more innovative approaches. Their long-term plans included ensuring financial and economic sustainability for future generations (Didier and Brunson 2004). By supporting pastoralist families in transitioning to family ranches and ensuring that these initiatives align with sustainability goals, Tanzania can harness the potential of these ranches to benefit both its people and its vast rangeland ecosystem. Ranch income was a valuable predictor of ranching operations that were innovative (Didier and Brunson 2004). As pastoralists transition to ranching families, they must be able to rely on ranch income to support their families.

In conclusion, satellite, group, and family ranching initiatives offer promising prospects for enhancing the sustainability of Tanzania's renowned and ecologically diverse rangelands. By embracing these initiatives and aligning government policies with sustainability goals, Tanzania can unlock the full potential of its rangelands, ensuring their long-term viability and prosperity. However, the conversion from pastoralism to generational ranching will depend on future generations being able and willing to

continue the family operation. In the US, generational transitions include the transition of capital (often land ownership, equipment, and animals) and knowledge; this can result in a culture of socialization of the heirs to continue the “family tradition”. First generation operations often face high barriers, such as the cost of equipment, animals, land, and knowledge. Therefore, creating family ranch operations will depend on policies and incentives that allow new ranchers to remove barriers to successfully establish satellite operations. This will likely require a combination of culturally relevant educational programs, financial assistance, and the needed capital to create economically sustainable ranching operations that can survive for multiple generations (Inwood 2013).

CONCLUSION AND RECOMMENDATIONS

Sustainable rangeland resource use and management in Tanzania can be achieved by employing a multifaceted approach that considers ecological, social, and economic factors. Strengthening policy enforcement, forming pastoral organizations, advancing technology for rangeland restoration, utilizing locally adapted livestock, and enforcing a grading system and price-based quality meat market are key possibilities to consider. Effective policy enforcement is essential to implement existing laws and regulations governing rangeland resource use and management. Forming pastoral organizations at various levels promotes community-based natural resource management practices, facilitates stakeholder coordination, and embraces public-private partnerships. Advances in technology offer valuable tools for rangeland restoration, enabling targeted interventions, efficient monitoring, and informed decision-making, leading to enhanced vegetation cover, biodiversity, and overall rangeland health. Utilizing locally adapted livestock breeds is crucial in utilizing and controlling invasive species in Tanzanian rangelands, contributing to ecological sustainability and resilience, and enhancing livelihoods of people. Enforcing a grading system and price-based quality meat market can transform Tanzania's beef industry, incentivizing quality meat production, increasing profitability for beef producers, and improving living standards. By embracing these prospects and implementing them effectively, Tanzania can achieve the sustainable use and management of its rangeland resources, leading to ecological preservation, economic growth, and improved livelihoods for local communities. Collaborative efforts among government agencies, local communities, researchers, and other stakeholders are crucial to ensure the successful implementation of these strategies and secure a prosperous future for Tanzania's people and rangelands.

REFERENCES

- Abdurehman A. 2019. Physiological and anatomical adaptation characteristics of Borana cattle to pastoralist lowland environments. *Asian J Biol Sci* 12: 364-372. DOI: 10.3923/ajbs.2019.364.372.
- Adkins SW, Shabbir A, Dhileepan K. 2019. An introduction to the demon plant *Parthenium* weed. In: Adkins SW, Shabbir A, Dhileepan K (eds). *Parthenium Weed: Biology, Ecology and Management*. CAB International, Wallingford UK. DOI: 10.1079/9781780645254.0001.
- Aliloo H, Mrode R, Okeyo AM, Gibson JP. 2020. Ancestral haplotype mapping for GWAS and detection of signatures of selection in admixed dairy cattle of Kenya. *Front Genet* 101: 9108-9127. DOI: 10.3168/jds.2018-14621.
- Allred BW, Scasta JD, Hovick TJ, Fuhlendorf SD, Hamilton RG. 2014. Spatial heterogeneity stabilizes livestock productivity in a changing climate. *Agric Ecosyst Environ* 193: 37-41. DOI: 10.1016/j.agee.2014.04.020.
- Anthony T, Shaban N, Nahonyo C. 2023. Land cover change as a proxy of changes in wildlife distribution and abundance in Tarangire-Simanjira-Lolkisale-Mto wa Mbu Ecosystem. *Tanzan J Sci* 49 (1): 196-206. DOI: 10.4314/tjs.v49i1.17.
- Armson B, Ekiri AB, Alafiatayo R, Cook AJ. 2020. Small ruminant production in Tanzania, Uganda, and Ethiopia: A systematic review of constraints and potential solutions. *Ve Sci* 8 (1): 5. DOI: 10.3390/vetsci8010005.
- Atmadja S, Eshete A, Boissiere M. 2019. Guidelines on Sustainable Forest Management in Drylands of Ethiopia. Food and Agricultural Organization, Rome, Italy.
- Auty H, Swai E, Virhia J, Davis A, De Glanville WA, Kibona T, Lankester F, Shirima G, Cleaveland S. 2021. How can we realise the full potential of animal health systems for delivering development and health outcomes? *Rev Sci Tech* 40 (2): 483-495. DOI: 10.20506/rst.40.2.3239.
- Ayantunde AA, Kango M, Hiernaux P, Udo HM, Tabo R. 2007. Herders' perceptions on ruminant livestock breeds and breeding management in southwestern Niger. *Hum Ecol* 35: 139-149. DOI: 10.1007/s10745-006-9049-6.
- Bailey DW, Trotter MG, Tobin C, Thomas MG. 2021. Opportunities to apply precision livestock management on rangelands. *Front Sustain Food Syst* 5. DOI: 10.3389/fsufs.2021.611915.
- Baker C. 2013. Integrating traditional ecological knowledge and practices with seed collection programs for public land management in the western United States. *J Integr Stud* 4 (1): 1-12.
- Baker D, Cadilhon J, Ochola W. 2015. Identification and analysis of smallholder producers' constraints: applications to Tanzania and Uganda. *Dev Pract* 25 (2): 204-220. DOI: 10.1080/09614524.2015.1007924.
- Beever EA, Huso M, Pyke DA. 2006. Multiscale responses of soil stability and invasive plants to removal of non-native grazers from an arid conservation reserve. *Divers Distrib* 12 (3): 258-268. DOI: 10.1111/j.1366-9516.2006.00253.x.
- Benjaminsen TA, Maganga FP, Abdallah JM. 2009. The Kilosa killings: Political ecology of a farmer-herder conflict in Tanzania. *Dev Change* 40 (3): 423-445. DOI: 10.1111/j.1467-7660.2009.01558.x.
- Biddulph R, Hillbom E. 2020. Registration of private interests in land in a community lands policy setting: An exploratory study in Meru district, Tanzania. *Land Use Policy* 99: 104830. DOI: 10.1016/j.landusepol.2020.104830.
- Biggs NB. 2022. Drivers and constraints of land use transitions on Western grasslands: Insights from a California mountain ranching community. *Landsc Ecol* 37(4): 1185-1205. DOI: 10.1007/s10980-021-01385-6.
- Blackmore E, Guarin A, Kinyua C, Vorley W, Grace D, Alonso S. 2022. The governance of quality and safety in Tanzania's informal milk markets. *Front Sustain Food Syst* 6: 971961. DOI: 10.3389/fsufs.2022.971961.
- Bolo PO, Sommer R, Kihara JM, Kinyua M, Nyawira S, Notenbaert AM. 2019. Rangeland Degradation: Causes, Consequences, Monitoring Techniques and Remedies. CIAT Publication, Nairobi, Kenya.
- Boone RB, BurnSilver SB, Thornton PK, Worden JS, Galvin KA. 2005. Quantifying declines in livestock due to land subdivision. *Rangel Ecol Manag* 58 (5): 523-532. DOI: 10.2111/1551-5028(2005)58[523:QDILDT]2.0.CO;2.
- Bossolani JW, Crusciol CA, Merloti LF, Moretti LG, Costa NR, Tsai SM, Kuramae EE. 2020. Long-term lime and gypsum amendment increase nitrogen fixation and decrease nitrification and denitrification gene abundances in the rhizosphere and soil in a tropical no-till intercropping system. *Geoderma* 375: 114476. DOI: 10.1016/j.geoderma.2020.114476.
- Bremer LL, Nathan N, Trauernicht C, Pascua P, Krueger N, Jokiel J, Barton J, Daily GC. 2021. Maintaining the many societal benefits of

- rangelands: The case of Hawai'i. *Land* 10 (7): 764. DOI: 10.3390/land10070764.
- Cao B, Bai C, Wu K, La T, Su Y, Che L, Zhang M, Lu Y, Gao P, Yang J, Xue Y. 2023. Tracing the future of epidemics: Coincident niche distribution of host animals and disease incidence reveal climate-correlated risk shifts of main zoonotic diseases in China. *Glob Change Biol* 29 (13): 3723-3746. DOI: 10.1111/gcb.16708.
- Castaño-Sánchez JP, Rotz CA, McIntosh MM, Tolle C, Gifford CA, Duff GC, Spiegel SA. 2023. Grass finishing of Criollo cattle can provide an environmentally preferred and cost-effective meat supply chain from United States drylands. *Agric Syst* 210: 103694. DOI: 10.1016/j.agry.2023.103694.
- Chambers JC, Urza AK, Board DI, Miller RF, Pyke DA, Roundy BA, Schupp EW, Tausch RJ. 2021. Sagebrush recovery patterns after fuel treatments mediated by disturbance type and plant functional group interactions. *Ecosphere* 12 (4): e03450. DOI: 10.1002/ecs2.3450.
- Claps S, Mecca M, Di Trana A, Sepe L. 2020. Local small ruminant grazing in the Monti Foy area (Italy): The relationship between grassland biodiversity maintenance and added-value dairy products. *Front Vet Sci* 7: 546513. DOI: 10.3389/fvets.2020.546513.
- CSIRO 2022. Dairy Production in Tanzania. <https://research.csiro.au/livegaps/findings/livestock-production/dairy-production-in-tanzania>
- Cullen B, Tucker J, Snyder K, Lema Z, Duncan A. 2014. An analysis of power dynamics within innovation platforms for natural resource management. *Innov Dev* 4 (2): 259-275. DOI: 10.1080/2157930X.2014.921274.
- Dakhil MA, El-Keblawy A, El-Sheikh MA, Halmy MW, Ksiksi T, Hassan WA. 2021. Global invasion risk assessment of *Prosopis juliflora* at biome level: Does soil matter? *Biology* 10 (3): 203. DOI: 10.3390/biology10030203.
- De Glanville WA, Nyarobi JM, Kibona T, Halliday JE, Thomas KM, Allan KJ, Johnson PC, Davis A, Lankester F, Claxton JR, Rostal MK. 2022. Inter-epidemic Rift Valley fever virus infection incidence and risks for zoonotic spillover in northern Tanzania. *PLoS Negl Trop Dis* 16 (10): e0010871. DOI: 10.1371/journal.pntd.0010871.
- Deshesh THMA. 2021. Amelioration of salt affected soils and its productivity using soil amendments and tillage system. *Menoufia J Soil Sci* 6 (2): 31-47. DOI: 10.21608/mjss.2021.161175.
- Didier EA, Brunson MW. 2004. Adoption of range management innovations by Utah ranchers. *J Range Manag* 57 (4): 330-336. DOI: 10.2111/1551-5028(2004)057[0330:AORMIB]2.0.CO;2.
- Dieters LS, Meale SJ, Quigley SP, Hoffman LC. 2021. Meat quality characteristics of lot-fed Australian Rangeland goats are unaffected by live weight at slaughter. *Meat Sci* 175: 108437. DOI: 10.1016/j.meatsci.2021.108437.
- Donovan M, Monaghan R. 2021. Impacts of grazing on ground cover, soil physical properties and soil loss via surface erosion: A novel geospatial modelling approach. *J Environ Manag* 287: 112206. DOI: 10.1016/j.jenvman.2021.112206.
- Eilola S, Duguma L, Käyhkö N, Minang PA. 2021. Coalitions for Landscape Resilience: Institutional Dynamics behind Community-Based Rangeland Management System in North-Western Tanzania. *Sustainability*. 13(19):10939. DOI: 10.3390/su131910939.
- El Shaer HM, Al Dakheel AJ. 2016. Sustainable diversity of salt-tolerant fodder crop-livestock production system through utilization of saline natural resources: Egypt case study. In: Khan MA, Ozturk M, Gul B, Ahmed MZ (eds). *Halophytes for Food Security in Dry Lands*. Academic Press, Amsterdam. DOI: 10.1016/B978-0-12-801854-5.00011-X.
- Enahoro D, Galiè A, Abukari Y, Chiwanga GH, Kelly TR, Kahamba J, Massawe FA, Mapunda F, Jumba H, Weber C, Dione M. 2021. Strategies to upgrade animal health delivery in village poultry systems: perspectives of stakeholders from northern Ghana and central zones in Tanzania. *Front Vet Sci* 8: 611357. DOI: 10.3389/fvets.2021.611357.
- Fernandez-Garcia V, Marcos E, Fule PZ, Reyes O, Santana VM, Calvo L. 2020. Fire regimes shape diversity and traits of vegetation under different climatic conditions. *Sci Total Environ* 716: 137137. DOI: 10.1016/j.scitotenv.2020.137137.
- Fertu C, Dobrota LM, Balasan DL, Stanciu S. 2021. Monitoring the vegetation of agricultural crops using drones and remote sensing-comparative presentation. *Sci Pap Manag Econ Eng Agric Rural Dev* 21: 249-254.
- Finca A, Linnane S, Slinger J, Getty D, Igshaan Samuels M. 2023. Implications of the breakdown in the indigenous knowledge system for rangeland management and policy: A case study from the eastern Cape in South Africa. *Afr J Range Forage Sci* 40 (1): 47-61. DOI: 10.2989/10220119.2022.2138973.
- Flintan FE. 2012. Making Rangelands Secure: Past Experience and Future Options. International Land Coalition, Rome, Roma.
- Fuhlendorf SD, Engle DM, Kerby JA, Hamilton R. 2009. Pyric herbivory: Rewilding landscapes through the recoupling of fire and grazing. *Conserv Biol* 23 (3): 588-598. DOI: 10.1111/j.1523-1739.2008.01139.x.
- Galvin KA, Backman D, Luizza MW, Beeton TA. 2020. African community-based conservancies: Innovative governance for whom? In: Levin J (eds). *Nomad-State Relationships in International Relations*. Palgrave Macmillan, Cham. DOI: 10.1007/978-3-030-28053-6.
- Gebeye BA. 2016. Unsustain the sustainable: An evaluation of the legal and policy interventions for pastoral development in Ethiopia. *Pastoralism* 6: 2. DOI:10.1186/s13570-016-0049-x.
- Gebreyohanes G, Yilma Z, Moyo S, Okeyo Mwai A. 2021. Dairy Industry Development in Ethiopia: Current Status, Major Challenges and Potential Interventions for Improvement. ILRI Position Paper, Nairobi, Kenya.
- Gelan D. 2014. Pastoral Rangelands Policy and Institutional Concerns in Ethiopia. Social Science Research Network. DOI: 10.2139/ssrn.2524948.
- Gerber PJ, Mottet A, Opio CI, Falcucci A, Teillard F. 2015. Environmental impacts of beef production: Review of challenges and perspectives for durability. *Meat Sci* 109: 2-12. DOI: 10.1016/j.meatsci.2015.05.013.
- Getabalew M, Alemneh T. 2019. Factors affecting the productivity of rangelands. *Med Pub J* 3 (1):19.
- Gomez-Casanovas N, Blanc-Betes E, Moore CE, Bernacchi CJ, Kantola I, DeLucia EH. 2021. A review of transformative strategies for climate mitigation by grasslands. *Sci Total Environ* 799: 149466. DOI: 10.1016/j.scitotenv.2021.149466.
- Grelet G, Lang S, Merfield C et al. 2021. Regenerative Agriculture in Aotearoa New Zealand-Research Pathways to Build Science-Based Evidence and National Narratives. https://mro.massey.ac.nz/bitstream/handle/10179/16144/Grelet_Lang_Feb-2021_Regen_Ag_NZ_White_ePaper.pdf?sequence=1.
- Gwaka JK, Demafo MA, N'konzi JP, Pak A, Olumoh J, Elfaki F, Adegboye OA. 2023. Machine-learning approach for risk estimation and risk prediction of the effect of climate on bovine respiratory disease. *Mathematics* 11 (6): 1354. DOI: 10.3390/math11061354.
- Hailemariam MB, Woldu Z, Asfaw Z, Lulekal E. 2021. Ethnobotany of an indigenous tree *Ptilostigma thonningii* (Schumach.) Milne-Redh.(Fabaceae) in the arid and semi-arid areas of South Omo Zone, southern Ethiopia. *J Ethnobiol Ethnomed* 17: 44. DOI: 10.1186/s13002-021-00469-6.
- Hailu B, Mehari H. 2021. Impacts of soil salinity/sodicity on soil-water relations and plant growth in dry land areas: A review. *J Nat Sci Res* 2: 1-10.
- Hall R, Cousins B. 2013. Livestock and the rangeland commons in South Africa's land and agrarian reform. *Afr J Range Forage Sci* 30 (1-2): 11-15. DOI: 10.2989/10220119.2013.768704.
- Haller T. 2019. The different meanings of land in the age of neoliberalism: Theoretical reflections on commons and resilience grabbing from a social anthropological perspective. *Land* 8 (7): 104. DOI: 10.3390/land8070104.
- Hannus V, Sauer J. 2021. It is not only about money German farmers' preferences regarding voluntary standards for farm sustainability management. *Land Use Policy* 108: 105582. DOI: 10.1016/j.landusepol.2021.105582.
- Harmel RD, Smith DR, Haney RL, Angerer J, Haile N, Grote L, Grote S, Tiner K, Goodwin J, Teague R, Derner J. 2021. Transitioning from conventional continuous grazing to planned rest-rotation grazing: A beef cattle case study from central Texas. *J Soil Water Conserv* 76 (6): 534-546. DOI: 10.2489/jswc.2021.00159.
- Henderson RR. 2021. Sustainable Family Farming and Yeoman Ideals: 1860 to 2000 in North-West Tasmania. Routledge, New York. DOI: 10.4324/9781003229841.
- Horák J, Kotuš T, Toková L, Aydın E, Igaz D, Šimanský V. 2021. A sustainable approach for improving soil properties and reducing N₂O emissions is possible through initial and repeated biochar application. *Agronomy* 11 (3): 582. DOI: 10.3390/agronomy11030582.
- Ingram DJ, Coad L, Milner-Gulland EJ, Parry L, Wilkie D, Bakarr MI, Benítez-López A, Bennett EL, Bodmer R, Cowlshaw G, El Bizri HR.

2021. Wild meat is still on the menu: Progress in wild meat research, policy, and practice from 2002 to 2020. *Ann Rev Environ Resour* 46: 221-254. DOI: 10.1146/annurev-environ-041020-063132.
- Ingram DJ. 2020. Wild meat in changing times. *J Ethnobiol* 40 (2): 117-130. DOI: 10.2993/0278-0771-40.2.117.
- Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland.
- Inwood S. 2013. Social forces and cultural factors influencing farm transition. *Choices* 28 (2): 1-5.
- Jamali AA, Zarekia S, Keshavarz SR. 2023. Assessing climatic, edaphic, vegetation cover data, and their trends around cities located in desert environments using online remote sensing. *Environ Dev Sustain* 11: 1-6. DOI: 10.1007/s10668-023-03550-0.
- Jawuro SO, Koech OK, Karuku GN, Mbau JS. 2017. Effect of piospheres on physio-chemical soil properties in the Southern Rangelands of Kenya. *Ecol Process* 6: 1-7. DOI: 10.1186/s13717-017-0082-8.
- John P, Kabote SJ. 2017. Land governance and conflict management in Tanzania: Institutional capacity and policy-legal framework challenges. *Am J Rural Dev* 5 (2): 46-54. DOI: 10.12691/ajrd-5-2-3.
- Kamwenda GJ. 2002. Ngitili agrosilvipastoral systems in the United Republic of Tanzania. *Unasylva* 53: 46-50.
- Kangalawe RY, Mung'ong'o CG, Mwakaje AG, Kalumanga E, Yanda PZ. 2017. Climate change and variability impacts on agricultural production and livelihood systems in western Tanzania. *Clim Dev* 9 (3): 202-216. DOI: 10.1080/17565529.2016.1146119.
- Karger DN, Saladin B, Wüest RO, Graham CH, Zurell D, Mo L, Zimmermann NE. 2023. Interannual climate variability improves niche estimates for ectothermic but not endothermic species. *Sci Rep* 13 (1): 12538. DOI: 10.1038/s41598-023-39637-x.
- Kelio A. 2022. Factors affecting small-scale livestock farming in Kenya. *Intl J Livest Policy* 1(2): 1-8. DOI: 10.47941/ijlp.889.
- Kerven C, Robinson S, Behnke R. 2021. Pastoralism at scale on the Kazakh rangelands: From clans to workers to ranchers. *Front Sustain Food Syst* 4: 590401. DOI: 10.3389/fsufs.2020.590401.
- Khwarahm NR. 2023. Predicting the spatial distribution of *Hyalomma* spp., vector ticks of Crimean–Congo Haemorrhagic fever in Iraq. *Sustainability* 15 (18): 13669. DOI: 10.3390/su151813669.
- Kicheleri RP, Kajembe GC, True T, Martin FM, Nielsen R. 2018. Dispossession and Power Struggles in Community – Based Natural Resources Management: A Case of Burunge Wildlife Management Area, Tanzania. [Thesis]. Sokoine University of Agriculture, Morogoro.
- Kideghesho JR. 2016. The elephant poaching crisis in Tanzania: A need to reverse the trend and the way forward. *Trop Conserv Sci* (1): 369-388. DOI: 10.1177/194008291600900120.
- Kimaro EG, Mor SM, Toribio J-ALML. 2018. Climate change perception and impacts on cattle production in pastoral communities of Northern Tanzania. *Pastoralism* 8 (1): 19. DOI: 10.1186/s13570-018-0125-5.
- Kimiti KS, Western D, Mbau JS, Wasonga OV. 2018. Impacts of long-term land-use changes on herd size and mobility among pastoral households in Amboseli ecosystem, Kenya. *Ecol Process* 7: 1-9. DOI: 10.1186/s13717-018-0115-y.
- Kitole FA, Sesabo JK. 2022. Smallholder livestock keepers' breeding choices and its implication on poverty reduction in developing countries: Empirical evidence from Tanzania. *Glob Soc Welfare* 9 (4): 241-251. DOI: 10.1007/s40609-022-00252-9.
- Kivelia J. 2007. *Cultivation Trends in the Buffer Zones of East African Rangeland Protected Areas: The Case of Ngorongoro and Loliondo in Tanzania*. [Dissertation]. University College London, London.
- Kotzé E, Sandhage-Hofmann A, Meinel JA, Du Preez CC, Amelung W. 2013. Rangeland management impacts on the properties of clayey soils along grazing gradients in the semi-arid grassland biome of South Africa. *J Arid Environ* 97: 220-229. DOI: 10.1016/j.jaridenv.2013.07.004.
- Lamont BB, He T, Yan Z. 2019. Evolutionary history of fire-stimulated resprouting, flowering, seed release, and germination. *Biol Rev* 94 (3): 903-928. DOI: 10.1111/brv.12483.
- Landau SY, Provenza FD, Gardner DR, Pfister JA, Knoppel EL, Peterson C, Kababya D, Needham GR, Villalba JJ. 2009. Neem-tree (*Azadirachta indica* Juss.) extract as a feed additive against the American dog tick (*Dermacentor variabilis*) in sheep (*Ovis aries*). *Vet Parasitol* 165 (3-4): 311-317. DOI: 10.1016/j.vetpar.2009.07.047.
- Leke JO, Leke EN. 2019. Environmental sustainability and development in Nigeria: Beyond the rhetoric of governance. *Intl J Dev Manag Rev* 14 (1): 25-37.
- Leroy G, Boettcher P, Besbes B, Peña CR, Jaffrezic F, Baumung R. 2020. Food securers or invasive aliens? Trends and consequences of non-native livestock introgression in developing countries. *Glob Food Secur* 26: 100420. DOI: 10.1016/j.gfs.2020.100420.
- Lindén E, Gough L, Olofsson J. 2021. Large and small herbivores have strong effects on tundra vegetation in Scandinavia and Alaska. *Ecol Evol* 11 (17): 12141-12152. DOI: 10.1002/ece3.7977.
- Lindsey PA, Roulet PA, Romanach SS. 2007. Economic and conservation significance of the trophy hunting industry in sub-Saharan Africa. *Biol Conserv* 134 (4): 455-469. DOI: 10.1016/j.biocon.2006.09.005.
- Lippi CA, Mundis SJ, Sippy R, Flenniken JM, Chaudhary A, Hecht G, Carlson CJ, Ryan SJ. 2023. Trends in mosquito species distribution modeling: Insights for vector surveillance and disease control. *Parasit Vector* 16 (1): 302. DOI: 10.1186/s13071-023-05912-z.
- Little PD. 2019. Land use conflicts in the agricultural/pastoral borderlands: The case of Kenya. In: Little PD (eds). *Inland's at Risk in The Third World*. Routledge, New York. DOI: 10.4324/9780429042065-10.
- Louhaichi M, Ouled Belgacem A, Petersen SL, Hassan S. 2019. Effects of climate change and grazing pressure on shrub communities of West Asian rangelands. *Intl J Clim Change Strateg Manag* 11 (5): 660-671. DOI: 10.1108/ijccsm-02-2018-0017.
- Ma'alin A, Abdimahad K, Hassen G, Mahamed A, Hassen M. 2021. Management practices and production constraints of indigenous Somali cattle breed in Shabelle Zone, Somali Regional State, Ethiopia. *Open J Anim Sci* 12 (1): 103-117. DOI: 10.4236/ojas.2022.121008.
- Mahajan SL, Jagadish A, Glew L, Ahmadiya G, Becker H, Fidler RY, Jeha L, Mills M, Cox C, DeMello N, Harborne AR. 2021. A theory-based framework for understanding the establishment, persistence, and diffusion of community-based conservation. *Conserv Sci Pract* 3 (1): e299. DOI: 10.1111/csp2.299.
- Mairomi HW, Kimengi JN. 2021. Governance dynamics in rangelands: An evaluation of the applicability of Ostrom's principles in the Western Highlands of Cameroon. *Sci Afr* 12: e00837. DOI: 10.1016/J.SCIAF.2021.E00837.
- Maleko DD. 2022. Essay: Milk and Meat Production in the Drylands of Tanzania Amidst Climate Change. Table. <https://tabledebates.org/blog/essay-milk-and-meat-production-drylands-tanzania-amidst-climate-change>.
- Maoncha MR. 2021. Effects of Perceived Climate Variability on Provisioning Ecosystem Services among Pastoral System of Laikipia West Sub-County-Kenya. [Dissertation]. Egerton University, Nakuru.
- Matano AS, Kanangire CK, Anyona DN, Abum PO, Gelder FB, Dida GO, Owuor PO, Ofulla AV. 2015. Effects of land use change on land degradation reflected by soil properties along Mara River, Kenya and Tanzania. *Open J Soil Sci* 5: 20-38. DOI: 10.4236/ojss.2015.51003.
- McKeney M, Ens E, Rangers YM, Costello O, Reid N. 2020. Indigenous knowledge and seasonal calendar inform adaptive savanna burning in northern Australia. *Sustainability* 12 (3): 995. DOI: 10.3390/su12030995.
- Mdegela TE, Maleko DD, Msalya GM, Mtengeti EJ. 2022. Vegetation composition, forage biomass and soil seed bank of a continuously grazed rangeland site in tropical sub-humid environment, Tanzania. *J Basic Appl Sci* 18: 58-64. DOI: 10.29169/1927-5129.2022.18.07.
- Mesfin S, Taye G, Desta Y, Sibhatu B, Muruts H, Mohammedbrhan M. 2018. Short-term effects of bench terraces on selected soil physical and chemical properties: Landscape improvement for hillside farming in semi-arid areas of northern Ethiopia. *Environ Earth Sci* 77: 1-4. DOI: 10.1007/s12665-018-7528-x.
- Middleton N. 2018. Rangeland management and climate hazards in drylands: dust storms, desertification and the overgrazing debate. *Nat Hazard* 92: 57-70. DOI: 10.1007/s11069-016-2592-6.
- Milisha BS. 2021. Assessments of Soil Fertility in Case of Some Selected Kebeles of LemmuandBilbilo Woreda, Oromia Region, Central Ethiopia. [Dissertation]. Debre Birhan University, Birhan.
- Ministry of Livestock and Fisheries (MLF). 2017. *Livestock Sector Analysis, Tanzania 2017*. http://192.111.141.171/media/127929_MOFL_Tanzania_LSA_compressed.pdf.
- Moorby JM, Fraser MD. 2021. New feeds and new feeding systems in intensive and semi-intensive forage-fed ruminant livestock systems. *Animal* 15: 100297. DOI: 10.1016/j.animal.2021.100297.

- Moyo F, Ijumba J, Lund JF. 2016. Failure by design? Revisiting Tanzania's flagship wildlife management area Burunge. *Conserv Soc* 14 (3): 232-242. DOI: 10.4103/0972-4923.191160.
- Msimi HM, Ponela-Mlelwa T, Mtei BJ, Kapaga AM. 2001. Contagious bovine pleuropneumonia in Tanzania: Current status. *Trop Anim Health Prod* 33: 21-28. DOI: 10.1023/a:1010377325566.
- Msofe NK, Sheng L, Lyimo J. 2019. Land use change trends and their driving forces in the Kilombero Valley Floodplain, Southeastern Tanzania. *Sustainability* 11 (2): 505. DOI: 10.3390/su11020505.
- Msoffe FU. 2010. Land Use Change in Maasailand Drivers, Dynamics and Impacts on Large Herbivores and Agro-pastoralism. [Dissertation]. The University of Edinburgh, Edinburgh, UK.
- Mudavadi OP, Emmanuel MA, Charles G, Namasake MF, Bernard LA. 2020. Effects of season variation on water, feed, milk yield and reproductive performance of dairy cows in smallholder farms in eastern Africa. *J Agric Ecol Res Intl* 21 (8): 1-15. DOI: 10.9734/jaeri/2020/v21i830157.
- Mueller SE, Thode AE, Margolis EQ, Yocom LL, Young JD, Iniguez JM. 2020. Climate relationships with increasing wildfire in the southwestern US from 1984 to 2015. *For Ecol Manag* 460: 117861. DOI: 10.1016/j.foreco.2019.117861.
- Munson SM, Yackulic EO, Bair LS, Copeland SM, Gunnell KL. 2020. The biggest bang for the buck: Cost-effective vegetation treatment outcomes across drylands of the western United States. *Ecol Appl* 30 (7): e02151. DOI: 10.1002/eap.2151.
- Muzzo BI, Mtengeti EJ, Mwilawa AJ. 2023. Allelopathic potential of *Chromolaena odorata* leaf extracts on seed germination and seedling growth of selected crop and pasture species in Serengeti, Tanzania. *Intl J Bot Stud* 8 (1): 12-22.
- Muzzo BI, Provenza FD. 2018. A review of strategies for overcoming challenges of beef production in Tanzania. *Livest Res Rural Dev* 30 (12).
- NAFORMA. 2015. National Forest Resources Monitoring and Assessment of Tanzania Mainland: Main Results. Report. <http://www.fao.org/forestry/43612-09cf2f02c20b55c1c00569e679197dcde.pdf>.
- Nandonde S, Gebru G, Stapleton J. 2017. Red meat production in the Tanzanian livestock master plan. Tanzania Livestock Master Plan Brief. https://cgspage.cgiar.org/bitstream/handle/10568/89059/TanzaniaLM_P_redmeat.pdf?sequence=5.
- Naumann H, Sepela R, Rezaire A, Masih SE, Zeller WE, Reinhardt LA, Robe JT, Sullivan ML, Hagerman AE. 2018. Relationships between structures of condensed tannins from Texas legumes and methane production during in vitro rumen digestion. *Molecules* 23 (9): 2123. DOI: 10.3390/molecules23092123.
- Ndesanjo RB, Theodory TF. 2021. Local-based initiatives to adapt to climate variability and change in Tanzania. *Tanzan J Dev Stud* 19 (2).
- Neely C, Bunning S, Wilkes A. 2009. Review of Evidence on Drylands Pastoral Systems and Climate Change. FAO, Roma.
- Nelson F, Sulle E, Roe D. 2016. Saving Africa's Vanishing Wildlife: How Civil Society Can Help Turn the Tide. <https://africaportal.org/publication/saving-africas-vanishing-wildlife-how-civil-society-can-help-turn-the-tide/>.
- Nganga IN, Robinson LW, Abdu NH, Ontiri E, Senda TS. 2019. A Comparative Analysis of Three Community-Based Rangeland Management Cases: Taking Successes in Land Restoration to Scale Project. ILRI Project Report, Nairobi, Kenya.
- Ngondya IB, Munishi LK. 2022. Managing invasive plants through a nature-based approach in complex landscapes. *Trend Ecol Evol* 37: 284-288. DOI: 10.1016/j.tree.2022.01.003.
- Niamir-Fuller M. 2005. Managing mobility in African rangelands. In: Mwangi E (eds). *Collective Action and Property Rights for Sustainable Rangeland Management*. CAPRI Research Brief, International Food Policy Research Institute, Washington, D.C.
- Nishi M, Subramanian SM, Melaku A. 2023. Synthesis: Ecosystem Restoration in the Context of Socio-Ecological Production Landscapes and Seascapes (SEPLS). In: Nishi M, Subramanian SM (eds). *Ecosystem Restoration through Managing Socio-Ecological Production Landscapes and Seascapes (SEPLS)*. Springer Nature, Singapore. DOI: 10.1007/978-981-99-1292-6_14.
- Njisane YZ, Mukumbo FE, Muchenje V. 2020. An outlook on livestock welfare conditions in African communities—A review. *Asian-Australasian J Anim Sci* 33 (6): 867-878. DOI: 10.5713/ajas.19.0282.
- Ntalo M, Ravhuhali KE, Moyo B, Mmbi NE, Mokoboki KH. 2022. Physical and chemical properties of the soils in selected communal properties associations of South Africa. *PeerJ* 10: e13960. DOI: 10.7717/peerj.13960.
- Nuhu S. 2019. Peri-urban land governance in developing countries: Understanding the role, interaction and power relation among actors in Tanzania. *Urban Forum* 30: 1-16. DOI: 10.1007/s12132-018-9339-2.
- Nzunda EF, Midtgaard F. 2019. Deforestation and loss of bushland and grassland primarily due to expansion of cultivation in mainland Tanzania (1995-2010). *J Sustain For* 38 (6): 509-525. DOI: 10.1080/10549811.2019.1598437.
- Nzunda EF, Yusuph AS. 2022. Forest Degradation in Tanzania: A systematic literature review. In: Samec P (eds). *Forest Degradation Under Global Change*. InTechOpen, London. DOI: /10.5772/intechopen.107157.
- O'Connor TG, van Wilgen BW. 2020. The impact of invasive alien plants on rangelands in South Africa. In: van Wilgen BW, Measey J, Richardson DM, Wilson JR, Zengeya TA (eds). *Biological Invasions in South Africa*. Springer, Cham. DOI: 10.1007/978-3-030-32394-3_16.
- Olayide OM. 2021. Nigeria - Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security. ZEF Working Paper Series, No. 201. University of Bonn, Center for Development Research (ZEF), Bonn. DOI: 10.22004/ag.econ.308807.
- Oloo RD, Ekine-Dzivenu CC, Ojango JM, Mrode RA, Chagunda M, Okeyo Mwai A. 2022. Effects of Breed Exoticness, Agro-Ecological Zone and Their Interaction on Production and Fertility Traits of Multibreed Dairy Cattle in Kenya. ILRI Research Report, Nairobi, Kenya.
- Olovsson E. 2019. Seroprevalence and Risk Factors for Rift Valley Fever and Capripoxvirus in Small Ruminants in the Border Region of Tanzania-Zambia. Swedish University of Agricultural Sciences, Uppsala.
- Opiyo F, Wasonga O, Nyangito M, Schilling J, Munang R. 2015. Drought adaptation and coping strategies among the Turkana pastoralists of northern Kenya. *Intl J Disaster Risk Sci* 6: 295-309. DOI: 10.1007/s13753-015-0063-4.
- Pas A, Watson EE, Butt B. 2023. Land tenure transformation: The case of community conservancies in northern Kenya. *Political Geogr* 106: 102950. DOI: 10.1016/j.polgeo.2023.102950.
- Pauler CM, Isselstein J, Suter M, Berard J, Braunbeck T, Schneider MK. 2020. Choosy grazers: Influence of plant traits on forage selection by three cattle breeds. *Funct Ecol* 34 (5): 980-992. DOI: 10.1111/1365-2435.13542.
- Provenza FD, Kronberg SL, Gregorini P. 2019. Is grassfed meat and dairy better for human and environmental health? *Front Nutr* 6: 26. DOI: 10.3389/fnut.2019.00026.
- Puyravaud JP. 2003. Standardizing the calculation of the annual rate of deforestation. *For Ecol Manag* 177: 593-596. DOI: 10.1016/S0378-1127(02)00335-3.
- Ragkos A, Koutouzidou G, Koutsou S, Roustemis D. 2017. A new development paradigm for local animal breeds and the role of information and communication technologies. In: Theodoridis A, Ragkos A, Salampanis M (eds). *Innovative Approaches and Applications for Sustainable Rural Development: 8th International Conference. HAICTA, Chania, Crete 21-24, September 2017*.
- Rainsford FW, Kelly LT, Leonard SW, Bennett AF. 2021. How does prescribed fire shape bird and plant communities in a temperate dry forest ecosystem? *Ecol Appl* 31 (4): e02308. DOI: 10.1002/eap.2308.
- Rathore MK, Sharma LK. 2023. Efficacy of Species Distribution Models (SDMs) for ecological realms to ascertain biological conservation and practices. *Biodivers Conserv* 32: 3053-3087. DOI: 10.1007/s10531-023-02648-1.
- Rego FC, Morgan P, Fernandes P, Hoffman C, Castro Rego F, Morgan P, Fernandes P, Hoffman C. 2021. Fire effects on plants, soils, and animals. In: Rego FC, Morgan P, Fernandes P, Hoffman C (eds). *Fire Science: From Chemistry to Landscape Management*. Springer, Cham. DOI: 10.1007/978-3-030-69815-7_9.
- Rhodes EC, Perotto-Baldivieso HL, Reeves MC, Gonzalez LA. 2022. Perspectives on the special issue for applications of remote sensing for livestock and grazingland management. *Remote Sens* 14 (8): 1882. DOI: /10.3390/rs14081882.
- Robinson NP, Allred BW, Naugle DE, Jones MO. 2019. Patterns of rangeland productivity and land ownership: Implications for conservation and management. *Ecol Appl* 29 (3): e01862. DOI: 10.1002/eap.1862.

- Ruvuga PR, Wredle E, Nyberg G, Hussein RA, Masao CA, Selemani IS, Sangeda AZ, Kronqvist C. 2021. Evaluation of rangeland condition in Miombo woodlands in eastern Tanzania in relation to season and distance from settlements. *J Environ Manag* 290: 112635. DOI: 10.1016/j.jenvman.2021.112635.
- Sangeda AZ, Maleko DD. 2018. Rangeland condition and livestock carrying capacity under the traditional rotational grazing system in northern Tanzania. *Livest Res Rural Dev* 30 (5): 79.
- Saputra M, Sutomo, Humaida N, Hadiyan Y. 2023. Smart farming: Modeling distribution of *Xanthomonas campestris* pv. *oryzae* as a leaf blight-causing bacteria in rice plants. *IOP Conf Ser: Earth Environ Sci* 1133 (1): 012026. DOI: 10.1088/1755-1315/1133/1/012026.
- Sargison ND. 2020. The critical importance of planned small ruminant livestock health and production in addressing global challenges surrounding food production and poverty alleviation. *N Z Vet J* 68 (3): 136-144. DOI: 10.1080/00480169.2020.1719373.
- Scasta JD, Thacker ET, Hovick TJ, Engle DM, Allred BW, Fuhlendorf SD, Weir JR. 2016. Patch-Burn Grazing (PBG) as a livestock management alternative for fire-prone ecosystems of North America. *Renew Agric Food Syst* 31 (6): 550-567. DOI: 10.1017/S1742170515000411.
- Scasta JD, Twidwell D, Donovan V, Roberts C, Thacker E, Wilbur R, Fuhlendorf S. 2023. Role and management of fire in rangelands. In: McNew LB, Dahlgren DK, Beck JL (eds). *Rangeland Wildlife Ecology and Conservation*. Springer International Publishing, Switzerland. DOI: 10.1007/978-3-031-34037-6_6.
- Selemani IS. 2014. Communal rangelands management and challenges underpinning pastoral mobility in Tanzania: A review. *Livest Res Rural Dev* 26 (5): 1-5.
- Selemani IS. 2015. Influence of ngitili management on vegetation and soil characteristics in semi-arid Sukumaland, Tanzania. *Livest Res Rural Dev* 27 (37): 213-225.
- Semenza JC, Menne B. 2009. Climate change and infectious diseases in Europe. *Lancet Infect Dis* 9 (6): 365-375. DOI: 10.1016/S1473-3099(09)70104-5.
- Sikiru AB, Velayudhan SM, Nair MR, Veerasamy S, Makinde JO. 2023. Sustaining livestock production under the changing climate: Africa scenario for Nigeria resilience and adaptation actions. In: Egbueri JC, Ighalo JO, Pande CB (eds). *Climate Change Impacts on Nigeria: Environment and Sustainable Development*. Springer International, Switzerland. DOI: 10.1007/978-3-031-21007-5_13.
- Sindato C, Karimuribo E, Mboera LE. 2011. The epidemiology and socio-economic impact of Rift Valley fever in Tanzania: A review. *Tanzan J Health Res* 13 (5): 305-318. DOI: 10.4314/thrb.v13i5.1.
- Sindato C, Karimuribo ED, Vairo F, Misinzo G, Rweyemamu MM, Hamid MM, Haider N, Tungu PK, Kock R, Rumisha SF, Mbilu T. 2022. Rift Valley fever seropositivity in humans and domestic ruminants and associated risk factors in Sengerema, Ilala, and Rufiji Districts, Tanzania. *Intl J Infect Dis* 122: 559-565. DOI: 10.1016/j.ijid.2022.07.012.
- Singleton AL, Glidden CK, Chamberlin AJ, Tuan R, Palasio RG, Pinter A, Caldeira RL, Mendonça CL, Carvalho OS, Monteiro MV, Athni TS, Sokolow SH, Mordecai EA, De Leo GA. 2023. Species distribution modeling for disease ecology: A multi-scale case study for schistosomiasis host snails in Brazil. *MedRxiv* 2023: 1-51. DOI: 10.1101/2023.07.10.23292488.
- Snaibi W, Mezhrab A. 2020. Livestock breeders' adaptation to climate variability and change in Morocco's Arid Rangelands. In: Filho WL, Ogue N, Ayal D, Adeleke L, da Silva I (eds). *African Handbook of Climate Change Adaptation*. Springer International Publishing, Cham, Switzerland. DOI: 10.1007/978-3-030-45106-6.
- Sulle E, Nelson F. 2009. *Biofuels, Land Access and Rural Livelihoods in Tanzania*. International Institute for Environment and Development, London.
- Sulle E. 2021. Qualitative Outcome Study: The Contribution of the CGIAR Research Program on Livestock to Land Use Planning Processes in Ethiopia, Kenya and Tanzania. ILRI, Nairobi, Kenya.
- Sutomo S, Van Etten E. 2017. Species distribution model of invasive alien species *Acacia nilotica* for Central-Eastern Indonesia using Biodiversity Climate Change. *Trop Drylands* 1: 36-42. DOI: 10.13057/tropdrylands/t010106.
- Sutomo S, Van Etten ED, Wahab L. 2016. Proof of *Acacia nilotica* stand expansion in Bekol Savanna, Baluran National Park, East Java, Indonesia through remote sensing and field observations. *Biodiversitas* 17 (1): 96-101. DOI: 10.13057/biodiv/d170114.
- Swai ES, Mkumbukwa AJ, Chaula SL, Leba BG. 2021. Epidemiological investigation of Bovine Brucellosis in indigenous cattle herds in Kasulu District of Tanzania. *Yale J Biol Med* 94 (2): 285-296.
- Tahir J, Belgacem AO, Jibrán R. 2022. Realizing food security in saline environments in a changing climate: Mitigation technologies. In: Behnassi M, Gupta H, Baig MB, Noorka IR (eds). *The Food Security, Biodiversity, and Climate Nexus*. Springer, Cham. DOI: 10.1007/978-3-031-12586-7_20.
- Tanzania National Bureau of Statistics (NBS). 2022. *Demographic and Health Survey and Malaria Indicator Survey (TDHS-MIS)*. https://www.nbs.go.tz/nbs/takwimu/dhs/Tanzania_DHS-MIS_2022_Final_Report.pdf.
- Taylor AN, Lindsey PA, Davies-Mostert HA, Goodman PE. 2016. An Assessment of the Economic, Social and Conservation Value of the Wildlife Ranching Industry and its Potential to Support the Green Economy in South Africa. *The Endangered Wildlife Trust, Johannesburg*.
- Tenga RW, Mramba SJ. 2015. *Tanzania LGAF Synthesis Report*. World Bank, Washington, DC. DOI: 10.1596/28512.
- Thacker E, Dahlgren D, Stoner D, Clayton M. 2023. A perspective on rangeland and wildlife disciplines: Similarities over differences. In: McNew LB, Dahlgren DK, Beck JL (eds). *Rangeland Wildlife Ecology and Conservation*. Springer, Cham. DOI: 10.1007/978-3-031-34037-6_29.
- Trefethen JB. 1975. *An American Crusade for Wildlife*. Winchester, New York, New York, USA.
- Tribaldos TM. 2021. Highlighting Sustainable Food Systems in Mountains for the UN Food Systems Summit. *Mountain Partnership Secretariat and Centre for Development and Environment, Bern, Switzerland*.
- Turbelin A, Catford JA. 2021. Invasive plants and climate change. In: Letcher TM (eds). *Climate Change*. Elsevier, Amsterdam. DOI: 10.1016/B978-0-12-821575-3.00025-6.
- Undargaa S. 2017. Re-imagining collective action institutions: Pastoralism in Mongolia. *Hum Ecol* 45: 221-234. DOI: 10.1007/s10745-017-9898-1.
- United Republic of Tanzania (URT). 2022. *Ministry of Livestock and Fisheries, 2022/2023 Budget Speech Presented to the Parliament by the Minister for Livestock and Fisheries, Dodoma, Tanzania*.
- United State Department of Agriculture (USDA). 2017. <https://plants.usda.gov/home/noxiousInvasiveSearch/noxiousInvasiveSearchResults?resultId=0f11424c-55c7-4282-b302-6431f5796f09>
- Van Beek C, Herold N, Kessler A, Vonk R. 2017. The quest for improving soil fertility: Why an integrated approach is needed. *Outlook Agri* 46: 289-294. DOI: 10.1177/0030727017745165.
- Van Vliet S, Provenza FD, Kronberg SL. 2021. Health-promoting phytonutrients are higher in grass-fed meat and milk. *Front Sustain Food Syst* 4: 555426. DOI: 10.3389/fsufs.2020.555426.
- Vetter S, Goodall VL, Alcock R. 2020. Effect of drought on communal livestock farmers in KwaZulu-Natal, South Africa. *Afr J Range Forage Sci* 37 (1): 93-106. DOI: 10.2989/10220119.2020.1738552.
- Villalba JJ, Beauchemin KA, Gregorini P, MacAdam JW. 2019. Pasture chemoecology and their ecological services. *Transl Anim Sci* 3: 829-841. DOI: 10.1093/tas/txz003.
- Ward JD, Sutton PC, Werner AD, Costanza R, Mohr SH, Simmons CT. 2016. Is decoupling GDP growth from environmental impact possible? *PloS one*. 11(10): e0164733. DOI: 10.1371/journal.pone.0164733.
- Wassie SB. 2020. Natural resource degradation tendencies in Ethiopia: A review. *Environ Syst Res* 9: 33. DOI: 10.1186/s40068-020-00194-1.
- Weldemichel TG, Lein H. 2019. Fencing is our last stronghold before we lose it all: A political ecology of fencing around the Maasai Mara National Reserve, Kenya. *Land Use Policy* 87: 104075. DOI: 10.1016/j.landusepol.2019.10407.
- Werner RD, Barbosa FT, Bertol I, Wolshick NH, Santos KF, Mota JM. 2016. Soil properties and plant biomass production in natural rangeland management systems. *Revista Brasileira de Ciência do Solo* 40. DOI: 10.1590/18069657rbcs20150117.
- Wiethase JH, Critchlow R, Foley C, Foley L, Kinsey EJ, Bergman BG, Osujaki B, Mbwambo Z, Kirway PB, Redeker KR, Hartley SE. 2023. Pathways of degradation in rangelands in Northern Tanzania show their loss of resistance, but potential for recovery. *Sci Rep* 13 (1): 2417. DOI: 10.1038/s41598-023-29358-6.
- Wilmer H, Fernández-Giménez ME, Ghajar S, Taylor PL, Souza C, Derner JD. 2020. Managing for the middle: rancher care ethics under

- uncertainty on Western Great Plains rangelands. *Agric Hum Value* 37: 699-718. DOI: 10.1007/s10460-019-10003-w.
- Wilson RT. 2021. When is a “breed” not a breed: The myth of the Mpwapwa cattle of Tanzania. *Trop Anim Health Prod* 53 (2): 233. DOI: 10.1007/s11250-021-02669-4.
- Yanda PZ, Mabhuve E, Mwajombe A, Johnson N, Yamat LE. 2021. Dynamics of land management and implications on pastoral livelihoods in northern Tanzania. *Environ Manag* 71 (1): 29-39. DOI: 10.1007/s00267-021-01568-6.
- Yanda PZ, Mung'ong'o CG. 2018. *Pastoralism and Climate Change in East Africa*. Mkuki na Nyota Publishers.
- Yonas K. 2020. Introduction of the exotic breeds and cross breeding of local chicken in Ethiopia and solution to genetic erosion. *Afr J Biotechnol* 19 (2): 92-98. DOI: 10.5897/AJB2019.16748.
- Zarekia S, Jafari M, Arzani H, Javadi SA, Jafari AA. 2012. Grazing effects on some of the physical and chemical properties of soil. *World Appl Sci J* 20 (2): 205-212. DOI: 0.5829/idosi.wasj.2012.20.02.1624.
- Zhang R, Wang J, Niu S. 2021. Toward a sustainable grazing management based on biodiversity and ecosystem multifunctionality in drylands. *Curr Opin Environ Sustain* 48: 36-43. DOI: 10.1016/j.cosust.2020.09.005.