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Scaling rangeland restoration in East Africa through synergies in the biodiversity-water-climate nexus

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Abstract

Healthy land is a prerequisite for sustainable development and human well-being. With high levels of biodiversity and provision of critical ecosystem services, rangelands support 50% of the world's livestock and over 2 billion people. Rangeland degradation thus represents a major global challenge with severe negative impacts on biodiversity, climate change, and water and food security, affecting the livelihoods of millions of people. In the drylands of East Africa, these challenges are particularly acute. Halting rangeland degradation and restoring degraded land is thus essential in safeguarding ecosystem services and ensuring human well-being. Understanding the dynamics and patterns of rangeland degradation is critical for guiding restoration efforts to achieve positive and sustainable outcomes.

Here, we present results from systematic assessments of soil and land health conducted across contrasting rangeland landscapes in East Africa using the Land Degradation Surveillance Framework (LDSF). We conducted assessments of vegetation diversity, with an average of 15 perennial grass species per 100 km^2 LDSF site. The results indicate contrasting land degradation dynamics among and within the different sites. We applied Earth Observation in combination with field and lab data collected using the LDSF to produce high-accuracy predictive maps of different biophysical indicators, including soil organic carbon and soil erosion. The maps of soil and land health indicators showed clear spatial patterns across the landscapes. These results demonstrate the importance of simultaneously assessing multiple indicators of soil and land health and their interactions. We also present results from our work in four 'Livestock Cafés' in the cross-

border area between northern Kenya and Uganda. Livestock Cafés are experimental sites and knowledge-sharing hubs where we are engaging with local stakeholders to test and demonstrate innovative land restoration options for enhanced fodder production and regenerative kitchen garden development for improved food and nutrition.

Introduction

Rangelands cover an estimated 50% of the world's land area and provide a wide range of ecosystem services, including habitat provisioning, carbon sequestration, and food and water supply (Briske, 2017; UNCCD, 2024). However, interlinked land degradation, climate change, and biodiversity loss crises threaten rangeland ecosystems, jeopardizing the provision of these vital ecosystem services and the livelihoods and well-being of the people they support (IPBES, 2018; IPCC, 2019; UNCCD, 2024). In East Africa, rangelands constitute the dominant land use system, covering vast areas of land and supporting the livelihoods of millions of pastoralists (ILRI, 2021). Here, widespread rangeland degradation, climate change, and biodiversity loss constitute significant social-ecological challenges. These crises are mutually reinforcing; climate change is a principal driver of land degradation and biodiversity loss, while land degradation and biodiversity loss further accelerate climate change (IPBES, 2018; IPCC, 2019). Halting land degradation and restoring degraded rangelands is critical to reverse these negative trends (IPBES, 2018). Kenya, Uganda, and Tanzania have pledged to restore millions of hectares of degraded lands in the coming years, and many of these commitments specifically target rangelands. Understanding the dynamics and patterns of rangeland degradation and tracking the impact of restoration interventions is crucial for guiding such restoration efforts to achieve more positive and sustainable outcomes.

Here, we present some preliminary results and experiences from the research project Restore4More (2024-2027). The entry point of Restore4More is to identify the synergies in the biodiversity-water-climate nexus to accelerate the restoration of degraded rangelands for enhanced climate change adaptation and mitigation, biodiversity, and water and food security in the drylands of East Africa. We conducted systematic assessments of soil and land health across five rangeland-dominated landscapes in northern Kenya and Uganda with the aim of understanding the dynamics and patterns of land degradation across these sites to guide the planning and implementation of restoration interventions. We show key findings from these assessments, some examples of rangeland restoration interventions co-designed and implemented with local communities in knowledge-sharing hubs, and how we monitor restoration activities through an innovative approach combining field and lab data, Earth Observation and assisted citizen data collection.

Systematic assessments of land and soil health

We systematically collected data on soil and land health indicators across five rangeland-dominated sites in the cross-border area between northern Kenya and Uganda using the Land Degradation Surveillance Framework (LDSF) (Vågen & Winowiecki, 2023). *Chepareria, Lokiriama,* and *Kalama* sites were located in West Pokot, Turkana, and Samburu counties (Kenya), respectively, while *Matany* and *Rupa* sites were located in Napak and Moroto districts (Uganda).

Indicators measured included soil organic carbon (SOC), soil infiltration capacity, erosion prevalence, vegetation structure, tree density and species diversity, herbaceous cover and species diversity, soil texture, and pH. A total of 778 plots were sampled across the five LDSF sites. Plots (1000 m^2) were nested within clusters (1 km^2) and clusters within sites (100 km^2), following a hierarchical sampling design. Further details on the LDSF methodology, including the field sampling protocols and analysis of soil samples, can be found in Vågen and Winowiecki (2023).

Lokiriama and *Kalama* had the highest woody cover, with an average density of woody plants (trees and shrubs) of 275 and 243 individuals ha^{-1}, respectively, whereas in *Matany*, the average density was only 18 individuals ha^{-1}. Species richness was highest in *Chepareria* (50) and lowest in *Matany* (10). In *Lokiriama* and *Rupa*, nearly 50% of the sampled trees belonged to a single species - *Acacia reficiens* and *Acacia mellifera*, respectively. Tree species diversity was also low in *Matany*, whereas *Chepareria* had the highest diversity of trees, including several species that are important sources of fodder, food, and fuelwood. *Chepareria* was also the site with the highest richness of perennial grass species (37), whereas *Lokiriama* was the lowest (16).

Soil erosion is a major problem in the Kenyan sites (*Lokiriama, Kalama,* and *Chepareria*), where severe erosion was detected in 50-100% of the plots per cluster. In contrast, only a few plots presented severe erosion in *Matany* and *Rupa* (Uganda). Median topsoil organic carbon (SOC) content was lowest in the *Kalama* and *Lokiriama* sites (3.6 and 4.6 g kg^{-1}), whereas in *Matany* and *Rupa*, it was nearly threefold. The differences in SOC among sites were partly explained by differences in soil texture, with more fine-textured soils with higher clay content in *Rupa* and *Matany* sites compared to the rest. Saturated topsoil hydraulic conductivity, which controls the soil infiltration capacity, was relatively low in all five sites, with median values ranging between 10 mm h^{-1} in *Chepareria* and 60 mm h^{-1}in *Matany.* There was a clear negative relationship between erosion prevalence and soil infiltration capacity, especially for soils with higher clay content. This hints at a critical self-reinforcing feedback loop that amplifies land degradation: soil degradation and reduced infiltration capacity lead to more surface runoff and erosion, which in turn lead to further land and soil degradation and reduced infiltration.

Results from this assessment indicate contrasting land degradation dynamics among and within the different sites. For example, In *Lokiriama*, the encroachment of the invasive *Acacia reficiens* is a major problem and soil erosion was widespread. In contrast, Chepareria had severe erosion despite no signs of woody encroachment and higher diversity of both trees and grass species. In *Matany* nearly no signs of erosion were observed in the surveyed plots, but the diversity of perennial grasses and tree species was low compared to the other sites.

Using machine learning models trained on field and lab data collected using the LDSF and Earth Observation data (Vågen & Winowiecki, 2019; Vågen et al., 2016), we produced high-accuracy predictive maps of different biophysical indicators, including SOC and soil erosion. The maps of soil and land health indicators showed clear spatial patterns across the five rangeland landscapes.

These results demonstrate that rangeland health is multidimensional and highlight the importance of simultaneously assessing multiple indicators of soil and land health and their interactions across the plant-soil-water nexus.

Rangeland restoration in knowledge-sharing hubs

In 2021, we established four knowledge-sharing hubs, known as 'Livestock Cafés', in *Chepareria*, *Lokiriama, Matany*, and Rupa sites. Here, we engage with local communities, extension workers, NGO practitioners, and authorities to co-develop, test, and demonstrate innovative rangeland restoration and management options. We draw from the baseline assessments of soil and land health and local needs and priorities to guide and tailor restoration. Restoration interventions span a combination of agronomic, vegetative, structural, and management measures – including half-moons, retention ditches, contour bounds, manure addition, reduction of grazing intensity and 'cut-and-carry' of fodder, reseeding of indigenous rangeland grasses and forage legumes, and planting of fodder trees and shrubs. By managing the plant-soil-water-nexus, such restoration interventions contribute to halting land degradation and

accelerating the recovery of degraded rangelands. Within the 'Livestock Cafés,' we have also established regenerative kitchen gardens together with local women's groups with the aim of enhancing food security and dietary diversity throughout the year and providing opportunities for income.

From the 'Livestock Cafés', the knowledge is disseminated further through a network of Community Facilitators and Lead Farmers & Pastoralists. Rangeland restoration activities across the four sites will be monitored using the newly launched Rangeland Module in The Regreening App (CIFOR-ICRAF, 2022) – a free mobile-based application for assisted citizen science data collection of restoration activities – combined with Earth Observation. These data will allow assessing the effectiveness of different restoration interventions and will provide much needed evidence regarding rangeland restoration efforts in the region. The app also provides a unique opportunity to promote wider public engagement and co-learning in rangeland restoration.

Conclusions

Restore4More will contribute to developing the capacity of restoration actors at multiple levels through context-specific co-learning and knowledge exchange. The project will provide restoration practitioners and other actors, including policymakers, local authorities, NGO's, farmers, and livestock keepers, with robust science-based evidence and tools to support and guide rangeland restoration efforts in the drylands of East Africa, improving their capacity to plan, implement, monitor, and assess restoration activities and practice adaptive management.

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