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Assessment and mapping of rangeland health in East Africa and globally

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Abstract

Rangelands across eastern Africa are in need of urgent interventions to restore rangeland health and build resilience to climate change. Drylands cover nearly half of the global land surface and harbor high biodiversity, yet they remain understudied and undervalued. The compounding effects of climate change and land degradation currently represent a major threat to drylands in general, and rangelands in particular. There are substantial gaps in the evidence base for land restoration with a significant bias towards the Global North and forest ecosystems. This research aims to address key gaps in East Africa around (1) the role of restoration interventions that consider and manage plant-soil-water feedbacks in accelerating the recovery of key ecosystem functions and related ecosystem services, (2) the link between above-ground and below-ground interactions, including biodiversity and (3) how such interventions can be scaled to improve restoration outcomes. The project builds on long-term and robust data collected in the field across a range of rangeland systems in East Africa using the Land Degradation Surveillance Framework (LDSF). We systematically assessed the impact of woody and non-woody vegetation (species, structure, cover, above-ground biomass, diversity), soil inherent properties (soil texture, pH), and land management (grazing and browsing intensity) on ecosystem functioning and the delivery of key ecosystem services, including erosion control, water regulation (soil infiltration capacity), and carbon storage. We present grass, forb and woody species diversity in 11 – 100 km² LDSF sites across East Africa, as well as maps of soil organic carbon, soil erosion and herbaceous cover. We will present the use citizen science to enhance the participation of local communities, and in particular women and youth, increasing transparency and inclusion in the various phases of rangeland restoration. These methods can be applied globally and fill key knowledge gaps around rangeland health and the impact of interventions on the ground.

Introduction

Rangelands are vital systems, covering 40-50% of the earth's terrestrial surface, providing essential goods and services such as livestock forage, biodiversity habitats, and carbon sequestration (Sala et al., 2017). In East Africa, these landscapes support pastoral livelihoods, harbour high biodiversity, and play critical roles in regulating regional and global climate systems (Little, 1996; Mgalula et al., 2021). However, they are currently under threat from a combination of pressures, including climate change, unsustainable land management, and socioeconomic factors (Otieno & Kinyamario, 2018). A systematic study of soil erosion prevalence, using the LDSF database, highlighted that drylands were more susceptible, including the vegetation classes of bushland and shrubland. (Vågen and Winowiecki, 2019). This degradation, evidenced by reduced productivity, soil erosion, and decreased biodiversity, demands targeted restoration interventions

that are locally relevant, scalable, and informed by robust data. Restoration interventions require both a focus on vegetation recovery, but an understanding of complex plant-soil-water interactions, ground-truthing data, and participatory approaches with local communities. Yet, despite their importance, substantial knowledge gaps around effective, locally applicable and scalable restoration practices in rangelands systems (Boyd & Svejcar, 2009). A pressing need is to develop integrated protocols and tools that capture on-the-ground conditions, produce practical insights, and support locally relevant restoration efforts at meaningful spatial scales.

Our work integrates field data from the Land Degradation Surveillance Framework (LDSF)—a robust field data collection protocol designed for systematic, repeatable environmental assessments of soil health, rangeland health, land degradation and vegetation diversity (Vågen and Winowiecki, 2023; Vågen et al., 2012)—with spatial modelling tools and a citizen science data collection platform. By combining rigorous plot-based data, geospatial remote-sensing analyses, and community-led monitoring through mobile apps, this approach aims to fill critical knowledge gaps and enhance the evidence base for rangeland restoration interventions. We focus on East Africa as a case study region, reviewing both the protocol and the emerging results, and discuss how these methods can scale to inform rangeland restoration interventions more broadly, and be integrated into monitoring, evaluation and adaptive management frameworks.

Methods

The LDSF is a comprehensive field data collection protocol for assessing soil and land health (Vågen and Winowiecki, 2023). It provides guidance and methods for designing and implementing robust sampling strategies across broad, heterogenous landscapes along with tools to sample vegetation dynamics (cover, structure, and function), key soil physical properties, evidence of soil degradation, and historic land use change. The LDSF includes a specific rangeland module tailored to rangeland systems and employs accessible, practical, and affordable methodologies that can be implemented in remote areas with limited technical resources. Data collected through the LDSF support a rangeland health and indicator framework, enabling assessments of soil organic carbon stocks, soil infiltration, soil erosion, vegetation cover and density, species composition and diversity, and overall land degradation status and risk.

The nested, randomized sampling design of the LDSF framework facilitates the evaluation of the indicators at multiple scales, capturing both within- and between-site variability. Moreover, the LDSF integrates effectively with earth observation (EO) data, allowing assessments to span broader spatio-temporal scales. By combining field-derived indicators with medium-resolution (10 – 30m) EO data from Landsat and Sentinel, and applying advanced machine learning modelling pipelines, we can predict indicators of rangeland condition across landscapes at 10 – 30m spatial resolution and through time. This approach supports the development of historic baselines and the evaluation of areas lacking extensive field data availability. In this study we present results from 11 LDSF sites, eight in Kenya, one in eastern Rwanda and two in northern Tanzania, with 1760-1000-m² sampling plots. In each plot, there were four subplots each of 100m², where erosion was scored, tree and shrubs were identified and measured and soil samples were collected. In addition, across each plot, two-15m transects are laid (N-S, E-W) where perennial and annual grasses, forbs and woody vegetation under 1 m tall are assessed.

Integrating field with EO products also improves long-term monitoring of restoration and degradation trends. To enhance the assessment of management and restorations interventions we incorporate a citizen science smart-phone application—The Regreening App (*The Regreening Africa App User Guidelines*, 2022)—which includes a rangeland module. This tool enables smallholder ranchers and land managers, to record the timing, location, and nature of specific interventions. By merging this localized, site-specific

information with medium-resolution predictions of rangeland condition indicators, we can produce more robust and context-relevant assessments and evaluations of rangeland restoration initiatives.

Results

As shown for the sites surveyed as part of the GCF-Twende project in Figure 1, they covered a strong gradient in terms of SOC and land degradation status, the latter expressed here as soil erosion prevalence. Sites in the northern parts of the study area are generally lower in SOC (median <5 g/kg) and have higher soil erosion prevalence than sites in southern Kenya, although there are relatively high levels of degradation in all sites. The sites also represented a wide range of management types, including private conservancies, private pastoral land, and communal pastoral land. Species diversity of annual and perennial grasses varied strongly between sites, as well as the types of species present. For example, Mbalambala had very few grass species present and a high proportion of bare ground, as well as presence of invasive species such as *Prosopis juliflora*. In contrast, Mbirikani had higher species diversity and no invasive species were observed. Results from the surveys in northern Tanzania show high levels of bush encroachment in some districts, as well as high rates of conversion of rangelands into agriculture. In West Pokot there has been a transition from communal pastoral systems to private land tenure over the last three decades, resulting in higher levels of fragmentation and hence variability in terms of land use was also high in the Chepareria site.

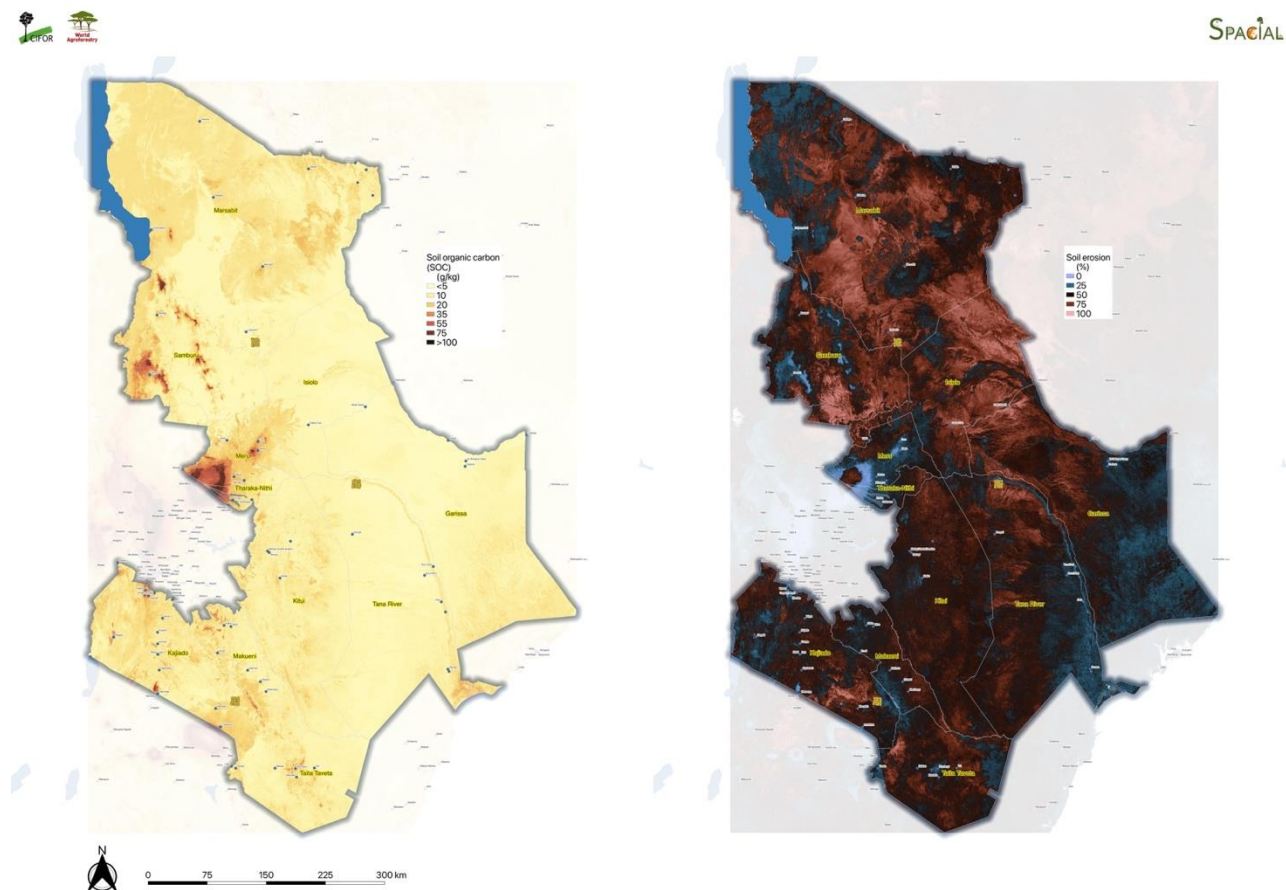


Figure 1: Maps of soil organic carbon (SOC) (left) and soil erosion prevalence (right) across southern and (north)eastern Kenya, within the GCF-Twende project.

Discussion [Conclusions/Implications]

Despite their immense ecological, economic, and cultural significance, rangeland systems remain challenging to monitor and assess due to their inherent spatio-temporal variability. This complexity has often hindered the development of robust, scalable frameworks for evaluating rangeland health, restoration progress, and management effectiveness. By integrating standardized field protocols, remote sensing data, participatory approaches, and advanced modeling techniques, our work contributes to overcoming these longstanding barriers. The approaches outlined here help establish reliable pipelines for data collection, analysis, and interpretation, ensuring that locally relevant interventions can be scaled to broader landscapes. Ultimately, this convergence of methods and tools provides a critical foundation for enhancing adaptive management practices, improving restoration outcomes, and ensuring that rangeland systems continue to sustain both livelihoods and ecosystems well into the future.

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