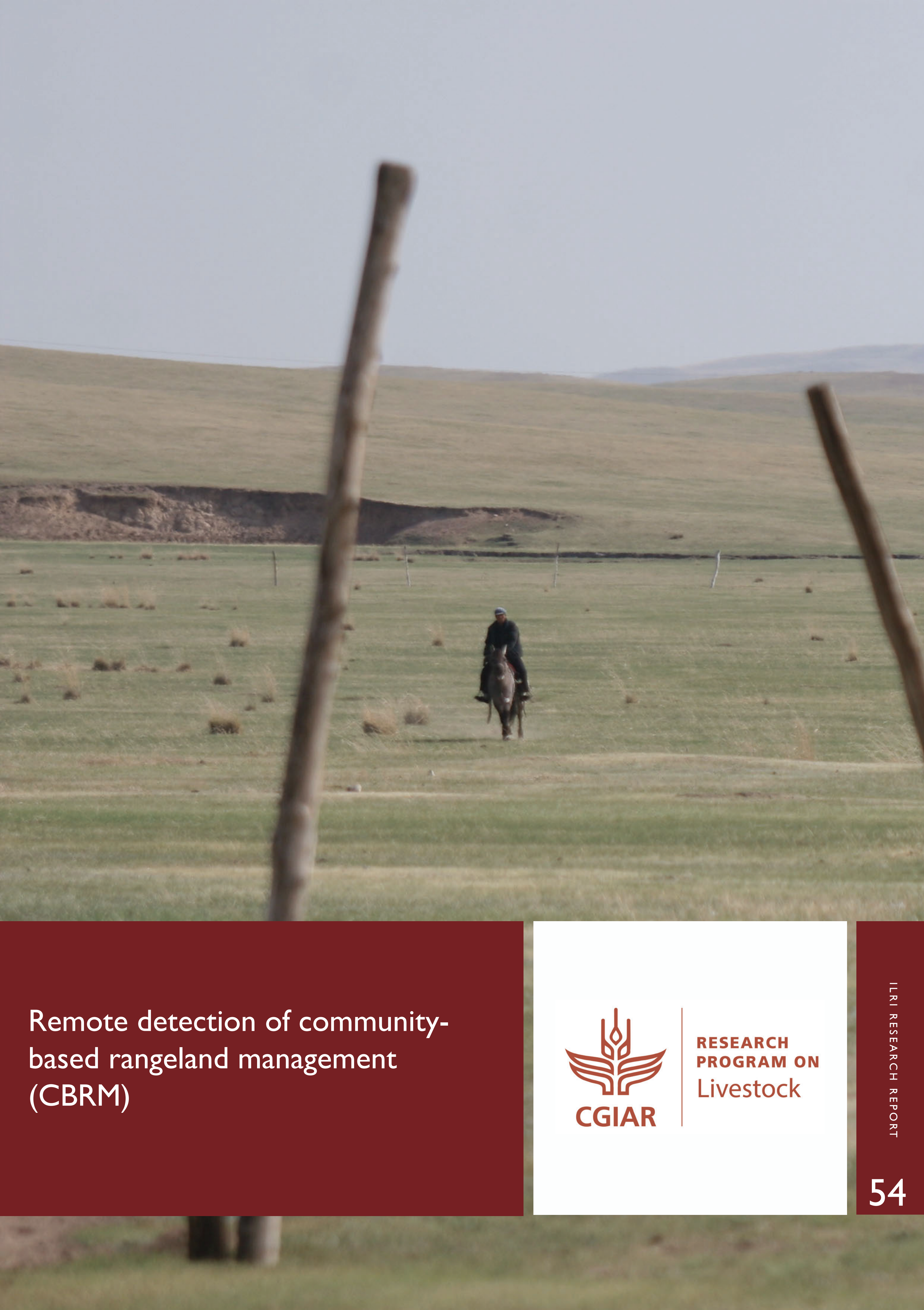


Remote detection of community-based rangeland management (CBRM)

CGIAR

RESEARCH PROGRAM ON Livestock

ILRI RESEARCH REPORT

54

CGIAR

RESEARCH PROGRAM ON
Livestock

Remote detection of community-based rangeland management (CBRM)

Jason Sircely, Francesco Fava and Stephen Oloo

International Livestock Research Institute

December 2019

This work was implemented as part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from CGIAR Fund Donors and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors. The views expressed in this document cannot be taken to reflect the official opinions of these organizations.

This document was made possible with support from the American people delivered through the United States Agency for International Development (USAID). The contents are the responsibility of the producing organization and do not necessarily reflect the opinion of USAID or the US Government.

ILRI thanks all donors and organizations which globally supports its work through their contributions to the CGIAR Trust Fund

Editing, design and layout—ILRI Editorial and Publishing Services, Addis Ababa, Ethiopia.

Cover photo—ILRI/Stevie Mann

ISBN: 92–9146–598–4

Citation: Sircely, J., Fava, F. and Oloo, S. 2019. *Remote detection of community-based rangeland management (CBRM)*. ILRI Research Report 54. Nairobi, Kenya: International Livestock Research Institute (ILRI).

Patron: Professor Peter C Doherty AC, FAA, FRS

Animal scientist, Nobel Prize Laureate for Physiology or Medicine–1996

Box 30709, Nairobi 00100 Kenya
Phone +254 20 422 3000
Fax+254 20 422 3001
Email ilri-kenya@cgiar.org

ilri.org
better lives through livestock

ILRI is a CGIAR research centre

Box 5689, Addis Ababa, Ethiopia
Phone +251 11 617 2000
Fax +251 11 667 6923
Email ilri-ethiopia@cgiar.org

ILRI has offices in East Africa • South Asia • Southeast and East Asia • Southern Africa • West Africa

Contents

Summary v

Introduction 1

Methods 2

- Sites 2
- Rangeland condition indicators 2
- Time periods 2
- Analysis structure 3
- Elevation classes and pasture types 3
- Statistical analyses 3

Results 4

- Kajiado, Kenya 4
- Laikipia, Kenya 4
- Borana, Ethiopia 4
- Agreement among indicators 4

Discussion 8

References 14

Summary

Several approaches based on remotely sensed data can be applied to assess landscape level management influences in rangelands, such as community-based rangeland management (CBRM). Rangeland condition indicators from remote sensing have their own advantages and assumptions. To test the ability of remote sensing indicators in tracking long–term trends in pastoral rangelands in East Africa, three rangeland condition indicators—cumulative annual normalized difference vegetation index (cNDVI), annual rainfall use efficiency (RUE; cNDVI/annual precipitation), and bare soil were calculated for three time periods between 2003 and 2019 in rangeland units applying CBRM in Kajiado and Laikipia counties in Kenya, and Borana Zone in Ethiopia. Spatiotemporal trends suggested that all three indicators, or a combination thereof, are feasible methods for detection of landscape level influences of community-based rangeland management, although the degree to which various indicators should be weighted in a larger analysis remains debatable. In the three research areas, trends among areas, time periods and indicators sometimes aligned and sometimes conflicted with one another. The substantial set of ecological and social factors are likely responsible for these observed trends and should motivate due diligence in conducting evaluation of rangeland condition indicators from remote sensing.

Introduction

Rangelands are the predominant land use worldwide, covering nearly half of the Earth's land surface (White et al. 2002). In East Africa, rangelands provide the main source of livelihoods for pastoralists, underpin the livestock sector that provides nearly half of the agricultural gross domestic product in the agriculture-dependent economies of Kenya and Ethiopia (Behnke 2010) and host greater wildlife numbers than the national park systems (Western et al. 2009). Rangelands provide these ecosystem benefits to humanity in spite of the fact that many rangelands globally and in East Africa have undergone extensive degradation, due to the combination of climate change, high stocking densities and disorganized grazing on account of weakened traditional or customary institutions for rangeland management (Kiage 2013).

Community-based rangeland management (CBRM) is a general term for any local level strategy for managing rangelands (Reid et al. 2014). In pastoral East Africa, CBRM mainly refers to the reorganization of currently haphazard grazing patterns by means of facilitative reinvigoration of traditional or customary institutions, or building new local institutions (Flintan and Cullis 2010) where no functional local institution exists. CBRM is designed to improve the control of communities (traditional or local institutions) over their land, improving perception of land tenure security and enabling pastoral communities to gain recognition for their efforts to manage their rangelands. While the social impacts of CBRM are significant (Flintan et al. 2019), more detailed study is required to assess its impact on the environmental condition of rangelands.

Remote sensing methods can be cost-efficient means of assessing environmental impacts of CBRM, although their external validity is difficult to demonstrate in rangelands. In arid landscapes most particularly, satellite signal limitations and calibration requirements can be non-trivial constraints on the usefulness of these models for tracking environmental impacts of CBRM (Zhao and Running 2008). A large set of remotely sensed indices have been applied to assess and track the condition of rangeland ecosystems over large scales (Prince 2019). The influences of management regimes are challenging to differentiate from changes in climate (Hopping et al. 2018; Miehe et al. 2010) and associated cascading effects and studies with thorough characterization of management regimes are desirable.

The objectives of the present study were to (i) apply three indicators of rangeland conditions derived from remote sensing in three pastoral landscapes in Ethiopia and Kenya; (ii) interpret spatiotemporal trends in the three indicators to assess the feasibility of their application to detect landscape level influences of community-based rangeland management; (iii) compare the three indicators in terms of their ability to distinguish areal trends in rangeland conditions over long time periods and large areas; and (iv) assess the need for modifications to the analyses conducted.

Methods

Sites

Three research areas were selected for the analysis on the basis that CBRM has been in place for several years (9-14 years) with plausible effects of CBRM on rangeland conditions over large areas CBRM operates (95-7100 km^2). In each site, analyses centered on a focal rangeland unit(s): (i) Olkiramatian and Shompole group ranches in Kajiado county, Kenya (who manage their land similarly and in close coordination); (ii) Il Ngwesi Group Ranch in Laikipia county, Kenya; and (iii) Dirre Dheeda in Borana Zone of Oromia Region in Ethiopia. The map for Dirre Dheeda was provided courtesy of the Pastoralist Areas Resilience Improvement through Market Expansion project (PRIME 2019). All sites have a bi-modal rainfall pattern with two rainy seasons and two dry seasons annually, with mean annual precipitation varying from approximately 500–800 mm yr^{-1}. To focus on rangelands typically used for grazing, all water bodies, areas with extensive cropland, forests and areas with >40% woody cover (Kahiu and Hanan 2018), were excluded from analyses.

Rangeland condition indicators

Three indicators were applied to assess trends in rangeland condition: (i) cumulative annual normalized difference vegetation index (cNDVI) (Jenkerson et al. 2010); (ii) annual rainfall use efficiency (RUE; cNDVI/annual precipitation) using CHIRPS precipitation (Funk et al. 2015); and (iii) bare soil (Guerschman and Hill 2018). cNDVI and RUE were selected on account of their widespread use for tracking changes in the productivity of vegetation as an indicator of environmental quality; and bare soil was selected due to its straight-forward interpretation as the amount of land not covered by any vegetation (Guerschman and Hill 2018).

Time periods

For the draft analyses presented here, trends were estimated by summing cNDVI annually across all seasons (both wet and dry seasons), and averaging RUE and bare soil (%) across entire years. Annual values were then combined with neighboring years in three time periods reflecting inflection points in management regime change as CBRM proceeded. The period between 2003 and 2005 denotes the pre-CBRM (baseline) period; 2011–2013, the early CBRM period; and 2017–2019, the ongoing CBRM period. These time periods were also selected to avoid including major droughts in the analysis, during which little or no improvement in rangeland condition should be observable. The 2003–2005 time period was selected to avoid the major drought in short rains from the end of 2005 to early 2006. The 2011–2013 period followed two successive droughts from 2010–2011 and 2017–2019. There were also two successive droughts in 2016 and 2017. The 2019 long rains were similarly excluded.

Analysis structure

In Kajiado and Laikipia, Kenya, a treatment-control approach was followed, with rangeland condition trends inside the focal rangeland units ('treatment') compared to trends outside the focal rangeland units in paired, ecologically similar pastoral lands nearby ('control'). The Kajiado group ranches were compared with neighboring group ranches within a 25-km perimeter and the Laikipia group ranch was compared with two neighboring group ranches. In these treatment–control sites, putative effects of CBRM were quantified as any improvement or decline in rangeland conditions inside the focal rangeland unit, relative to rangeland condition outside the focal rangeland unit. In Borana, Ethiopia, no such control areas were available as identical CBRM processes were initiated in all rangeland units in Borana at the same time by the same institutional consortium (Craft 2019). Therefore, a treatment-only approach was adopted, tracking change within Dirre Dheeda over time without reference to outside areas. "Improvement" in rangeland condition is defined as positive changes (increase) in cNDVI and RUE; negative changes (reduction) in bare soil; and "decline" in rangeland condition as the converse.

Elevation classes and pasture types

In each site, elevation classes were delineated to enable more direct comparisons in space and time between pastures of similar ecological potential. In the Kajiado site, higher quality pastures at lower elevation (<680 m) were separated from lower quality pastures at higher elevation (>680 m). In the Laikipia site, draft analyses presented here focus only on higher quality pastures at lower elevation <1277 m. In the Borana site, higher quality pastures at higher elevation with higher rainfall (>1400 m) were separated from more arid lower quality pastures at lower elevation (<1400 m).

Statistical analyses

A simple and robust statistical approach was adopted for all sites, using analysis of variance (ANOVA) to detect significant differences between areas and time periods, with pair-wise comparisons of area-time-period combinations verified by means of Tukey post-hoc tests.

Results

Kajiado, Kenya

In the Magadi area group ranches, trends in rangeland conditions differed greatly among elevation classes (Table 1, Figure 1). Inside the two group ranches, higher quality pastures at lower elevation (<680 m) appeared to have improved relative to the 25 km^2 buffer outside the two group ranches, according to all three indicators. In contrast, lower quality pastures at higher elevation suggested no change in terms of cNDVI or RUE (or even a relative decline in cNDVI) yet appeared to have improved in terms of reduction in the difference in bare soil between inside and outside the group ranches.

Laikipia, Kenya

In the Laikipia group ranch, trends in rangeland conditions differed greatly according to both the indicator selected and the control-treatment pair (Table 2, Figure 2). Inside the group ranch, higher quality pastures at lower elevation appeared to decline in terms of cNDVI relative to one neighboring conservancy ('control A') but appeared to improve compared to a second neighboring conservancy ('control B'). Bare soil showed the converse pattern—an improvement in terms of bare soil compared to conservancy A, and a decline relative to conservancy B. RUE trends were weak, with the only significant difference between areas inside and outside of the rangeland unit being a decline relative to conservancy A during the period 2017–2019.

Borana, Ethiopia

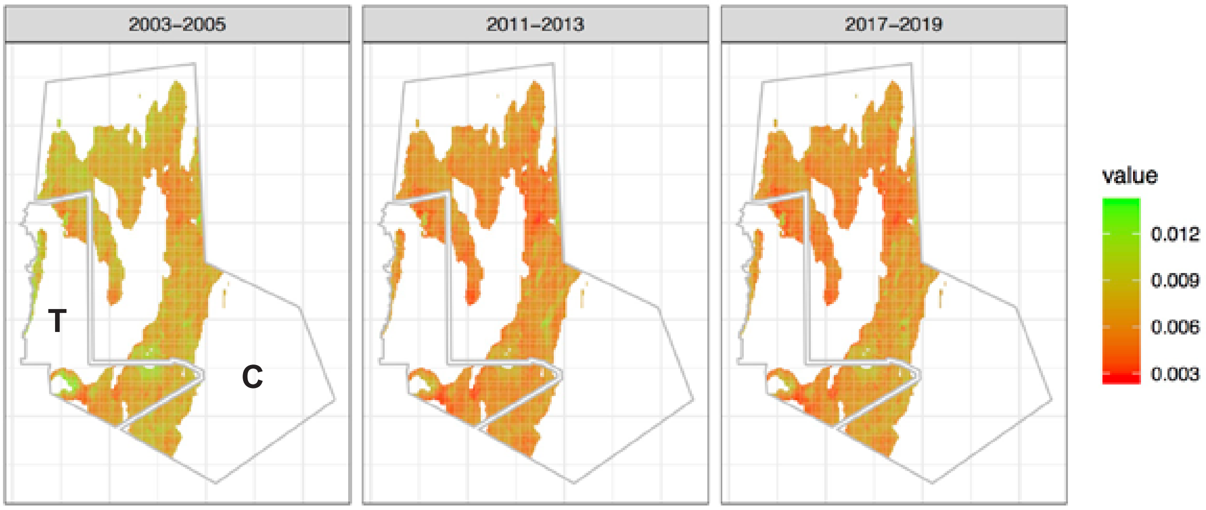
In the Dirre area, trends in rangeland conditions again differed greatly according to elevation classes (Table 3, Figure 3). Lower quality pastures at lower elevation (<1400 m) showed no change for cNDVI, slight improvement in RUE from 2011–2013 and 2017–2019; and a decline in terms of bare soil from 2011–2013 and 2017–2019. Higher quality pastures above 1400 m elevation exhibited generally slight and recent (since 2013) improvements in cNDVI, RUE and bare soil.

Agreement among indicators

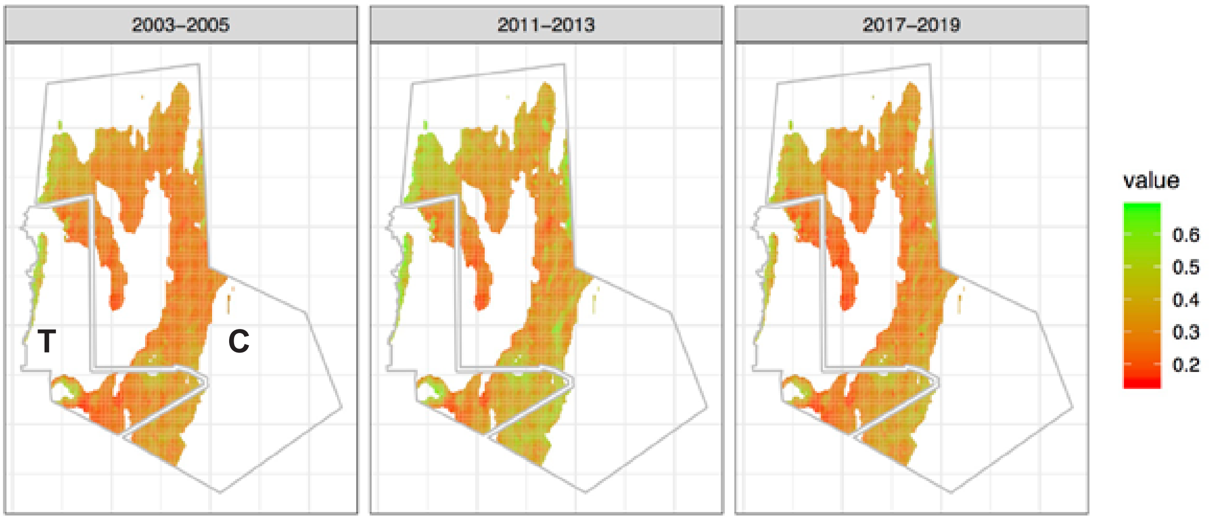
The differences in cNDVI, RUE, and bare soil among management areas and time periods indicate the potential utility of each of the three rangeland condition indicators. However, the tendency within sites was for the three indicators to generally disagree on the direction of trends in rangeland conditions among management areas and analysis periods (Table 4). All three indicators were aligned and suggest parallel trends in two of the six cases analyzed—in higher quality pastures in Kajiado and lower-quality pastures in Borana. cNDVI and RUE tended to agree more often with one another than did bare soil, primarily due to the use of cNDVI in calculating RUE (RUE = annual cNDVI/annual precipitation). Otherwise, little convergence was found among indicators in terms of the rangeland condition trends their values suggested.

Figure 1. Kajiado, Kenya: trends in cNDVI, RUE and bare soil in poorer quality pastures (elevation >680 m); T = CBRM treatment focal rangeland unit; C = control outside the focal rangeland unit.

A. cNDVI



B. RUE



C. Bare soil

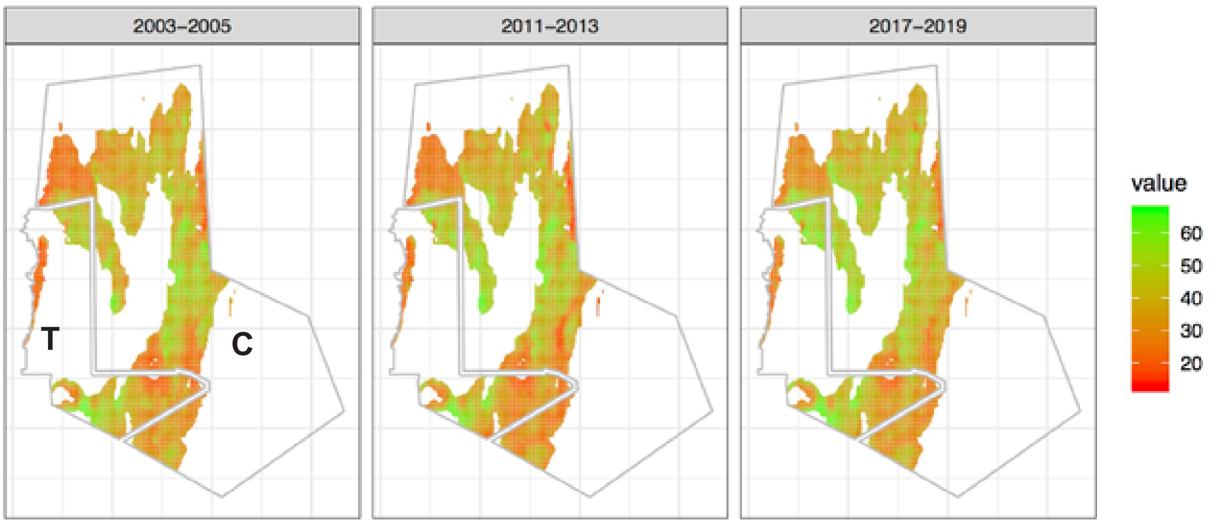
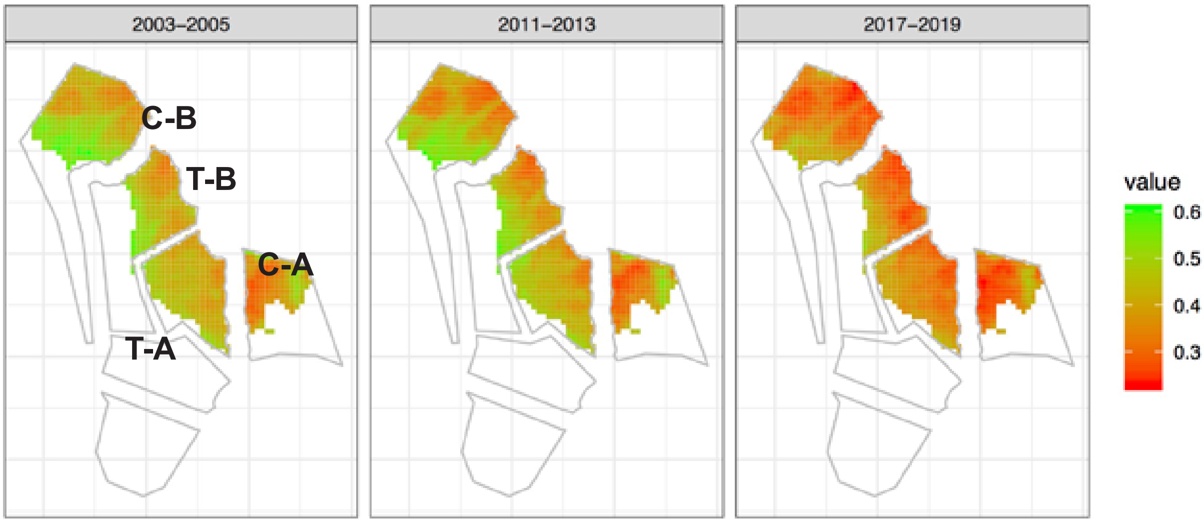


Figure 2. Laikipia, Kenya: trends in cNDVI and bare soil in higher quality pastures (elevation <1277 m); T–A = CBRM treatment area "A" inside the focal rangeland unit, C–A = Control "A" outside the focal rangeland unit; T–B = CBRM treatment area "B" inside the focal rangeland unit; C–B = control "B" outside the focal rangeland unit.

A. cNDVI



B. Bare soil

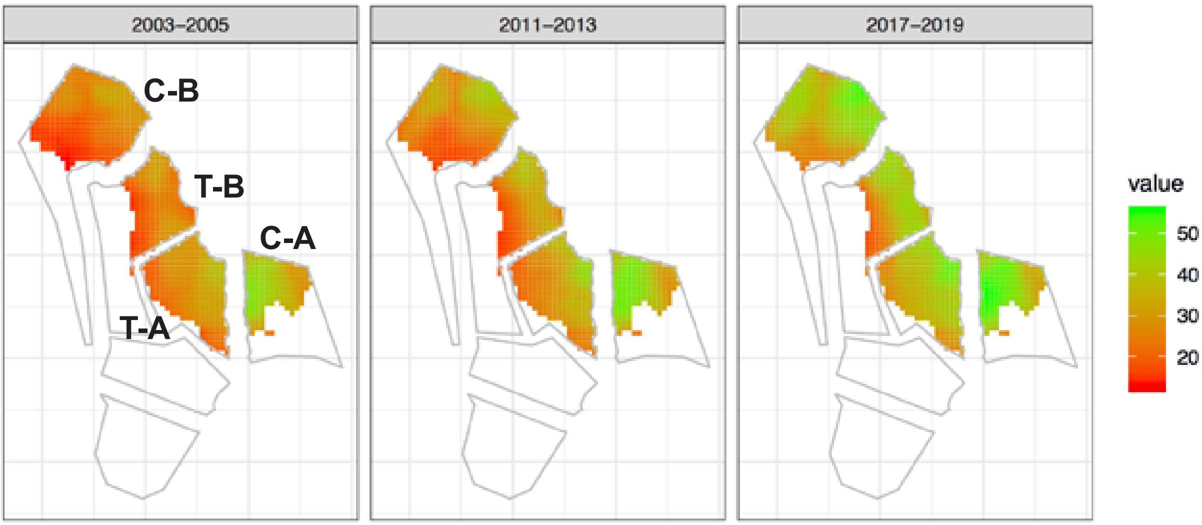
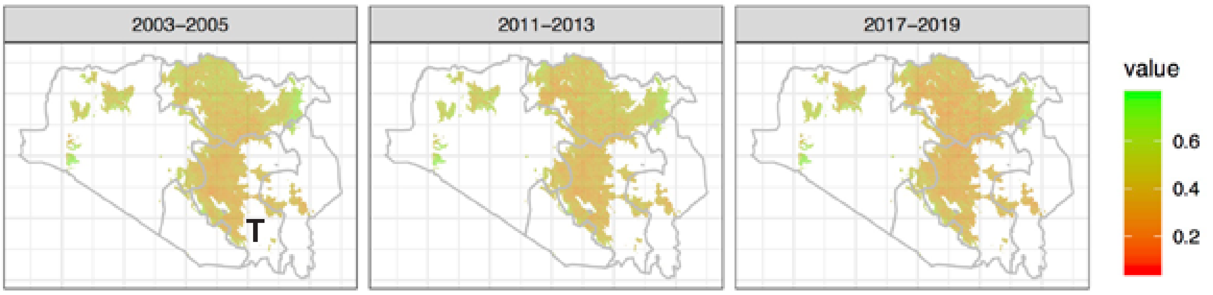
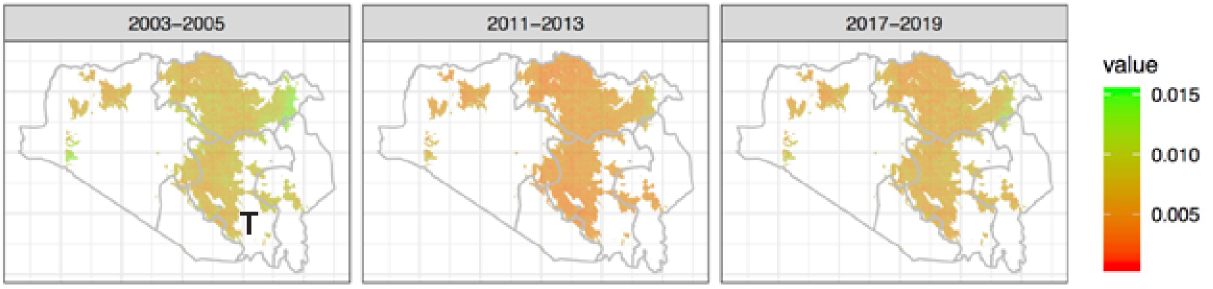


Figure 3. Borana, Ethiopia: trends in cNDVI, RUE and bare soil in higher quality pastures (elevation >1400 m); T = CBRM treatment focal rangeland unit (Dirre Dheeda). The other boundaries are for the other dheedas in Borana Zone.

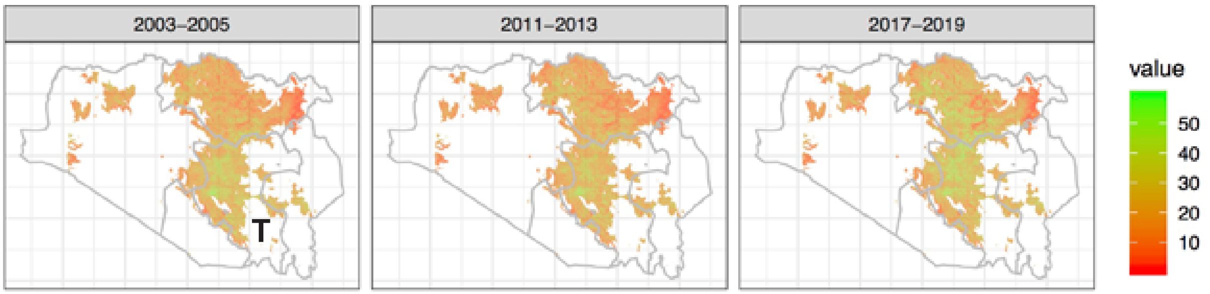
A. cNDVI



B. RUE



C. Bare soil



Discussion

All three rangeland condition indicators appeared valid for detecting differences in trends suggestive of degradation and restoration occurring in response to the combined influences of major drivers, particularly changes in climate and management regimes. Each indicator likely tells a fraction of a larger picture. cNDVI and RUE are more ecosystem process-focused indicators, with cNDVI primarily indicative of overall photosynthesis and plant growth, and RUE of the same per unit rainfall. Bare soil, on the other hand, indicates the spatial distribution of ground with neither photosynthetic nor non-photosynthetic vegetative cover, a property of ecosystems rather than a process. These differences are notable as the intrinsic relative rates of change in ecosystem processes and properties often differ by an order of magnitude or more in response to ecosystem drivers operating over vastly different time scales through multiple mechanisms leading to emergent changes (O'Neill et al. 1987).

In Kajiado, Kenya, the apparent improvement in higher quality pastures at lower elevation inside the focal rangeland units—Shompole and Olkiramatian group ranches—relative to similar areas outside may be significantly attributable to land arrangements outside the group ranches. These areas outside the focal rangeland units are under lease to the Tata Chemicals company, which allows herders from neighboring areas (and perhaps much further away) to graze their animals in their leasehold area. For these herders, the lack of secure land tenure in this area may disincentivize effective rangeland management. One important next step for the Kajiado analysis will be to clarify grazing use patterns in these lower elevation pastures. The apparent relative reduction in bare soil in lower quality pastures at higher elevations could relate to higher reliance on these poorer pastures due to degradation at lower elevations outside the focal rangeland units, including invasion by *Prosopis juliflora* in substantial tracts within the 25 km buffer zone (less so within the focal rangeland units).

In Laikipia, Kenya, the two conservancies neighboring the focal rangeland unit—Il Ngwesi group ranch—also apply community-based rangeland management in some form and for variable durations and intensities. Management differences among the three rangeland units likely to relate to the observed differences in rangeland condition trends are not yet clear making further confirmation of management regimes and timelines a priority. However, the contrasts between these trends—nearly opposite for cNDVI and bare soil most particularly—was great and it appears unlikely that management differences could fully explain this divergence.

In Borana, Ethiopia, differences in aridity appear related to the differences in rangeland condition trends in the focal rangeland unit—Dirre Dheeda. The widespread degradation over recent decades on account of rapid shrub encroachment into grassy savannas and major soil erosion (Coppock 2016) could be reflected in the pattern of fairly static cNDVI and slight improvement in RUE coupled with increasing bare soil in lower quality pastures below 1400 m elevation. Although these conflicting patterns could indicate anything between degradation and restoration, the increase in bare soil is noteworthy as soil erosion is a preeminent symptom of degradation in these areas. In contrast, the central Borana plateau (<1400 m) exhibited generally slight and recent (since 2013) improvements in cNDVI, RUE and bare soil, suggesting a long-term trend of improvement in these higher rainfall savannas of higher quality. The contrast between the apparent improvement in the condition of more humid pastures at higher elevations in comparison to the apparent overall stability (or possible decline) in rangeland conditions in more arid pastures at lower elevations appears significant in light of the tendency of more arid rangelands to better resist grazing-induced degradation (Von Wehrden et al. 2012) in spite of slower recovery rates. If reliance on lower elevation pastures has increased during the analysis period, apparent improvement in higher elevation pastures could relate to the lack of improvement in lower elevation pastures.

The general absence of agreement among indicators suggests that explicit quantitative field evaluation of the three indicators remains a valuable pursuit. Evaluation is costly but useful, especially in relation to systems and questions that challenge the ability of satellites to discriminate meaningful differences. The influence of management regimes on rangeland condition in the context of a changing climate is an excellent example. Rangelands are typically comprised of multiple plant species of multiple plant growth forms (annual and perennial grasses and forbs, and evergreen and drought-deciduous shrubs and trees) with differing growth rates and seasonal phenology (Whitecross et al. 2017) responses to precipitation (Ogle and Reynolds 2004), and utility to grazing and browsing species of livestock and wildlife. These vegetation components exhibit substantial natural variation and co-variation along gradients in soils, hydrology and vegetation that evolve over time in response to increasingly erratic rainfall. The contrasting trends among indicators and areas in Laikipia is particularly confounding and strongly suggest that field evaluation should be a priority for scientists, managers and policymakers.

Each of the three rangeland condition indicators analyzed are likely reflective of different ecosystem processes and properties with potentially divergent responses to management and climate. Their use in combination (and with other indicators) may be complementary and could form a more complete assessment of how management and climate interact to determine rangeland condition. As with any remote sensing approach for quantifying changes in ecosystem condition, the ability of these methods to depict valid changes in rangeland conditions relates to their accuracy, specific indicative value and the rates of change in these indicators as the structural and functional attributes of rangeland ecosystems shift over time. To effectively pinpoint the causes of change in rangeland condition, field evaluation of remotely sensed indices is an essential element of assessing the robustness and effectiveness of the various existing means of quantifying degradation and restoration trends in rangelands.

Table 1. Kajiado, Kenya draft rangeland trends assessment

cNDVI

Better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	0.049	0.04–0.05	0.000	Inside
2011–2013: early CBRM	Inside-outside	0.069	0.06–0.07	0.000	Inside
2017–2019: ongoing CBRM	Inside-outside	0.062	0.06–0.07	0.000	Inside
Poorer pastures (higher elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	-0.042	-0.05 to -0.04	0.000	Outside
2011–2013: early CBRM	Inside-outside	-0.038	-0.04 to -0.03	0.000	Outside
2017–2019: ongoing CBRM	Inside-outside	-0.045	-0.05to -0.04	0.000	Outside

RUE

Better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	0.001	0.001–0.001	0.000	Inside
2011–2013: early CBRM	Inside-outside	0.0008	0.001–0.001	0.000	Inside
2017–2019: ongoing CBRM	Inside-outside	0.0011	0.001–0.001	0.000	Inside
Poorer pastures (higher elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	-0.0006	-0.001 to -0.001	0.000	Outside
2011–2013: early CBRM	Inside-outside	-0.0007	-0.001 to -0.001	0.000	Outside
2017–2019: ongoing CBRM	Inside-outside	-0.0006	-0.001 to -0.001	0.000	Outside

Bare soil

Better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	0.608	-0.05 to 1.27	0.103	N/A
2011–2013: early CBRM	Inside-outside	-4.272	-4.93 to -3.61	0.000	Inside
2017–2019: ongoing CBRM	Inside-outside	-4.653	-5.31 to -3.99	0.000	Inside
Poorer pastures (higher elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	2.458	1.91–3.01	0.000	Outside
2011–2013: early CBRM	Inside-outside	1.13	0.58–1.68	0.000	Outside
2017–2019: ongoing CBRM	Inside-outside	2.186	1.64–2.73	0.000	Outside

Table 2. Laikipia, Kenya draft rangeland trends assessment

cNDVI

Control-treatment pair A: better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	0.023	0.002–0.04	0.009	Outside
2011–2013: early CBRM	Inside-outside	0.011	-0.01–0.03	0.994	N/A
2017–2019: ongoing CBRM	Inside-outside	0.037	0.02–0.06	0.000	Outside
Control-treatment pair B: better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	0.019	0.0002–0.04	0.042	Outside
2011–2013: early CBRM	Inside-outside	0.005	-0.01–0.02	1.000	N/A
2017–2019: ongoing CBRM	Inside-outside	-0.006	-0.02–0.01	1.000	N/A

RUE

Control-treatment pair A: better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	0.0002	-0.0001–0.0004	0.579	N/A
2011–2013: early CBRM	Inside-outside	-0.0001	-0.0003–0.0002	1.000	N/A
2017–2019: ongoing CBRM	Inside-outside	0.0003	0.00002–0.00052	0.015	Outside
Control-treatment pair B: better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	0.0002	-0.0001–0.0004	0.599	N/A
2011–2013: early CBRM	Inside-outside	0.0001	-0.0001–0.0003	1.000	N/A
2017–2019: ongoing CBRM	Inside-outside	-0.0001	-0.0003–0.0002	1.000	N/A

Bare soil

Control-treatment pair A: better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condition found:
2003–2005: pre-CBRM (baseline)	Inside-outside	-0.087	-2.18–2.01	1.000	N/A
2011–2013: early CBRM	Inside-outside	0.577	-1.52–2.67	1.000	N/A
2017–2019: ongoing CBRM	Inside-outside	-2.666	-4.76–-0.57	0.000	Inside
Control-treatment pair B: better pastures (lower elevation)					
Time period	Contrast	Difference (Inside-outside)	95% CI	p	Better condi-tion found:
2003–2005: pre-CBRM (baseline)	Inside-outside	-1.367	-3.19–0.46	0.633	N/A
2011–2013: early CBRM	Inside-outside	-0.684	-2.51–1.14	1.000	N/A
2017–2019: ongoing CBRM	Inside-outside	2.568	0.74–4.396	0.000	Outside

Table 3. Borana, Ethiopia draft rangeland trends assessment

cNDVI

Poorer pastures (lower elevation)				
Contrast	Change (Later-earlier)	95% CI	p	Better condition found:
2011–2013, early CBRM to 2003–2005, pre-CBRM (baseline)	0.0041	0.002 to 0.006	0.000	After
2017–2019, ongoing CBRM to 2011–2013, early CBRM	0.0001	-0.002 to 0.002	1.000	N/A
2017–2019, ongoing CBRM to 2003–2005, pre-CBRM (baseline)	-0.0041	-0.006 to -0.002	0.000	Before
Better pastures (higher elevation)				
Contrast	Change (Later-earlier)	95% CI	p	Better condition found:
2011–2013, early CBRM to 2003–2005, pre-CBRM (baseline)	-0.0094	-0.012 to -0.007	0.000	Before
2017–2019, ongoing CBRM to 2011–2013, early CBRM	-0.0058	-0.008 to -0.004	0.000	Before
2017–2019, ongoing CBRM to 2003–2005, pre-CBRM (baseline)	0.0036	0.001 to 0.006	0.000	After

RUE

Poorer pastures (lower elevation)				
Contrast	Change (Later-earlier)	95% CI	p	Better condition found:
2011–2013, early CBRM to 2003–2005, pre-CBRM (baseline)	-0.0006	-0.001 to -0.001	0.000	Before
2017–2019, ongoing CBRM to 2011–2013, early CBRM	-0.0002	-0.0002 to -0.0001	0.000	Before
2017–2019, ongoing CBRM to 2003–2005, pre-CBRM (baseline)	0.0004	0.0004 to 0.0005	0.000	After
Better pastures (higher elevation)				
Contrast	Change (Later-earlier)	95% CI	p	Better condition found:
2011–2013, early CBRM to 2003–2005, pre-CBRM (baseline)	-0.0003	-0.0003 to 0.0002	0.000	Before
2017–2019, ongoing CBRM to 2011–2013, early CBRM	0.0001	0.0001 to 0.0001	0.000	After
2017–2019, ongoing CBRM to 2003–2005, pre-CBRM (baseline)	0.0004	0.0003 to 0.0004	0.000	After

Bare soil

Poorer pastures (lower elevation)				
Contrast	Change (Later-earlier)	95% CI	p	Better condition found:
2011–2013, early CBRM to 2003–2005, pre-CBRM (baseline)	-0.294	-0.53 to -0.059	0.001	Before
2017–2019, ongoing CBRM to 2011–2013, early CBRM	-0.903	-1.1386 to -0.6681	0.000	Before
2017–2019, ongoing CBRM to 2003–2005, pre-CBRM (baseline)	-0.609	-0.8442 to -0.3737	0.000	Before
Better pastures (higher elevation)				
Contrast	Change (Later-earlier)	95% CI	p	Better condition found:
2011–2013, early CBRM to 2003–2005, pre-CBRM (baseline)	0.195	-0.0431–0.4333	0.333	N/A
2017–2019, ongoing CBRM to 2011–2013, early CBRM	0.804	0.566–1.0424	0.000	After

Table 4. Synthesis and comparison of trends among indicators and sites.

		Trends by indicator			
Site	Contrast	cNDVI	RUE	Bare soil	Indicator agreement
Kajiado	Control-treatment: better pastures (lower elevation)	Improvement	Improvement	Improvement	Good
	Control-treatment: poorer pastures (higher elevation)	No change/decline	No change	Improvement	Poor
Laikipia	Control-treatment pair A: better pastures (lower elevation)	Decline	Recent slight recent decline	Improvement	Poor
	Control-treatment Pair B: better pas-tures (lower elevation)	Improvement	No change	Decline	Poor
Borana	Before-after: poorer pastures (lower elevation)	No change	Recent slight improvement	Recent de-cline	Poor
	Before-after: better pastures (higher elevation)	Recent slight improvement	Recent slight improvement	Recent improvement	Good

References

Behnke, R. 2010. *The contribution of livestock to the economies of IGAD member states—study findings, application of the methodology in Ethiopia and recommendations for further work*. Intergovernmental Authority on Development LPI Working Paper No. 02–10.

Coppock, D.L. 2016. Pastoral System dynamics and environmental change on Ethiopia's north-central Borana plateau—influences of livestock development and policy. In: Behnke, R. and Mortimore, M. (eds), *The end of desertification? Disputing environmental change in the drylands*. Berlin, Germany: Springer: 327–362. doi:10.1007/978-3-642-16014-1_12

Craft, T. 2019. *Enabling resilience for pastoral communities in Ethiopia: PRIME impact and results report*. Portland, Oregon.

Flintan, F. and Cullis, A. 2010. *Introductory guidelines to participatory rangeland management in pastoral areas*. Addis Ababa, Ethiopia.

Flintan, F., Ebro, A., Eba, B., Assefa, A., Getahun, Y. et al. 2019. *Review of participatory rangeland management (PRM) process and implementation*. Rangelands Research Report 2. Nairobi, Kenya: ILRI. https://hdl.handle.net/10568/106017

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J. et al. 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data* 2. 150066. doi:10.1038/sdata.2015.66

Guerschman, J.P. and Hill, M.J. 2018. Calibration and validation of the Australian fractional cover product for MODIS collection 6. *Remote Sensing Letters* 9: 696–705. doi:10.1080/2150704X.2018.1465611

Hopping, K.A., Yeh, E.T., Gaerrang, H.R.B., 2018. Linking people, pixels, and pastures: A multi-method, interdisciplinary investigation of how rangeland management affects vegetation on the Tibetan Plateau. *Applied Geography* 94: 147–162. doi:https://doi.org/10.1016/j.apgeog.2018.03.013

Jenkerson, C.B., Maiersperger, T. and Schmidt, G. 2010. eMODIS: A user-friendly data source, open-file report. *U.S. Geological Survey*. doi:10.3133/ofr20101055

Kahiu, M.N. and Hanan, N.P. 2018. Estimation of woody and herbaceous leaf area index in sub-Saharan Africa using MODIS data. *Journal of Geophysical Research: Biogeosciences* 123: 3–17. doi:10.1002/2017JG004105

Kiage, L.M. 2013. Perspectives on the assumed causes of land degradation in the rangelands of sub-Saharan Africa. *Progress in Physical Geography: Earth and Environment* 37(5): 664–684. doi:10.1177/0309133313492543

Miehe, S., Wehrden, H.V. and Retzer, V. 2010. Long-term degradation of Sahelian rangeland detected by 27 years of field study in Senegal. *Journal of Applied Ecology* 47: 692–700. doi:10.1111/j.1365-2664.2010.01815.x

O'Neill, R.V., Deangelis, D.L., Waide, J.B. and Allen, T.F.H. 1987. *A hierarchical concept of ecosystems*. New Jersey, USA: Princeton University Press.

Ogle, K. and Reynolds, J.F. 2004. Plant responses to precipitation in desert ecosystems: integrating functional types, pulses, thresholds, and delays. *Oecologia* 141: 282–294. doi:10.1007/s00442-004-1507-5

PRIME (Pastoralist Areas Resilience Improvement through Market Expansion). 2019. https://www.prime-ethiopia.org/

Prince, S.D. 2019. Challenges for remote sensing of the Sustainable Development Goal SDG 15.3.1 productivity indicator. *Remote Sening Environment* 234: 111428. doi:https://doi.org/10.1016/j.rse.2019.111428

Reid, R.S. Fernández-Giménez, M.E. and Galvin, K.A. 2014. Dynamics and resilience of rangelands and pastoral peoples around the globe. *Annual Review of Environment and Resources* 39: 217–242. doi:10.1146/annurev-environ-020713-163329

Von Wehrden, H., Hanspach, J., Kaczensky, P., Ficher, J. and Weche, K. 2012. Global assessment of the non-equilibrium concept in rangelands. *Ecological applications* 22: 393–399.

Western, D., Russell, S. and Cuthill, I. 2009. The status of wildlife in protected areas compared to non-protected areas of Kenya. *PLoS One* 4: e6140. doi:10.1371/journal.pone.0006140

White, R.P., Tunstall, D. and Henninger, N. 2002. *An ecosystem approach to drylands: building support for new development policies*. Washington, DC.: WRI.

Whitecross, M.A., Witkowski, E.T.F. and Archibald, S. 2017. Savanna tree-grass interactions: A phenological investigation of green-up in relation to water availability over three seasons. *South African Journal of Botany* 108: 29–40. doi:https://doi.org/10.1016/j.sajb.2016.09.003

Zhao, M. and Running, S.W. 2008. Remote sensing of terrestrial primary production and carbon cycle. In: Liang, S. (ed), *Advances in land remote sensing*. Maryland, USA: Springer: 423–444.

ISBN: 92–9146–598–4

ILRI
INTERNATIONAL
LIVESTOCK RESEARCH
INSTITUTE

The International Livestock Research Institute (ILRI) works to improve food and nutritional security and reduce poverty in developing countries through research for efficient, safe and sustainable use of livestock. Co-hosted by Kenya and Ethiopia, it has regional or country offices and projects in East, South and Southeast Asia as well as Central, East, Southern and West Africa. ilri.org

CGIAR

CGIAR is a global agricultural research partnership for a food-secure future. Its research is carried out by 15 research centres in collaboration with hundreds of partner organizations. cgiar.org