Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Biology

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Uncovering the Impacts of Fencing in the Mara

An assessment of vegetation and bare soil using remote sensing and stakeholder participation

Master's thesis in Natural Resources Management
Supervisor: Bente J. Graae
May 2019

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AfricanBioServices

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Contents

Abstract

Land-use and land cover change (LULCC) detection studies often utilize remote sensing for ecological monitoring and management, conservation, and quantification of land-cover change. Remote sensing is an effective tool for these applications but can be imperfect as it tends to be one-dimensional. Understanding human-resource interactions is essential to interpretation and management implementation of remote sensing studies. Increasingly, studies have begun to integrate indigenous and local knowledge (ILK) to gain a better understanding of the changes detected from satellite data. Here we conducted a Before-After Impact-Control Paired (BACIP) study on the effects of recent fence construction in pastoral communities near the border of Maasai Mara National Reserve, Kenya. In this study we detected the impact of fencing on two remotely sensed indices, the normalized difference vegetation index (NDVI) and the bare-soil index (BI). We engaged ILK through stakeholder perceptions of changes in greenness (NDVI) and bareness (BI) before and after fencing. We found that wet season BI decreased by 87.1% inside fences, while variability in wet season NDVI increased by 33% inside fences, post-construction. Wet season mean NDVI increased within fences but was not significant. This result was misaligned with our prediction that local stakeholders would corroborate the NDVI findings. However, wet season BI results were corroborated by interviews with local and high-level stakeholders. Changes in dry season NDVI and BI were not due to the impact of fences. Spatially and temporally varied land-use practices inside fenced areas may account for wet season NDVI variability and mean BI increases after fence construction.

Sammendrag

Studier av arealbruk- og arealdekkeendringer benytter seg ofte av fjernregistrering via satelitter for overvåkning- og forvaltning av økosystemer, bevaringstiltak, samt kvantifisering av arealbruksendringer. Fjernregistrering er et effektivt verktøy, men det har en tendens til å være endimensjonalt – noe som gjør at det ikke alltid er tilstrekkelig i forvaltningssammenhenger. Forståelse av interaksjoner mellom mennesker og naturressurser er vesentlig for både å kunne tolke, samt benytte seg av fjernregistreringer i forvaltningssammenhenger. Derfor har studier begynt å inkorporere urfolk- og lokal kunnskap (ILK) for å oppnå en bedre forståelse av endringer oppdaget av satellittdata. Vi har gjennomført et «Before-After Control-Impact Paired»-studie på effekten av nyetablerte gjerder i pastorale samfunn nær grensen til Maasai Mara National Reserve, Kenya. Vår målsetning var å utforske effekten av nyetablerte gjerder på to indekser koblet til fjernmåling, nemlig NDVI («normalized difference vegetation index») og BI («bare-soil index»). Vi inkorporerte ILK gjennom å utforske forskjellige aktørers oppfatning av endring i grønnheten til vegetasjon (NDVI) og barheten til jordsmonnet (BI), før og etter gjerdeetablering. Vi fant at etter gjerdeetablering minket BI i våte perioder med 87.1% innenfor gjerdene, mens NDVI økte med 33%. Lokale aktører rapporterte forskjell i NDVI med gjerdeetablering, i motsetning til våre funn som ikke viste forskjell i gjennomsnittlig NDVI innenfor og utenfor gjerdene i våte perioder. Imidlertid ble BI-resultatene fra våte perioder bekreftet av intervjuer med både lokale og høytstående aktører. Endringer i NDVI og BI i tørre perioder viste seg å ikke skyldes virkningen av gjerder. Arealbruk varierte både i tid og rom innenfor gjerdene, noe som kan forklare at både variasjon i NDVI i våte perioder og gjennomsnittlig BI økte etter gjerdeetablering.

I. Introduction

Remote sensing is a powerful tool for visualizing and extracting spatial data on a large scale. It has been widely used for ecological monitoring and quantification of land-cover changes. Given that land-use and land-cover changes (LULCC) can influence the robustness and resilience of ecosystems to global environmental drivers, such as the effects of climate change, remote sensing has become a highly effective tool for management of natural resources whilst accounting for large-scale drivers. (Lambin et al, 2001). However, ecologists, geographers, and policy-makers alike run into difficulties when it comes to implementing recommended policy changes that arise from such analyses of ecological data through remote sensing alone (Quan et al, 2001). The most effective management strategies should consider human interactions with the resources in question (Byers, 1996).

Ecological studies that utilize both remotely sensed LULCC data and indigenous and local knowledge (ILK) through stakeholder participation, can have a greater impact with regards to the effectiveness of resource monitoring and management, including policy changes (Ndzabandzaba, 2018). ILK can not only assist in identifying resource issues; it can also provide insights into potential underlying reasons for change detected through remote sensing, such as variation among land-use practices (Quan et al, 2001). ILK may offer solutions in order to manage resources in a more equitable and sustainable fashion (Egeru et al, 2015).

Following a mixed methods approach utilizing both remote sensing and ILK allows researchers to deepen knowledge and understanding about ecological systems affected by conservation and land tenure policy, climate, and livelihoods. The pastoral communities of Narok County in southwestern Kenya that border the Maasai Mara National Reserve (MMNR, 152,300ha, established in 1961), are highly relevant for such an approach with respect to resource management studies.

This community has been affected by land-tenure policy changes in addition to new strategies for wildlife conservation (Wily, 2018). These changes have effectively squeezed the Maasai into a smaller space. The increased population density precipitates a more sedentary, rather than pastoral, way of life (Homewood et al, 2019). Taken together, these factors have led to an increase in fence construction in the villages near the border of the MMNR. Fencing is a possible strategy to cope with the high demand for grass, decreased mobility, and highly variable rainfall patterns (Nyberg et al, 2015). Because pastoralism as a land use is well adapted to systems with high rainfall variability, fences may have adverse effects to people, land, and wildlife by restricting movement and access to resources (Bedelian et al, 2017 and Said et al, 2016).

Construction of fences has been estimated by Løvschal et al. (2017) to have increased by 20% between 2010-2016 with the most rapid increased in the time since 2014. These recent, rapid increases in fence construction are the motivation of this study (*Fig.1.1*). Løvschal et al. suggest that the implications of these fences will lead to a collapse of the greater Mara ecosystem due to habitat fragmentation. Despite successes in increasing carnivore populations, preventing the spread of disease, and decreasing human-wildlife conflicts, fences ultimately create a barrier to migration, may cause overgrazing and soil compaction and become fatal traps to large ungulates (Løvschal et al, 2017, Woodrooffe et al, 2014). Therefore, the question of whether the benefits outweigh the costs is still under debate (Woodrooffe et al, 2014).

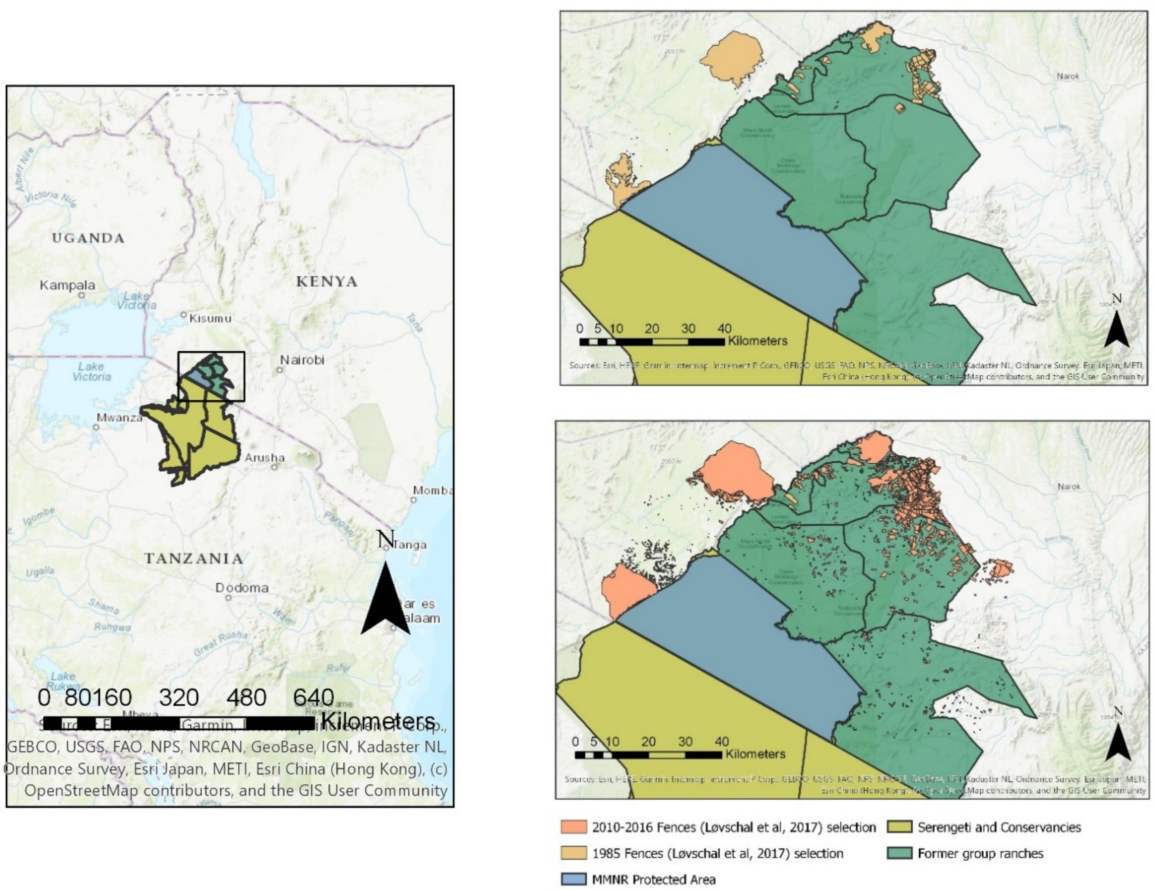


Fig.1.1 Fences in 1985 (top) and 2010-2016 (bottom) as mapped by Løvschal et al. (2017).

The grasslands of the MMNR ecosystem support an iconic annual migration of more than a million wildebeest (*Connochaetes taurinus*), upwards of 200,000 zebra (*Equus burchelli*) and hundreds of thousands of Thomson's gazelle (*Gazella thomsoni*) in addition to the livelihoods of an increasing population of Maasai, who reside outside the park boundary and rely on the seasonal growth of grass to support their livestock (Løvschal et al, 2017) (*Fig.1.2*). In unprotected areas near the border, wildlife and livestock are in direct competition for resources (Lamprey and Reid 2004). There is a long-wet season which is coupled with a spike in net primary productivity (NPP) of grasses that subsequently support the annual migration (Boone et al, 2006). Grass is therefore sparse by the end of the dry season (Serneels and Lambin, 2001). There is a short and often unreliable wet season, during which the NPP is variable. Therefore, wild herbivore mobility is necessary to take advantage of the highly seasonal grass productivity where it is most abundant (Homewood et al, 2019).

Fig.1.2 Grass in MMNR protected area (left), and in unprotected areas (right) near MMNR border, taken December 2018.

Maasai land tenure and sedentarization began in 1970, with the formation of so-called group ranches (Lamprey and Reid, 2004). These divisions and land allocations in the districts bordering Maasai Mara National Reserve were intended to help manage natural resources and secure land tenure for the Maasai people (Ntiati, 2002).

By the 1980s, many group ranches had become subdivided as people transitioned to a more sedentary lifestyle including the construction of more permanent housing structures (Groom et al, 2013) and with the implementation of conservancies. A conservancy is a parcel of land formed by investors and local landowners who voluntarily vacate their property and pool neighboring parcels together. Landowners enter into agreements with investors who plan to increase tourism on the conservancy and are then paid monthly rents in exchange for their land, which becomes open for both wildlife and tourism and is no longer an available grazing area for livestock (Osano et al, 2013, Norton-Griffiths et al, 2008).

Fig.1.3 Examples of fences, highlighting differences in land-use: livestock safety (top left), grass banks (middle left and right) and one of the unintended consequences of fencing – a fatality caused by entanglement in a wire fence (bottom left). Taken December 2018.

The division of group ranches, loss of rights to high quality lands by conservancies, the densification of human settlements, and thereby livestock, and competition with wildlife, has led many landowners to fence the remaining property they had (Weldemichel and Lein, 2017).

Fencing of land is seen as a solution for securing access to dry season grass banks for the grazing of livestock, and to protect the resource from wild herbivores in the region (Weldemichel and Lein, 2017) (*Fig.1.3*). However, a cascade of effects follows when land becomes fragmented by fences (Woodrooffe et al, 2014). Fencing can disrupt the seasonal inputs of carbon, nitrogen, and phosphorus to the soil. Overgrazing can lead to a decrease in plant litter inputs where herbivores may be densified via fences. On the other hand, fences which exclude herbivores entirely may have an adverse effect on soil nutrients by restricting inputs from animal dung. Disruptions to soil inputs can lead to changes in the primary productivity of the system and result in changes in grass production (Morgan, 2009).

Further impacts include soil erosion. Movement of people and animals are squeezed into a smaller area and land-use and trampling become more intensified (Veldhuis et al, 2019). In regions where overgrazing occurs, absence of plant cover exposes the soil, and it becomes compacted by trampling (Xie and Wittig, 2004). Compaction alters the soil structure by breaking down soil aggregates, which further decreases soil porosity (Kozlowski, 1999 and Leão et al, 2006) and subsequently, water run-off leads to further soil erosion which can be higher in overgrazed areas (Evans, 1998).

Erosion can potentially be severe in savannah systems where the combination of fencing and grazing occur together. Additional disturbances can include agriculture, fire and logging which further exacerbate soil mineral loss and gullying of the land. This cascade of processes can be difficult to reverse (Belsky 1986, Yong-Zhong et al, 2005).

Analysis of remotely sensed Normalized Difference Vegetation Index (NDVI) is a common and highly useful method for monitoring changes to vegetation over time (Yengoh et al. 2015). NDVI measures the reflectance from green vegetation and is effective for gathering information about NPP. Monitoring NDVI over time can reveal impacts of land-use changes such as fences. For example, exclusion of herbivores by fences may increase the NPP inside a fence, and thus the NDVI, after the fence was built. Although NDVI represents greenness well, it lacks capability with respect to plant height, forage quality, and nutrient contents. NDVI is sensitive to plant heights up to 0.45-meters, becoming less sensitive to heights beyond this (Payero et al, 2004). This suggests that taller vegetation may not be detected by NDVI, effectively masking information about biomass which may be used as fodder for livestock.

Assessments of NDVI as a proxy for NPP show the coupling of greenness that follows precipitation. In savannahs, NDVI assessments show a high interannual variation, which suggests that rangeland NPP changes quickly in response to variability in both rainfall and LULCC (Fuller, 1998). In one study, the response of NDVI to precipitation was displaced in an area of high irrigation, which suggests that LULCC may cause unexpected variability in NDVI in response to precipitation (Lotsch et al, 2003). Land-use changes such as construction of fences may have an impact on the expected response of NDVI to precipitation.

The Bare-soil Index (BI) was introduced by Chen et al. (2004) to classify landcover types in conjunction with NDVI. Fragmentation via fences and the land-use intensification observed near the MMNR may have an impact on the exposure of bare soils over time. Gill and Phinn (2008 and 2009) demonstrated that NDVI together with an index for bare soil, complement each other and can increase our understanding of ecological effects of LULCC in a savannah.

In 2010, the Intergovernmental Platform on Biodiversity and Ecosystems Services (IPBES) moved to recognize and respect the contribution of ILK to the conservation and sustainable use of biodiversity and ecosystems (Thaman et al, 2013). This integration is becoming commonplace especially among conservation research. In a study by Egeru et al. (2015), pastoralists' ILK was used to link grassland forage availability with a remotely sensed study using NDVI to monitor LULCC. In the West Usambara Mountains of Tanzania (near the Kenyan border), researchers utilized farmers' knowledge and perceptions to develop a tool for identification of soil erosion (Vigiak et al, 2005). However, studies like Okobo and de Graaf (2005) demonstrate that local knowledge can have gaps, thereby strengthening the need for more integrated mixed method approaches. This is highly relevant especially in cases where ILK can be bolstered by more nuanced scientific research, potentially improving, for example, crop yields over time (Minang and McCall, 2006; Gray and Morant, 2003).

A better understanding of the consequences of fencing will require an integration of ILK through stakeholder participation in the Mara region coupled with an analysis of the ecological effects of fencing via remotely sensed indices (Serneels and Lambin, 2001), particularly with regards to bare soil and productivity of grasses. The gaps in remote sensing with respect to the causes of variability in NDVI and BI, or the diminished capability of NDVI to monitor plant heights over 0.45m may be better understood through ILK and stakeholder precipitation.

Aim

The aim of this research is to evaluate the impact of fencing in Narok County on grass and bare soil. This study utilized remotely sensed images to measure the Normalized Difference Vegetation Index (NDVI) and the Bare-soil Index (BI). Remote based measures of land quality were complimented by on-the-ground surveys of local and high-level stakeholders' perceptions and interpretations of these remote satellite proxies to answer two research questions.

(i) What is the impact inside and outside fences on mean and variation in NDVI and BI?

(ii) How do stakeholders perceive the impacts of fencing on grass greenness, height, and bare soil, and are their perceptions aligned with remotely sensed measurements of NDVI and BI?

We expect fences to explain a difference in NDVI and BI. Based on field observations by Weldemichel in 2017, we expect NDVI to be higher inside fences than outside fences. We expect BI to be higher outside fences than inside. We also expect land-owners to have perceived an increase in greenness (measured by NDVI) inside fences and an increase in bareness (measured by BI) outside fences.

II. Methods

Study area and site selection

The region straddling the eastern border of MMNR near the Talek River (S 1°30', E 35°19') was selected as the study area for this analysis. This region lies within the former Koyake and Siana group ranch areas of Narok County (*Fig.2.1*), in southwestern Kenya. Koyake has had an annual human population growth rate of 4.4%, with population of livestock averaging 25,000 in the period 1983-1999 (Lamprey and Reid, 2004). Residents rear livestock to support their livelihoods.

Maasai Mara National Reserve and associated conservancies, together with Serengeti National Park and its surrounding wildlife management areas (*Fig.2.1*), form the Serengeti-Mara Ecosystem, which is dominated by tropical grassland and savannah ecosystems. Savannahs are defined by Frost and Robertson (1985) as having a continuous herbaceous cover of (mostly C4) grasses, sedges, herbs and a discontinuous cover of trees. The study area is dominated by *Themeda triandra*, *Pennisetum spp*. (and other Poaceae), and *Vachellia spp.* trees with increasing incidence of shrubs. Underlying soils are dominated by Vertisols, more commonly known as black cotton soils (Lamprey and Reid, 2004 and Bussmann et al, 2006). The climate is characterized by a wet season (February-June) which has a mean monthly rainfall 96 ± 56 mm and a dry season (July-October), with mean monthly rainfall 53 ± 34mm, contributing to an environment of water-stress within the ecosystem (Bartzke et al, 2018).

The area is patchy with both communal, unfenced grassland and privately fenced lands, crisscrossed by unimproved dirt roads and is heavily grazed and trampled by herds of sheep, goat, and cattle. The region is shared by wildlife and Maasai peoples who reside in bomas (homestead enclosure, also for livestock), clustered houses or small townships which are semi-developed. Livelihoods are derived primarily from raising livestock, tourism, or payment for ecosystem services from conservancies (Weldemichel and Lein, 2017).

The unfenced *protected area* (PA) within MMNR was used as the 'control' area, while the *unprotected area* (UPA) outside the border of the MMNR was the 'treatment' area where fencing occurs, following a Before-After Control-Impact Paired (BACIP) approach (outlined below). Preliminary selection of target areas was based on prior remote survey work by Løvschal et al. (2017) (*Fig.1.1*). The fieldwork took place in December 2018 and February 2019.

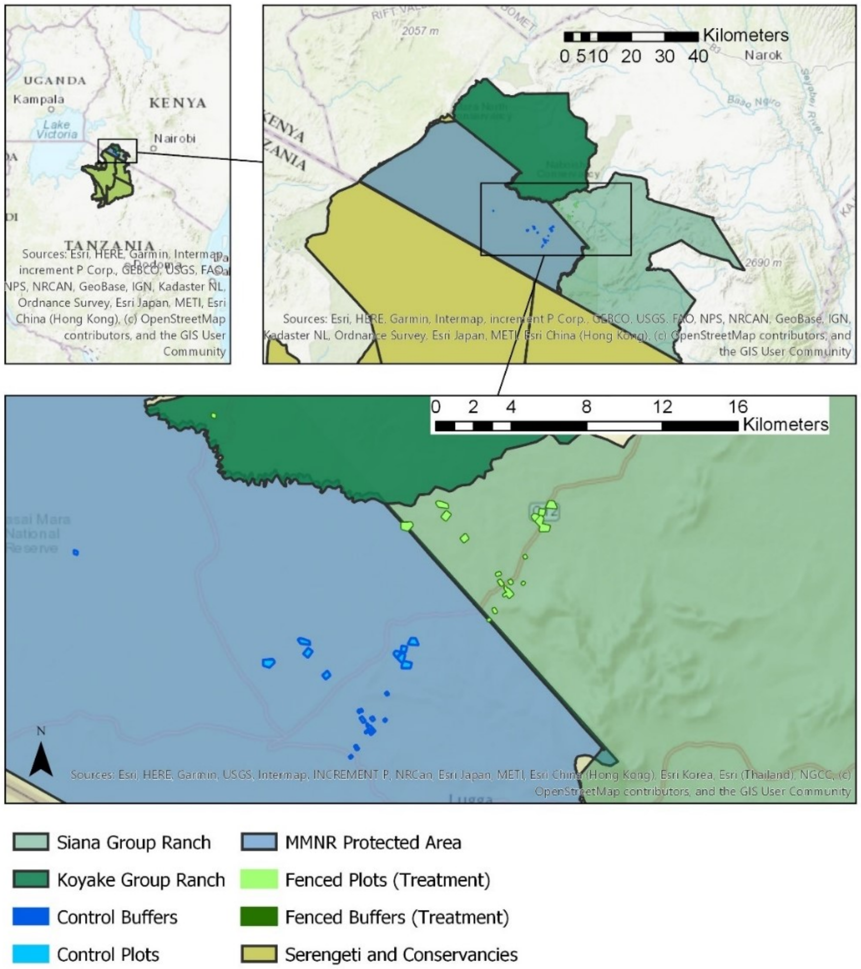


Fig.2.1 Map of study area shows protected area 'control' plots (blue), inside MMNR. Unprotected 'treatment' area plots (green), are within the former group ranches Koyake and Siana. Three fence clusters are contained within a total area of ca. 42.5km^2 and an average area of 3.2km^2 per cluster. The average distance between clusters is 3km.

Study Design

A Before-After Control-Impact Paired (BACIP) (*Fig.2.2*) design as synthesized by Smith et al. (2002), was utilized for this study. In a BACIP design, impact sites are paired with control sites, and each location is measured multiple times before and after a known impact has occurred (Meroni et al, 2017 and Smith et al, 2002). Furthermore, an interview was linked to each impact site. The impact is defined as "…any change in means that is correlated to the start of some new human activity." (Underwood, 1991). To assess the impact of fences on NDVI and BI, we measured the indices inside the fence and outside of the fence (in a 60-meter buffer). Statistical models were used to reveal the impact of fences on NDVI or BI, which will be defined as a difference in slopes of the response variables between the inside and outside of fences, before and after construction. The significance of the impact was determined by a difference in means of the response before and after the impact occurred.

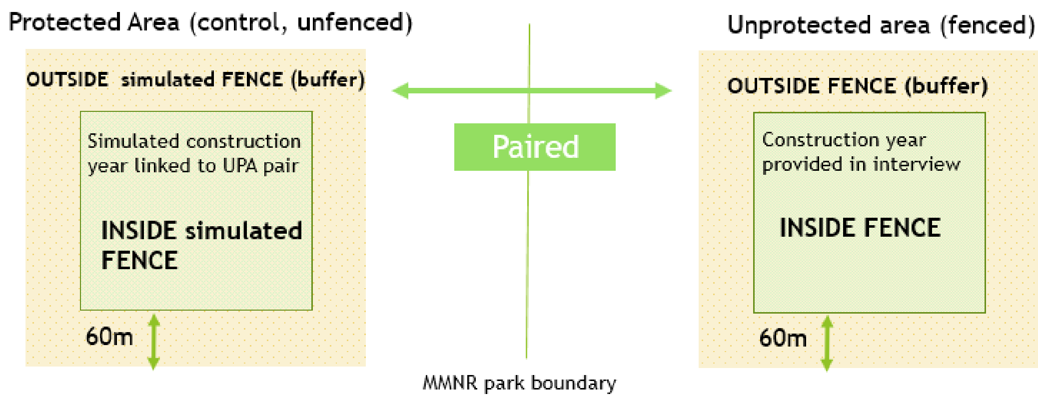
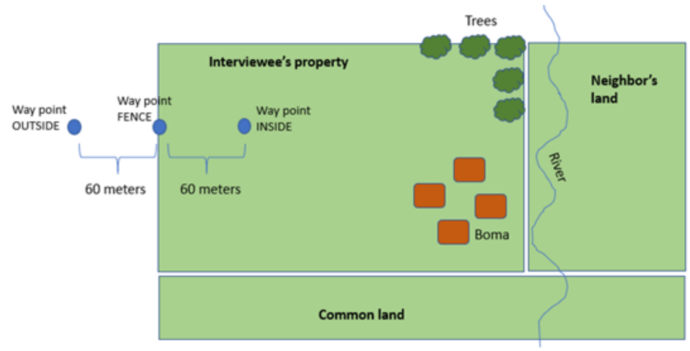


Fig.2.2 Before-After Impact-Control Paired (BACIP) design. Fence data in UPA was gathered, digitized with buffers, then replicated as pairs in the PA. Fence construction dates are used to determine the impact of fences before and after construction.

At 21 fenced sites, which were owned by interviewees (details in Interview section), GPS points were collected using a Garmin Etrex 30 (±3 m accuracy). Points were recorded on the fence line, 60 meters inside the fence line, and 60 meters outside the fence line (*Fig.2.3*). Points were later used to digitize fence areas using ArcMap Pro (version 2.1.0) and Google Earth Pro (version 6.2). A 60m buffer was constructed around the digitized fence plots. This area will be considered the 'outside' of the fence, while the area inside the polygons will be considered 'inside' of the fence for data collection and analysis purposes. The layer of digitized fence plots and buffers was replicated inside the PA to form paired control plots. Control plots were placed near the MMNR border and away from disturbances such as roads, waterways and livestock paths.

Fig.2.3 Outline of data collection in conjunction with interview data. We marked GPS points inside fenced areas as well as on and buffering the fence line in order to digitize with GIS.



Remote Sensing

To derive the indices NDVI and BI, satellite data was utilized from USGS Earth Explorer (https://earthexplorer.usgs.gov/) and downloaded between January 4 and February 14, 2019. All images are Landsat Level 1 Tier 1 data which is standardized by the USGS. They are contained within a single scene (path 169, row 061) and are therefore not subject to any additional geometric corrections during pre-processing (Young et al, 2017).

Data was collected by Landsat 5 with Thematic Mapper (TM), Landsat 7 with Enhanced Thematic Mapper (ETM+), and Landsat 8 with Operational Land Imager (OLI), with all sensors at 30-meters resolution each.

Images were filtered by sensor coverage to include study area and by seasonality. The study was based on the height of the wet season in Narok county, between April and June (Oindo et al, 2003) and end of dry season, between August and October (Serneels and Lambin, 2001). Images affected by the failure of the Scan Line Corrector (SLC) on Landsat 7, which occurred on May 31, 2003, were not used. Therefore, the study utilized Landsat 5 Thematic Mapper (TM) data for images selected after May 2003, until the launch of Landsat 8 in 2013. Images selected for the analysis of the study sites had negligible cloud interference. However, in two scenes, dry season 2017 and wet season 2018, the individual plots which were affected by clouds were removed from the data set (see 'adjusted' values, *Table 2.1, 2.2*).

Raw data was processed using ArcGIS Pro. The multispectral band with metadata was pre-processed using the Apparent Reflectance function which also corrects for sun angle. This function corrects to the Top of Atmosphere (TOA) reflectance [*equations 1,2*] and is a method of standardization for multiple images within one Landsat scene across multiple sensors and times of year (Young et al, 2017).

Table 2.1 Wet season (April -June) image data (Landsat Missions, USGS).

Year	Acquisition Date	Satellite/Sensor	Resolution	Scene Cloud Cover	PA	UPA
1984	June 15	LS 5 TM	30m	29%	Suitable	Suitable
1986	May 4	LS 5 TM	30m	40%	Suitable	Suitable
2001	April 3	LS 7 ETM+	30m	4%	Suitable	Suitable
2002	May 24	LS 7 ETM+	30m	7%	Suitable	Suitable
2003	April 25	LS 7 ETM+	30m	3%	Suitable	Suitable
2008	June 1	LS 5 TM	30m	23%	Suitable	Suitable
2009	June 4	LS 5 TM	30m	3%	Suitable	Suitable
2013	May 30	LS 8 OLI	30m	19.21%	Suitable	Suitable
2014	May 17	LS 8 OLI	30m	6.81%	Suitable	Suitable
2015	June 21	LS 8 OLI	30m	17.96%	Suitable	Suitable
2016	June 7	LS 8 OLI	30m	24.59%	Suitable	Suitable
2017	May 25	LS 8 OLI	30m	10.79%	Suitable	Suitable
2018	May 28	LS 8 OLI	30m	4.43%	Adjusted	Suitable

Table 2.2 Dry season (August -October) image data (Landsat Missions, USGS).

Year	Acquisition Date	Satellite/Sensor	Resolution	Scene Cloud Cover	PA	UPA
1984	September 3	LS 5 TM	30m	28%	Suitable	Suitable
1986	October 27	LS 5 TM	30m	41%	Suitable	Suitable
1999	September 5	LS 7 ETM+	30m	31%	Suitable	Suitable
2000	October 25	LS 7 ETM+	30m	1%	Suitable	Suitable
2001	August 25	LS 7 ETM+	30m	1%	Suitable	Suitable
2002	September 13	LS 7 ETM+	30m	2%	Suitable	Suitable
2008	September 21	LS 5 TM	30m	25%	Suitable	Suitable
2013	October 5	LS 8 OLI	30m	6.15%	Suitable	Suitable
2014	October 24	LS 8 OLI	30m	19.1%	Suitable	Suitable
2015	October 11	LS 8 OLI	30m	16.83%	Suitable	Suitable
2016	September 11	LS 8 OLI	30m	12.52%	Suitable	Suitable
2017	September 30	LS 8 OLI	30m	11.68%	Adjusted	Suitable
2018	October 3	LS 8 OLI	30m	4.25%	Suitable	Suitable

Young et al. (2017) recommend utilizing the fewest possible steps in pre-processing. This is due to several factors. Namely, it can introduce errors, is often time consuming, and depending on the measurement, can be unnecessary. Therefore, only images used for NDVI analysis were corrected for TOA. The corrected multispectral data were then clipped to the study area and analyzed for NDVI.

[*1*] $$\rho\lambda' = M\rho * Qcal + A\rho$$

Where,
$\rho\lambda'$ = TOA Planetary Spectral Reflectance, without correction for solar angle.
$M\rho$ = Reflectance multiplicative scaling factor for the band
$A\rho$ = Reflectance additive scaling factor for the band
Qcal = L1 pixel value in DN
(USGS)

[*2*] $$\rho\lambda = \frac{\rho\lambda'}{\sin(\theta)}$$

Where,
$\rho\lambda$ = TOA Planetary Reflectance
θ = Solar Elevation Angle (from the metadata)
(USGS)

NDVI was extracted using the ‘red’ and ‘near infrared’ [*equation 3*] bands. The BI index [*equation 4*] was extracted using the raster calculator function on bands 1, 3, 4, 5 (Landsat 5 & 7) and bands 2, 4, 5, 6 (Landsat 8).

[*3*] $$NDVI = \frac{NIR - RED}{NIR + RED}$$

Where,
NIR is the Near Infrared wavelength, 0.76 – 0.90mm
RED is the wavelength 0.63 – 0.69mm
(Yengoh et al, 2015)

[*4*] $$BI = \frac{[(SWIR + R) - (NIR + B)]}{[(SWIR + R) + (NIR + B)]}$$

Where,
SWIR is the Short-Wave Infrared wavelength, 1.55 – 1.75mm
NIR is the Near Infrared wavelength, 0.76 – 0.90mm
R is the Red wavelength, 0.63 – 0.69mm
B is the Blue wavelength, 0.45 – 0.52mm
(Chen et al, 2004)

The resultant two indices were extracted by mask of the overlaying polygon fenced areas (inside fence) and a 60-meter buffer (outside fence) around each polygon. Raster points were extracted by mean, maximum, minimum, and standard deviation values. The final step was to perform a spatial join of the polygons and point data. The entire workflow of processing remotely sensed data has been outlined in *Figure 2.4*.

Precipitation data was acquired from Bartzke et al. (2018) and Dr. Holekamp at the Mara Hyena Project (U.S. National Science Foundation) and was used in the analysis of remotely sensed indices (Appendix C). Rain gauges were located in Narok (Bartzke data) and inside the Mara near the

Talek gate (NSF data). Data was used based on the date of the satellite image acquisition. Precipitation data was used from the month prior to image acquisition if images occurred before the 20th of the month. For images taken on the 20th or after, precipitation data from the same month was used to account for a lagged response of NDVI to rainfall (Lotsch et al, 2003).

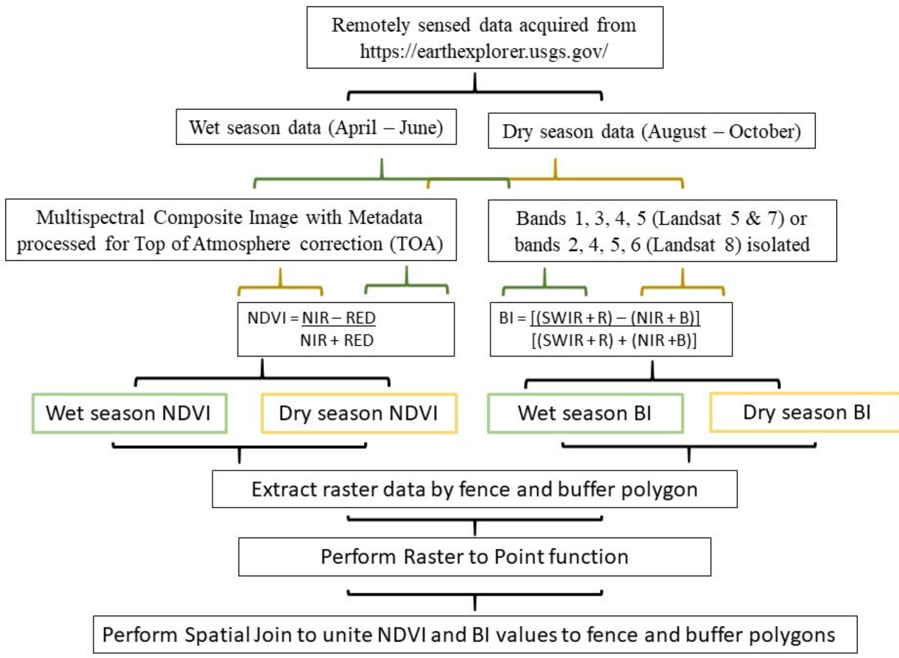


Fig.2.4 Workflow processing of remotely sensed data to extract NDVI and BI for wet and dry seasons.

Interviews

Interview questions were derived through methodology developed by Byers (1996), Creswell and Creswell (2017) and Hauck (2013). More specifically, all interview questions were narrated in a neutral tone and direction and allowed for multiple choice responses. A 5-10-minute open-ended interview was conducted following the set questionnaire (Appendix A). Here, respondents volunteered information on the characteristics of their land, their fenced property, and any land-use practices they adopted on their property.

In the field, interviewees were divided by stakeholder level. High-level stakeholders were policy-makers, conservancy wardens or managers. They were part of a research conference in Narok town. Although they or a family member owned fenced land in the villages, they did not live on that land. The data from these interviews was not connected to a fenced plot for the remote sensing analysis. Local-level stakeholders were Maasai people living in the villages near the border of MMNR. They lived on the fenced properties which were used in the remote sensing analysis. Twenty-one local interviewees were selected by availability and willingness to participate in a joint research project and were compensated for their time. They were selected by community facilitators who were familiar with fence owners and requested their permission to be interviewed. Among local stakeholders, one person gave a partial interview while one person declined to be interviewed (n=28).

Interviewees answered a survey (Appendix A) of 11 questions which were communicated in English or through translation into Swahili or the local language (Maa) by community facilitators who accompanied the research team. Interviewees had 5 levels of multiple-choice answers or indicated an answer between levels, giving each question a total of 9 possible answers. The questions were focused on visual perceptions of grass greenness, height, and coverage. Each question was therefore supported by a related pictorial image (following Hauck 2013) created using Adobe Photoshop (version CS5). The survey targeted stakeholder perceptions during the wet season both before and after fences were constructed and emphasized the inside and outside of fences. They were also asked the year in which their fence was constructed. The construction date for the fence which not supported by an interview was taken as the median fence dates from the interview data set, which was 2015. If the landowner did not have a fence, they were asked to consider the fenced area on a neighboring property which they were familiar with. A final question referred to the preference of grass greenness as fodder for livestock.

Analysis

To model the response indices, NDVI and BI, as a function of the covariates, a Gaussian Generalized Linear Mixed Model using Template Model Builder (GLMMTMB) function was used for mean NDVI and BI, and a GLMMTMB with Gamma distribution was used to model the variability (measured by standard deviation) of NDVI and BI. Gamma distribution was selected to model variability of responses due to both poor heteroscedasticity of the residuals (with a Gaussian distribution), as well as the skewed, continuous and strictly positive nature of the response variable (Pelabon, 2018). The gamma distribution utilizes a reciprocal canonical link function based on all data in a gamma distribution being greater than zero.

Fixed covariates in the model were *before_after* (categorical with two levels indicating before or after fence construction), *area* (categorical with two levels indicating the paired data; UPA fence plots were paired with control plots inside the PA), and *fence* (categorical with two levels indicating inside the fence or outside the fence in the 60-meter buffer). Each model included all two and three-way interactions between these fixed terms. To incorporate the spatial structure of our experiment in our analysis, we used a nested random structure of *location* (each unique plot and buffer) nested within *cluster* (the spatial grouping of the plots into villages identified by proximity). An additional crossed random effect of *precipitation* (numeric, monthly total rainfall), was included to account for the influence of variable rain before and after fencing [*equation 5*]. Due to correlation between variables for season and precipitation, and to tease out seasonal effects by reducing interaction complexity, models were separated by season and index for a total of eight models.

$$[5] \qquad \text{Index} = \textit{fence} * \textit{treatment} * \textit{before\_after} + (1|\textit{cluster:location}) + (1|\textit{precipitation})$$

To visualize the potential impact of fencing in the context of the PA and UPA and both inside and outside fences, the full model estimates were used to construct interaction plots (*Fig.3.2*). To obtain values of significance, model selection was based on backward elimination of non-significant covariates using Likelihood Ratio Testing (LRT). Model comparison was based on the difference of Akaike Information Criterion for small sample sizes (AICc) between the full model and the final model (Appendix E) (Bolker et al, 2009 and Zuur et al, 2010). We then ran an ANOVA between the full and reduced models. This procedure was used for both NDVI and BI, on mean and standard deviation response variables in wet and dry seasons. *Table 3.1* shows the final models with significant fence impact (bold).

Interview data was analyzed using descriptive statistics and visual comparison of plotted responses.

We used the packages tidyr (Wickham, 2017), dplyr (Wickham et al, 2017), ggplot2 (Wickham and Chang, 2016), ggpubr (Kassambara 2018), forcats (Wickham, 2018), effects (Fox et al, 2019), gridExtra (Auguie, 2016) and glmmTMB (Brooks et al, 2017) in the software RStudio version 3.1.5 (R Core Team 2018).

III. Results

Remote Sensing

Wet season

Full models indicated that there was a non-significant effect of fences on mean NDVI. Values tended to increase inside fences and buffers by 5.7% and 4.4% respectively (*Fig. 3.2*, A) (*Table 3.1*). However, fences impacted mean BI which has decreased (indicating less bare soil) within fences by 87.1% and buffers 18.3%, post-construction. Fencing also impacted the variability of NDVI. Fences increased variation in NDVI inside and outside by 33% and 11.5% , respectively (*Fig. 3.2*, B). Before and after fencing variability in BI tended to be higher in buffers. There was an 18.3% increase outside fences, and a 21.3% increase in BI variability inside fences after construction (*Fig. 3.2*, C).

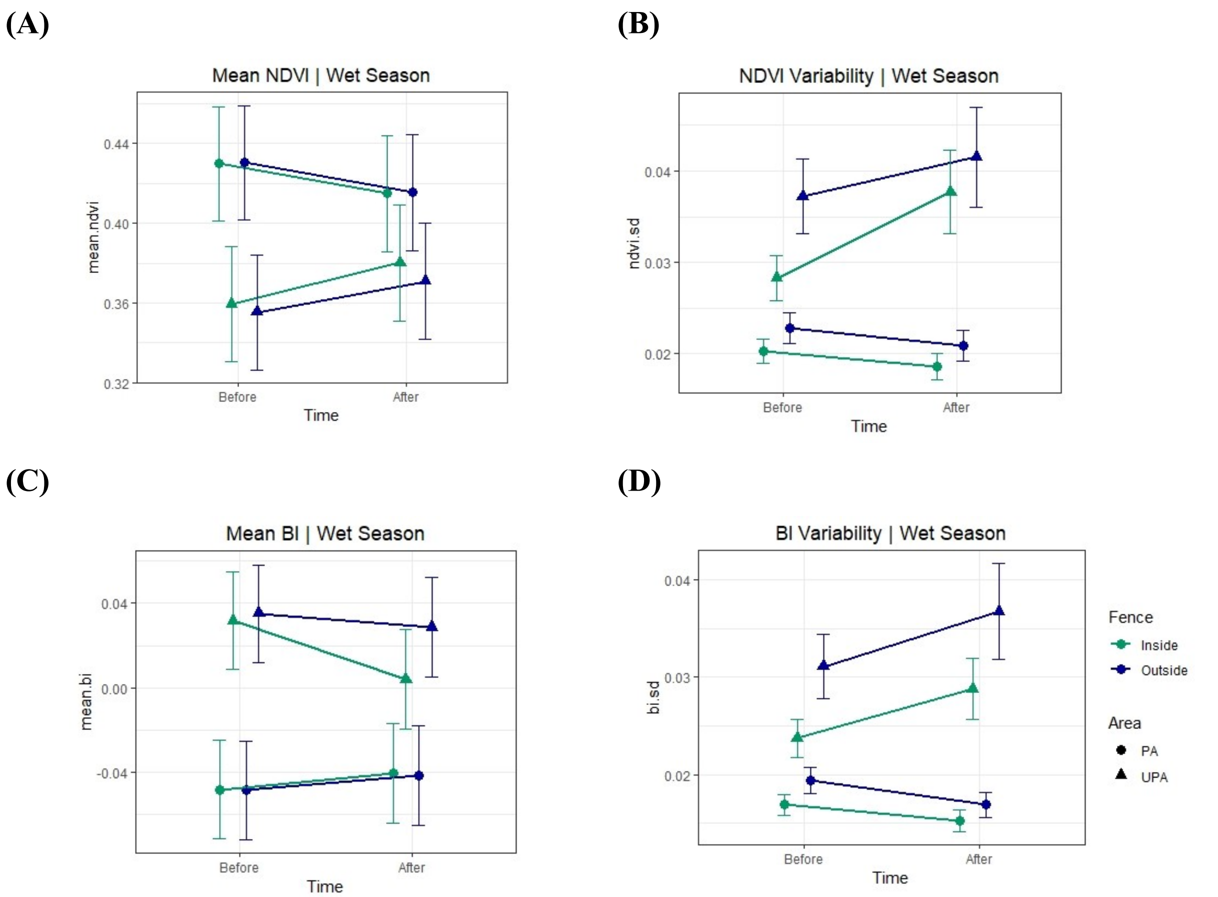


Fig.3.2 Interaction plots show impact of fences on wet season mean and variability of NDVI and BI, with standard error bars using model estimates. The impact of fences may explain the increasing variability in NDVI (B, green triangle), while tending to decrease mean BI inside fences post-construction (C, green triangle).

Figure 3.1 shows a cluster of fences in the UPA during the wet season from the earliest satellite image from this study (1984), to the most recent (2018). The 1984 image is pre-construction of fences, and when compared to the post-construction image from 2018, patterns in the NDVI and BI values due to fences become apparent.

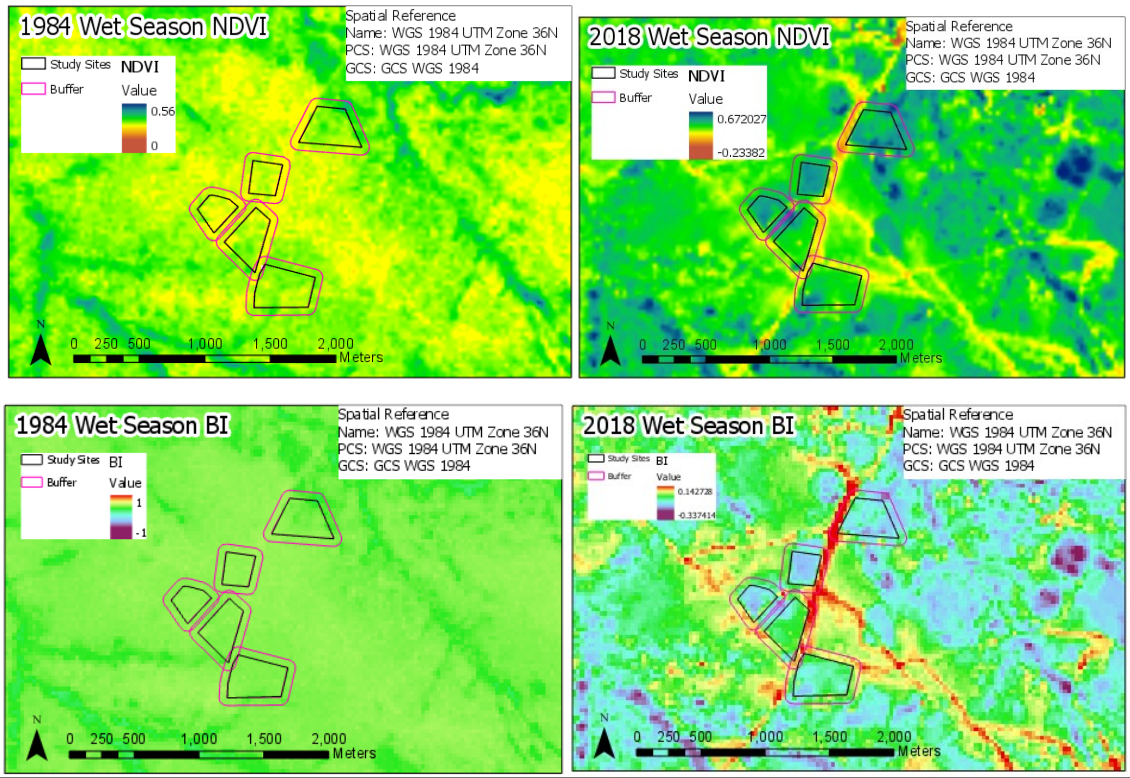


Fig.3.1 NDVI patterns pre-construction (1984) and post-construction (2018) of fences during the wet season. Dark blue indicates areas of high NDVI (top), red indicates areas of high BI (bottom). Both indices use a standardized scale of -1 to 1.

Table 3.1 Wet season fencing impact, given by the full model, Index ~ *fence*before_after*area.* Here we show estimates for the impact in the UPA, which are plotted in *Fig.3.2.* PA estimates not shown for simplicity.

		before:outside	*after:outside*	*before:inside*	*after:inside*	*P*	*df*	*logLik*	*AIC*
Mean	*Estimates*	0.355	0.371	0.360	0.380	0.82	9	1782.9	-3547.7
NDVI	*SE*	±0.028	±0.028	±0.028	±0.028				
SD	*Estimates*	0.037	0.041	0.028	0.037	<0.01	9	3210.0	-6402.1
NDVI	*SE*	± 0.004	±0.005	±0.002	±0.004				
Mean	*Estimates*	0.035	0.029	0.032	0.004	<0.01	9	2001.7	-3985.4
BI	*SE*	±0.022	±0.023	±0.022	±0.023				
SD BI	*Estimates*	0.031	0.037	0.024	0.029	0.56	9	3393.4	-6768.9
	SE	±0.003	±0.005	±0.002	0.003				

Model selection was utilized to tease out significant factors, should the impact of fences be non-significant in the full models. Reduced models supported that fences had a significant effect on the responses of NDVI variability and mean BI in the wet season in comparison to the full models (the impact of fence construction was demonstrated through the interactions *fence*time* and *fence*time*area, Table 3.2*). The interaction *before_after*area,* for mean NDVI and variability in BI, was significant in all models, suggesting that there was a strong effect caused by the initial difference in the indices between the protected and unprotected areas.

Table 3.2 Reduced wet season models derived using backward elimination and ΔAICc model selection (Appendix E). Bolded values indicate the impact of fences.

	NDVI – Mean			NDVI – Var			BI – Mean			BI – Var		
	L.ratio	df	P-value	L.ratio	df	P-value	L.ratio	df	P-value	L.ratio	df	P-value
Before_after	1766.9	6	0.762	3201.7	7	0.057	1986.9	7	0.252	3381.9	7	0.098
Fence	--	--	--	3201.7	7	<0.001	1986.9	7	0.039	3381.9	7	<0.001
Area	1766.9	6	<0.001	3201.7	7	<0.001	1986.9	7	<0.001	3381.9	7	<0.001
*Before_after*Fence*	--	--	--	**3213.6**	**9**	**0.007**	**2004.1**	**10**	**<0.001**	--	--	--
*Before_after*Area*	1781.7	7	<0.001	3213.6	9	<0.001	2004.1	10	0.023	3393.2	8	<0.001
*Area*Fence*	--	--	--	--	--	--	2004.1	10	0.028	--	--	--
*Before*Area*Fence*	--	--	--	--	--	--	**2006.6**	**11**	**0.027**	--	--	--

Dry season

Fences had weak tendencies to affect NDVI and BI in the dry season. Although variability in both NDVI and BI differed outside and inside fences, the slope of the interaction before and after fencing was nearly the same. Variability in NDVI outside fences decreased by 10.6% while decreasing by 9.2% inside fences (*Fig.3.4*, B). Variability in BI increased outside fences by 12.3% while also increasing inside fences by 13.4% (*Fig.3.4*, D). This suggests that fences explained little to none of the changes in variability in the dry season. Mean NDVI decreased by 3.2% within fences while having nearly no effect (-0.82%) on the NDVI outside fences, post-construction (*Fig.3.4*, A). Likewise, fences had a weak effect on mean BI. Bareness increased by 9.1% inside fences while increasing by 19.5% outside fencing in the time since construction (*Fig.3.4*, C). Although the slopes are different for both mean indices, there is no difference in model estimates, suggesting the impact of fences is not significant (*Table 3.3*).

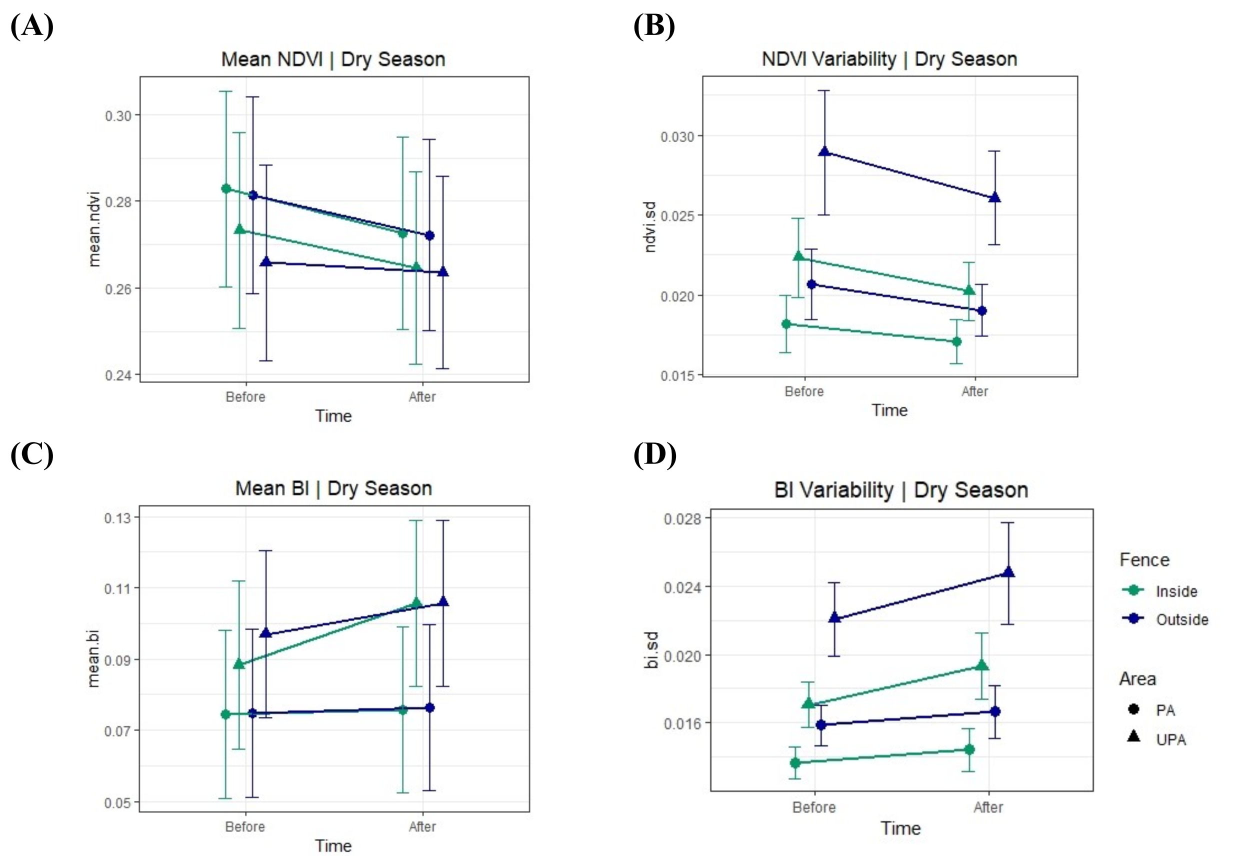


Fig.3.4 Interaction plots show impact of fences on dry season mean and variability of NDVI and BI, with standard error bars using model estimates. The impact of fences may explain the increasing variability in NDVI (B, green triangle), while tending to decrease mean BI inside fences post-construction (C, green triangle).

Figure 3.3 shows a cluster of fences in the UPA during the dry season in 1984 and 2018. Patterns in NDVI and BI values due to fences are apparent between pre-construction (1984), and post-construction of fences (2018).

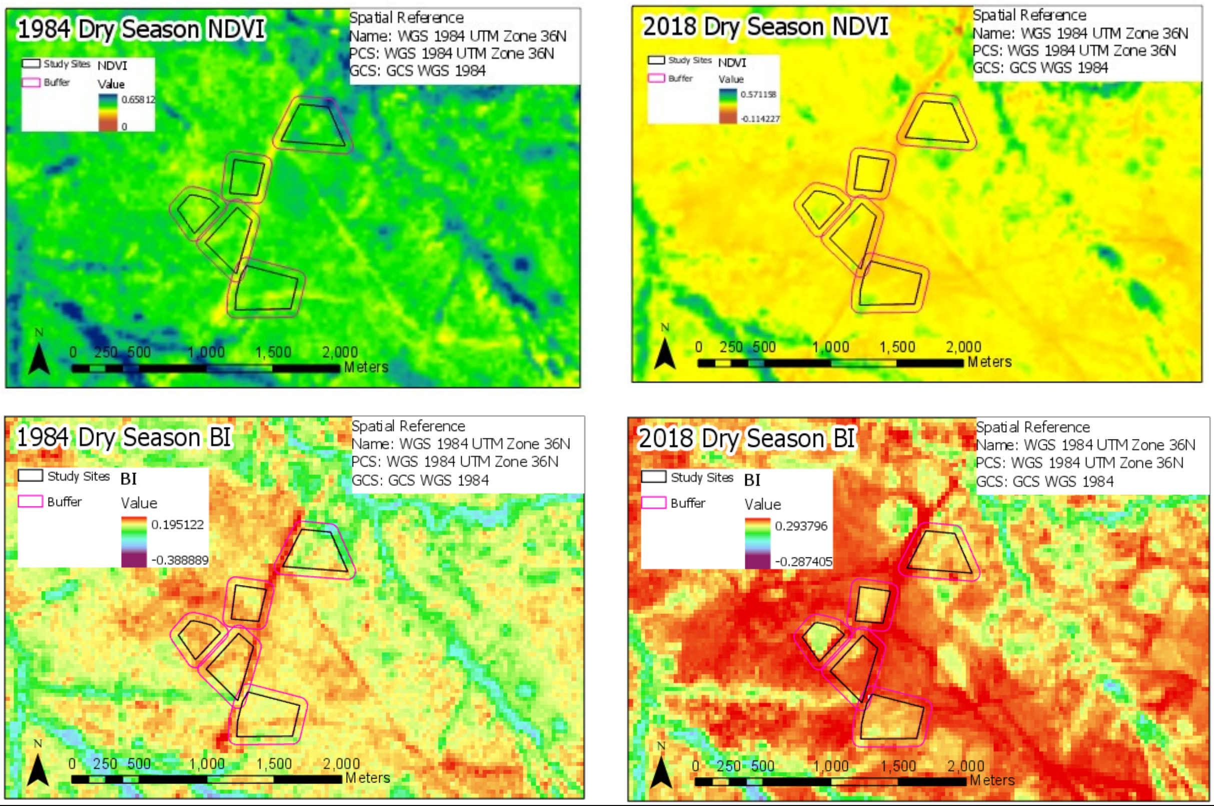


Fig.3.3 NDVI and BI patterns pre-construction (1984) and post-construction (2018) of fences during the wet season. Red indicates areas of high BI, while blue indicates high NDVI. Index scales are -1 to 1.

Table 3.3 Dry season fencing impact, given by the full model, Index ~ *fence*before_after*area.* Here we show estimates for the impact in the UPA. PA estimates not shown for simplicity.

		before:outside	*after:outside*	*before:inside*	*after:inside*	*P*	*df*	*logLik*	*AIC*
Mean NDVI	*Estimates*	0.266	0.264	0.273	0.265	0.71	9	1751.2	-3484.4
	SE	±0.023	±0.022	±0.023	±0.022				
SD NDVI	*Estimates*	0.029	0.026	0.022	0.020	0.97	9	3178.1	-6338.3
	SE	±0.004	±0.003	±0.002	±0.002				
Mean BI	*Estimates*	0.097	0.106	0.088	0.106	0.35	9	2068.5	-4119.0
	SE	±0.023	±0.022	±0.023	±0.022				
SD BI	*Estimates*	0.022	0.025	0.017	0.019	0.88	9	3381.0	-6744.0
	SE	±0.002	±0.003	±0.001	±0.002				

Dry season response indices were not explained by the fence impact interactions *fence*before_after*area* or *fence*before_after.* We have used reduced models to uncover the significant covariates that might explain the response of NDVI and BI. The *area* variable as significant in all four dry season models (*Table 3.4*). This suggests that the affect is mostly due to initial differences in NDVI and BI between the protected and unprotected areas.

Table 3.4 Reduced dry season models derived using backward elimination and ΔAICc model selection (Appendix E).

	NDVI – Mean			NDVI – Var			BI – Mean			BI – Var		
	L.ratio	df	P-value	L.ratio	df	P-value	L.ratio	df	P-value	L.ratio	df	P-value
Before_after	--	--	--	--	--	--	2064.3	6	0.054	--	--	--
Fence	--	--	--	3175.3	6	<0.001	--	--	--	3378.8	6	<0.001
Area	12.87	1	<0.001	3175.3	6	<0.001	2064.3	6	<0.001	3378.8	6	<0.001
*Before_after*Fence*	--	--	--	--	--	--	--	--	--	--	--	--
*Before_after*Area*	--	--	--	--	--	--	2068.0	7	0.006	--	--	--
*Area*Fence*	--	--	--	--	--	--	--	--	--	--	--	--
*Before*Area*Fence*	--	--	--	--	--	--	--	--	--	--	--	--

The results of our analysis reveal fence impacts that are differentiated by season. Within the wet season, the predictors and interactions accounted for much of the expected variation, while in the dry season, many of the predictors and interactions were found to be non-significant through the model selection process.

Interviews

Greenness

Generally, high-level respondents perceived that the fence maintained a level of greenness after it was built, whereas locals perceived the grass to become greener after the fence was constructed inside fenced area but less green outside fenced areas. Meanwhile, both stakeholder groups perceived a decrease in greenness on the outside of fences.

More specifically, 74% of local stakeholders responded that grass had become greener inside fences after they were constructed and 57% perceived it to be less green on the outside of the fence. 68% selected a greenness at level 3 or lower before fencing and 100% selected level 4 or greater inside fences after construction. 53% perceived a greenness of level 2 or less on the outside of fences after construction (*Fig.3.5*). Among high-level stakeholders, 44% said that their grass inside the fence had become greener while 67% said grass became less green on the outside of their fence. 33% chose level 5 greenness to describe their grass before fencing, with 56% perceiving level 5 greenness after building a fence.

Fig.3.5a Pictorial response options as taken from interview questionnaire, showing levels and intermediate levels. Here we asked, ‘During the wet season, how green was your grass before fence construction? After fence construction, how green was the grass on the inside and outside of the fence?’ (Appendix A).

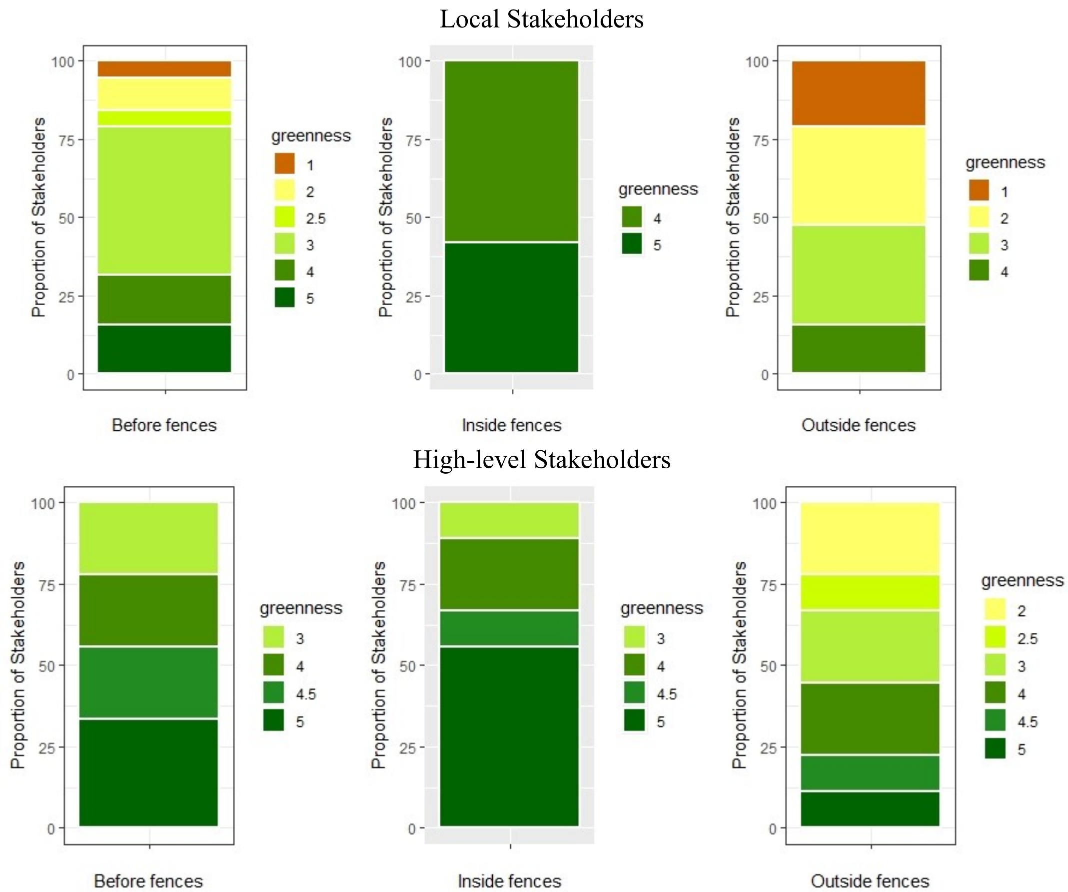


Fig.3.5b Perceptions of grass greenness before fence construction, inside, and outside fences post-construction. Local-level stakeholders (top) and high-level stakeholders (bottom).

Height

All local respondents perceived that grass height had increased on the inside of constructed fences, with 89% selecting level 3 or shorter grass in the time before fence construction, while 84% said grass height had reached level 4 or greater on the inside of their fences (*Fig.3.6a*). They also perceived that height on the outside of fences decreased. 95% of locals responded that grass was shorter outside than inside fences, with 21% reporting that grass was shorter than it was before fences were constructed (*Fig.3.6b*). 89% of high-level respondents perceived the height of grass to increase inside fences, with 56% selecting a height at level 2 before fences and 67% perceiving height between levels 3-4 on the inside of their fences after construction.

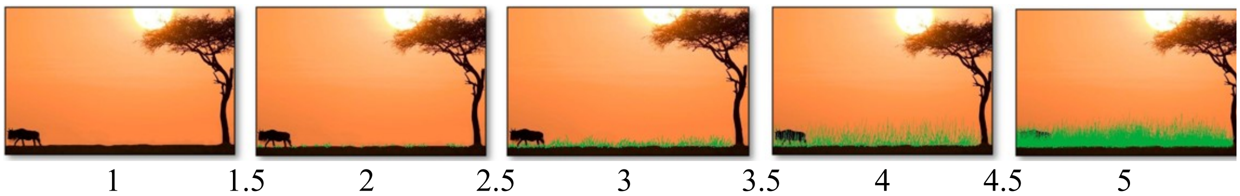


Fig.3.6a Pictorial response options as taken from interview questionnaire, showing levels and intermediate levels. Stakeholders were asked, 'During the wet season, how tall was your grass before fence construction? After fence construction, how tall was the grass on the inside and outside of the fence?'

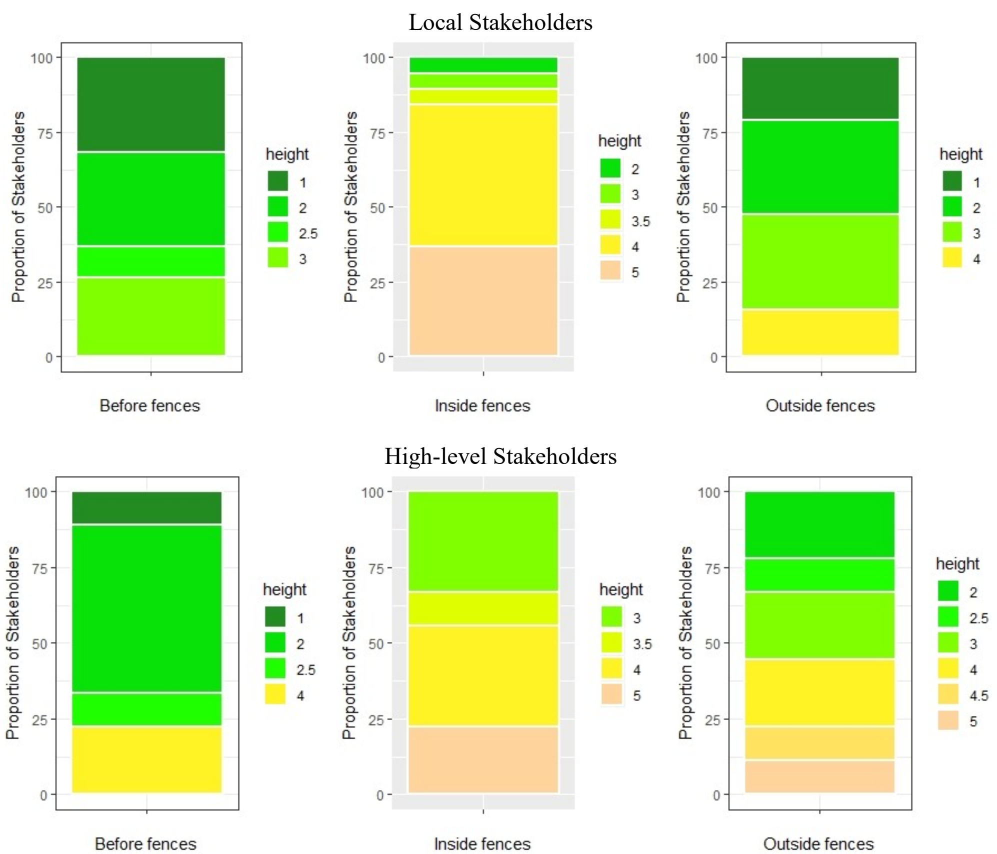


Fig.3.6b Perceived height of grass before fence construction, inside and outside post-construction between local (top) and high-level (bottom) stakeholders.

Bare soil

All local stakeholders perceived the bare soil to decrease on the inside of fences, with 42% selecting level 2 before fences and 53% selecting level 4 inside fences after construction. 47% said bareness was level 3 outside fences (*Fig.3.7a*).

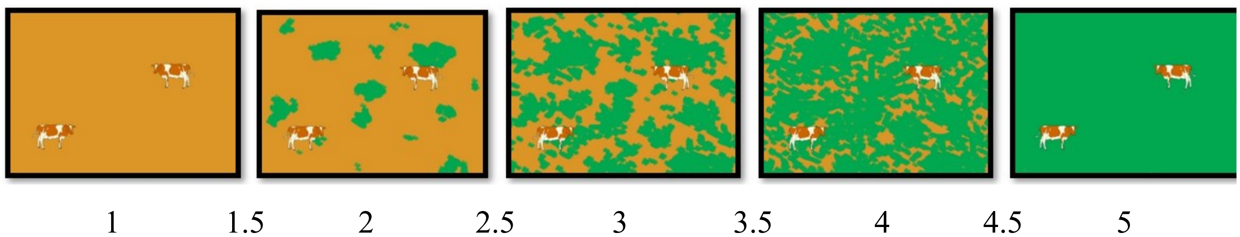


Fig.3.7a Pictorial response options as taken from interview questionnaire, showing levels and intermediate levels. Here we asked, 'During the wet season, how bare was your land before fence construction? After fence construction, how bare was your land on the inside and outside of the fence?'

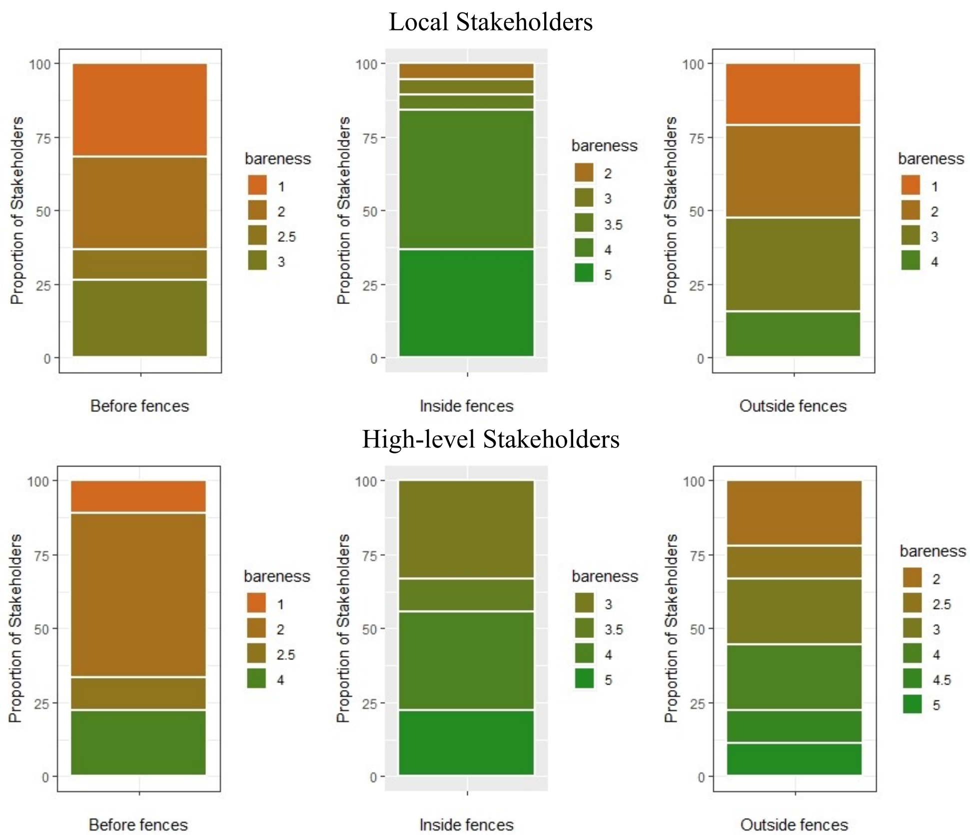


Fig.3.7b Perceived bare ground before fence construction, inside and outside post-construction between local (top) and high-level (bottom) stakeholders.

Similar perceptions were shown between stakeholders (*Fig.3.7b*) whereby 78% of high-level stakeholders said bareness had been affected by fences. 67% said bareness was level 3 or less before fencing, while after fencing, 89% said bareness was level 3 or greater inside fences, with 67% responding that bareness was level 2 or less on the outside of fences.

Additional data gathered during interviews

Stakeholders were also asked about the color of grass that they preferred to feed their livestock, based on the same scale of greenness. Among high-level stakeholders, 33% preferred level 3, while 68% of local stakeholders preferred level 5 for their livestock. Several of the interviewees commented that even though very green grass can make cattle sick, they would compensate with medication (*Fig.3.8*).

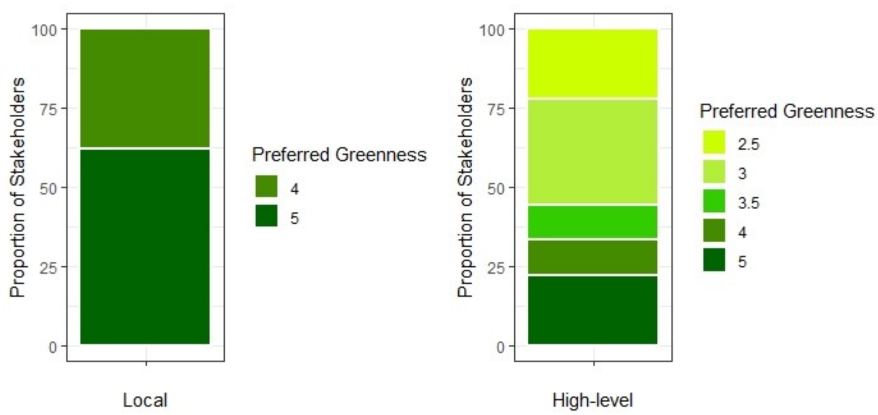


Fig.3.8 Local and high-levels stakeholder responses to question regarding greenness of grass preferred as livestock fodder.

The mean fence size was 32 acres and mean year of construction was 2012 within the high-level stakeholder group. Among local stakeholders, the mean fence size was smaller, at 22.6 acres and on average built later, in 2014. Fencing type varied among stakeholders; 89% of high-level stakeholders had a wood-post and wire fence while 11% had electric fences; 50% of local stakeholders' fences were electric while 38% had wood-post and wire, with less than 1% owning a fence with just wooden posts (without wire).

Seven land-use practices were identified from interviews with both levels of stakeholder that occurred inside fenced areas, including: grass cutting, grass banks (i.e. preserving grass for livestock), tree removal, tree planting, agriculture, grazing, and livestock safety (Appendix E). Many landowners utilized paddocks in order to combine two or more of the practices inside their fenced property.

IV. Discussion

We expected that wet season NDVI inside fences would increase after construction. We found that although mean NDVI increased slightly, it was not significant. This was misaligned with stakeholder perceptions, who reported greenness to increase inside fences during the wet season. Instead, we found a significant increase in the variability of NDVI inside fences.

The impact of fences was demonstrated most significantly by a decrease in mean wet season BI inside fences. BI results followed our predictions and were also corroborated by stakeholders who perceived bare ground to decrease inside fences after construction.

In an ethnobotanical study by Bussman et al. (2006), researchers found that the Maasai people residing in our study area (Sekenani Maasai) had an exceptional knowledge of local plant species. They identified 149/155 local species, of which 16 were grasses and sedges (used as livestock fodder). They also identified 12 species of grass with high water content utilized as dry season fodder. Because of the breadth of knowledge that local Maasai people have about their rangelands and resource-dependent livelihoods, it is surprising that there was a mismatch in the two measures of greenness (mean NDVI and local perceptions). Despite a well-established connection between Maasai people and their land, it may be possible that variable greenness has been misinterpreted by locals as average increases year to year. Alternatively, this mismatch suggests potential issues in the use of NDVI for assessing the impact of fencing on vegetation.

The variability of NDVI however, did increase significantly inside fences. It is possible that stakeholders considered spikes in NPP (i.e. strong green years) when assessing greenness and were unable to assimilate a gradual or average change. Stakeholders might interpret fence-induced spikes in NPP as having a higher utility for livestock. Bhola et al. (2012) suggest that high values of wet season NDVI may be associated with herbivory by small and medium herbivores. This keeps grass in the active stages of growth whereby they are both shorter and sparser yet are also greener (with a higher NDVI) than grass that is left to grow un-grazed. Riginos et al. (2012) suggest boma nutrient hotspots, together with short, nutritious grasses, attract wild herbivores who prefer both greener grass and more-open (and thus predator-free) landscapes such as the unprotected areas. Thus, increasing both competition for resources and nutrient inputs to the soil through herbivore dung.

If grass is predicted to be greener around bomas, and stakeholders perceived it as such, then it may be a problem of the study design. We used satellite images with 30-meter resolution and constructed a 60-meter buffer around fences. A higher resolution and larger buffer may be able to detect the predicted and observed increases in mean NDVI inside fences (Yengoh, et al, 2015). Local and high-level stakeholders alike perceived an increase in grass height inside fences after they were constructed. Many perceived the grass outside of fences to have become shorter and sparser than in the time before fencing. NDVI is not sensitive to plant heights over 0.45m (Payero et al, 2004), therefore tall grasses, despite high biomass, would not necessarily precipitate a higher NDVI output. However, the use of fences to facilitate grass growth for dry season banks was reiterated among stakeholders.

Stakeholders corroborated decreased bare soil, meanwhile reporting increases in grass height inside fences. This may be an indication that fenced plots are excluding herbivores, thereby allowing vegetation to increase coverage of bare soil. In a study by Veblen (2012), nutrient hotspots around bomas promoted the expansion of *Pennisetum* into herbivore-exclusions which increased vegetation coverage three-fold in a three-year period. Yong-Zhong et al. (2005) found that herbivore exclusion in a savannah improved vegetation cover and increased litter inputs to the soil, thereby facilitating a recovery of degraded vegetation and soils due to overgrazing.

In the dry season, fences did not significantly influence NDVI and BI, despite stakeholder reports that fences facilitated dry season grass banks. However, there was a significant *area* effect, suggesting a mismatch between 'treatment' and 'control' levels of NDVI and BI before fence construction. An intensification of land-use near the park border may be responsible for this misalignment. This could be attributed to the Maasai resettlement of the Talek area after the eradication of tse-tse flies in the 1960s (Lamprey and Reid, 2004). In this resettlement period, there was an expansion of bomas which may have contributed to the pre-fencing differences in NDVI and BI between the UPA and the PA. As suggested by Velduis et al. (2019), human activity is intense in unprotected areas near park borders.

It remains difficult, however, to reconcile these explanations. NDVI is suggested to increase due to herbivory of new growth, by both livestock and wild herbivores. While bare soil in the same areas is suggested to decline when herbivores are excluded. Local stakeholders who have nuanced knowledge about grass had perceived changes that were not detected by remote sensing, including an unambiguous increase in grass height. Yet there was no statistically significant effect of fences during the dry season when we expect end-of-season standing biomass to be higher in grass banks. These misalignments may be resolved by understanding the differences in land-use practices among stakeholders, defined by stakeholders' livelihoods strategies (Appendix F). Local stakeholders indicated they preferred darker green grass to feed their animals. The color of grass they prefer could influence how and when they either cut, graze, or save the grass for the dry season. Meanwhile several respondents are actively planting or removing trees from their property. These practices can influence the responses of NDVI and BI.

According to interviewees and field observations, fenced plots were often used as rotational grazing paddocks. Several stakeholders commented that this was their strategy for maintaining grass availability. In a study by Olsen et al. (2015), paddocks under different grazing intensities, with identical precipitation, were monitored by MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI. Paddocks excluded from grazing had higher end-of-season standing biomass than paddocks under varied grazing regimes. However, the NDVI was lower where grass was left un-grazed. It was also suggested that grazing induces a succession of the vegetation towards shorter-cycled annuals, which tends to alter the peak NPP from year to year.

Rotational use of fenced areas could reconcile the relationship between greenness, bare soil, herbivory, and land-use. Pulses of grazing intensity could account for the high variability. Different grazing strategies and intensities can affect grass and herb species composition within paddocks which can be detected by NDVI (Blanco et al, 2008). Thus, it may be possible to have fenced plots that are intermittently excluded and grazed at preferred levels of growth and greenness. This points to a strategy which stakeholders may employ knowing the benefits that rotated grazing can bring. Here we detect these benefits as increased variation in NDVI and coverage of bare soils (BI).

We therefore suggest that increases in the wet season variability of NDVI coupled with increases in mean wet season BI, which were detectable through remotely sensed proxies, could be explained by spatial and temporal variation in land-use practices.

Challenges and future considerations

There was a discrepancy in perceptions between the two levels of stakeholders. Although high-level respondents owned fenced property in the village, they did not live on it year-round.

Therefore, it is possible that they are less attuned to the differences before and after fencing. This finding could have implications with regards to land-use policy. High-level stakeholders are decision-makers in the community, and if they are meant to represent the local stakeholders, different perspectives about the effects of land-use could result in disagreements about resource management with respect to fencing.

The general results of this study could also be assessed and interpreted visually using maps of wet season NDVI and dry season BI. In conjunction, the two indices taken at the two seasonal extremes can provide insights to LULCC prior to data extraction and statistical analysis. The use of both NDVI and BI give a clearer picture of land-use changes than NDVI alone (Gill and Phinn 2008, 2009). Future endeavors in the field should consider using NDVI and BI in conjunction to avoid erroneous measurements. Indeed, satellite images represent a snapshot of the indices, therefore, cannot fully represent how landowners use their grass. It would be advantageous to utilize higher resolution data at multiple points per season; however, acquisition of this data is often cost-prohibitive.

To analyze points inside and outside fences, a 60-meter buffer was constructed in GIS. However, in the visual analysis, much of the land extending beyond the buffer had increased in bareness, some of it attributed to road construction. Therefore, it may be important in future studies to focus on a larger region outside fences. Nevertheless, without accurate maps of all extant fences and roads, it will be difficult to obtain an accurate assessment of bareness outside fences. Additionally, this buffer may have limited the study due to fence proximity. Because fences were constructed in different years, a full buffer, instead of a dissolved buffer, was utilized. A consideration for future studies would be to reduce the area of a buffer if a fence or road is known to be constructed within the buffer in the future.

V. Conclusion

Through remote sensing, we found that wet season bare ground decreased significantly due to the impact of fencing in Narok County. This result was corroborated by perceptions of stakeholders who reported a decrease in bare ground after fences were constructed. Stakeholders also reported an increase in wet season greenness following construction of their fences. This result was detected by the standard deviation of NDVI rather than the mean values. This result suggests that increased variability in greenness may be associated with an increase in spatially and temporally variable land-use practices that have coupled fence ownership. Although stakeholders reportedly retain grass for use in the dry season, an increase in dry season NDVI was not significant. However, full mixed models revealed a difference in mean NDVI slopes between the inside and outside of fences. This suggests that dry season plant height, together with variable land management practices inside fenced areas, may account for the mismatch between sensed NDVI and stakeholder perceptions.

Although there are short term benefits to fences, namely the control and ownership of grass resources, there are long term trade-offs. The literature suggests that fences cause fragmentation, trampling and soil compaction, erosion, and become traps for wildlife. There is also the cost-benefit ratio; as fences become damaged by wildlife, they will become increasingly costly to maintain. However, in the meantime, the demarcation of land for the purposes of guaranteed access to resources is a trend that is growing. If the Maasai continue to migrate into smaller land areas, the densification will ensure the persistence of fences for many generations.

Tourism has been a growing industry in the Maasai Mara, and although some Maasai do directly benefit from a livelihoods perspective, most do not, and it may be at the expense of Maasai cultural heritage vis-à-vis sedentarization and decline of pastoral livelihoods. If Maasai people become dissatisfied with allowances from their conservancy land, while at the same time feel an unwelcomed cultural shift, they will likely not agree to extend conservancy leases. This could be exacerbated by the discrepancies in perceptions of land-use and land cover changes between different levels of stakeholders.

The outcomes of fencing continue to be investigated from ecological, political and geographical perspectives. We hope our study also sheds light on the importance of integrating stakeholder perspectives and participation into future studies in this region.

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Landsat-5 images courtesy of the U.S. Geological Survey

Landsat-7 images courtesy of the U.S. Geological Survey

Landsat-8 images courtesy of the U.S. Geological Survey

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Appendix A

Interview questionnaire

"Effect of fences on grass and soil"

____ My land (If landowner has a fence) ____ My neighbor's land (If landowner does NOT have a fence) ____ Village land

Interviewee number____________ Fence Size__________ Village ________________ GPS in ____________________ GPS out ____________________

1. Before the fence was constructed *how green was the grass* on [your / neighbor's / village] land during the growing season?

2. After the fence was constructed *how green was the grass* on [your / neighbor's / village] land *inside the fence* during the growing season?

3. After the fence was constructed *how green was the grass* on [your / neighbor's / village] land *outside of the fence* during the growing season?

4. Before the fence was constructed, *how tall was the grass* on [your / neighbor's / village] land during the growing season?

0-2cm | 2-20cm | 20-50cm | 50-100cm | 100cm+

5. After the construction of the fence, *how tall was the grass* on [your / neighbor's / village] land *inside* the fence during the growing season?

0-2cm | 2-20cm | 20-50cm | 50-100cm | 100cm+

6. After the construction of the fence, *how tall was the grass* on [your / neighbor's / village] land *outside* of the fence during the growing season?

0-2cm | 2-20cm | 20-50cm | 50-100cm | 100cm+

7. Before the construction of the fence, *how much bare soil* was on [your / neighbor's / village] land during the growing season:

75 – 100% bare soil | 50 – 75% bare soil | 50% bare soil | 25 – 50% bare soil | 0 – 25% bare soil

8. After the construction of the fence, *how much bare soil* was on [your / neighbor's / village] land *inside* the fence during the growing season:

75 – 100% bare soil | 50 – 75% bare soil | 50% bare soil | 25 – 50% bare soil | 0 – 25% bare soil

9. After the construction of the fence, *how much bare soil* was on [your / neighbor's / village] land *outside* of the fence during the growing season:

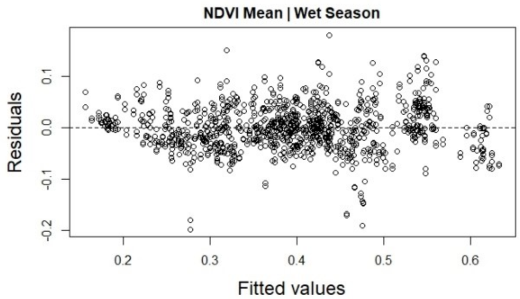
75 – 100% bare soil | 50 – 75% bare soil | 50% bare soil | 25 – 50% bare soil | 0 – 25% bare soil

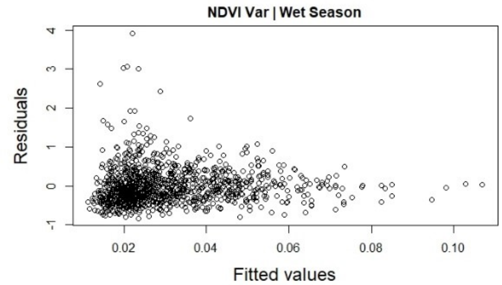
10. Which color of grass provides the best food for your cows?

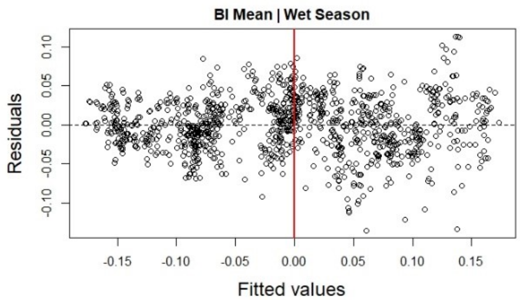
11. When was the fence constructed? ______________________________

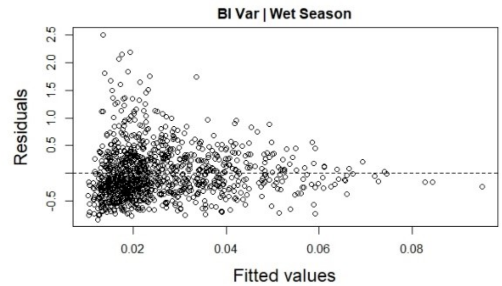
Appendix B

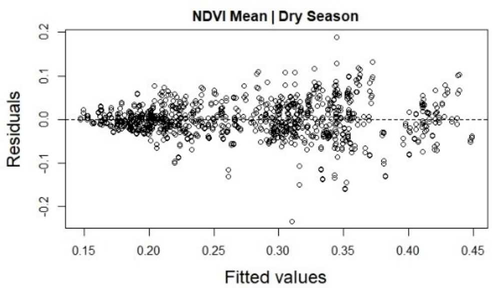
Residual plots of glmmTMB analysis

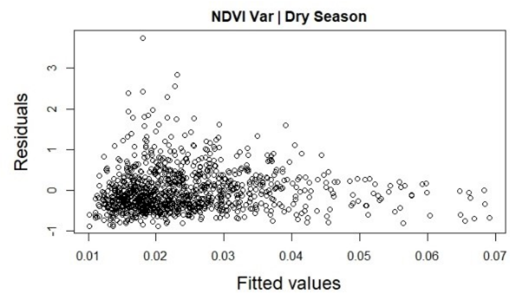


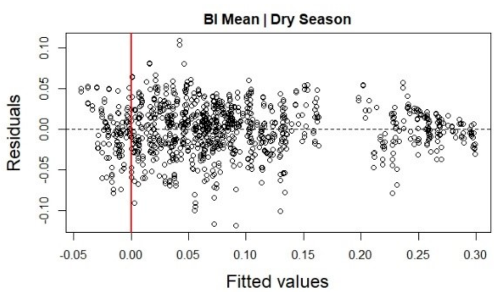


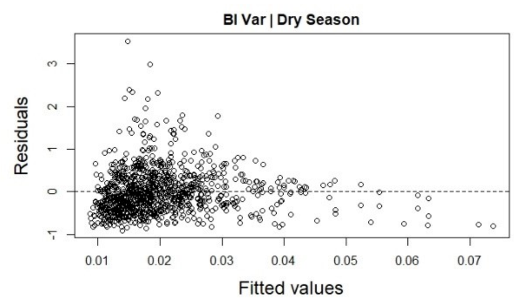






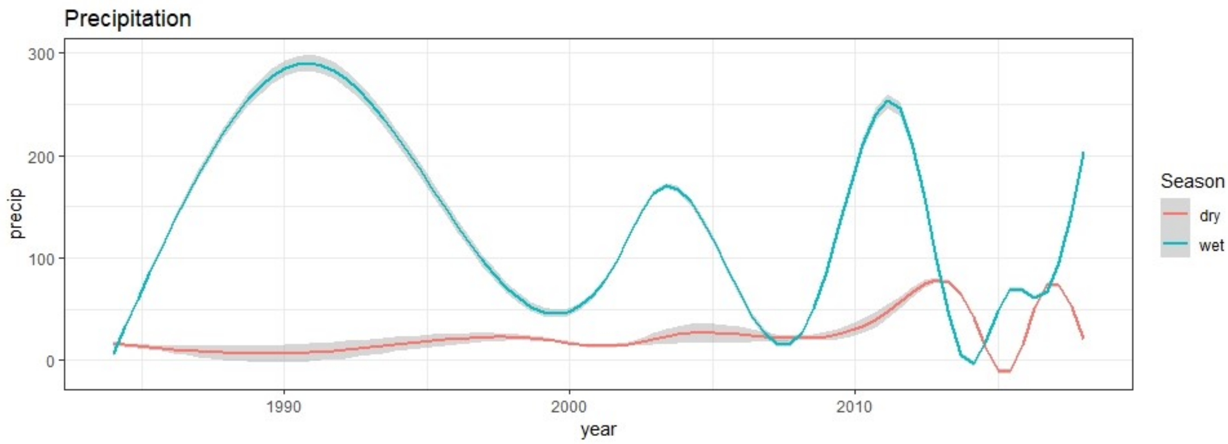






Appendix C

Rainfall data and BACI mixed model design



Precipitation data

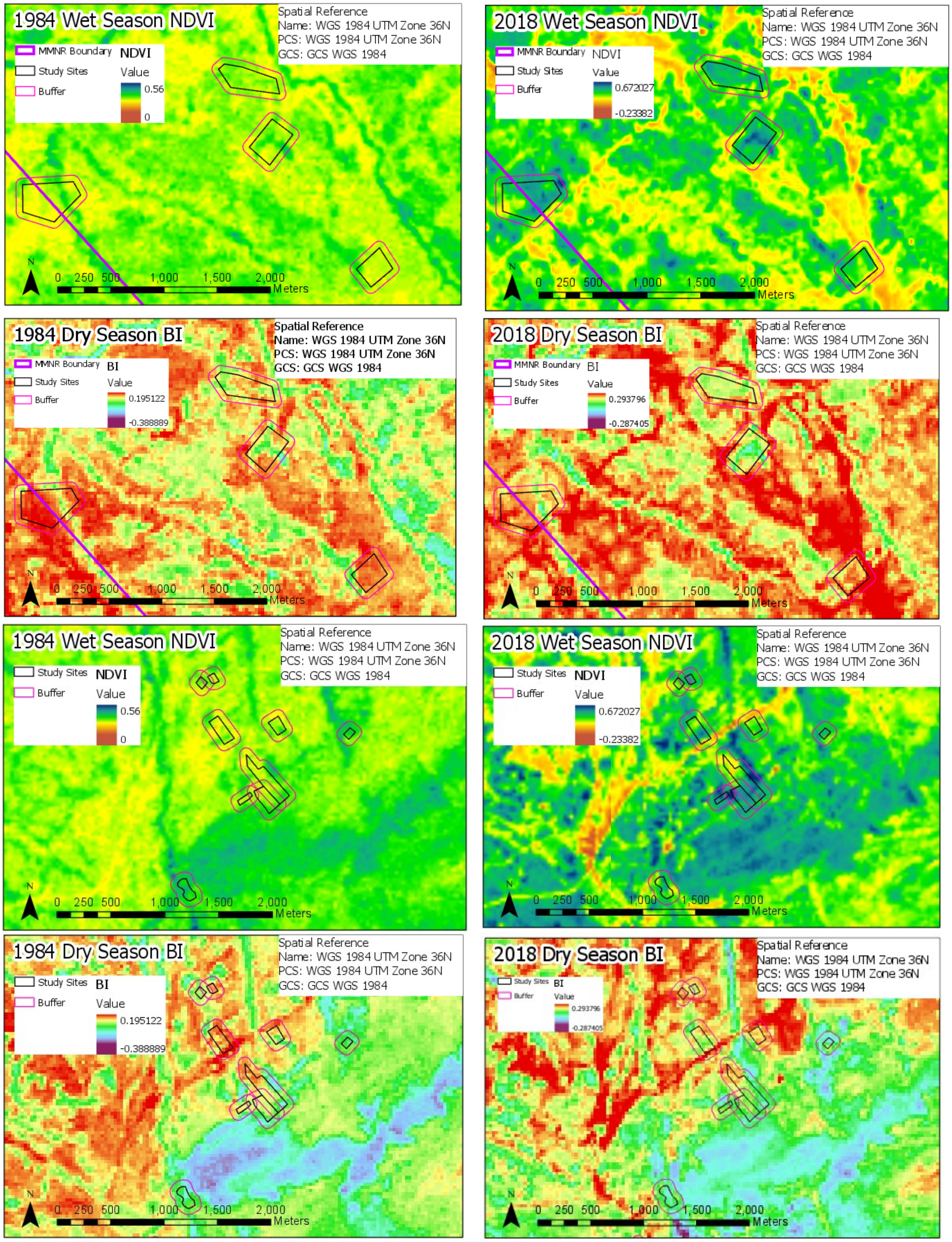
$$X_{ijk} = \alpha_i + \beta_j + \tau_k + (\alpha\beta_{ij}) + (\beta\tau_{jk}) + (\alpha\tau_{ik}) + (\alpha\beta\tau)_{ijk} + \varepsilon_{ijk}$$

Where, α_i is the effect of period (i= before or after), β_j is the effect of area (j = control or impact), τ_k represents impact location (k = inside or outside fence), the associated interactions among them, and ε_{ijk} represents the remaining error with random structure.

Mixed model for a BACI design, adapted from Smith et al. (2002).

Appendix D

Additional cluster maps



Appendix E

Full and reduced models as a response of seasonal indices, with ΔAICc values. Shaded models were selected as final models.

Response			Predictors	df	logLik	ΔAICc
Wet season	NDVI	Mean	*before_after, area, before_after*area*	7	1781.69	0.00
			*fence, before_after, area, before_after*area,*	8	1782.19	1.04
			*fence, before_after, area, before_after*area, fence*area*	9	1782.86	1.73
		Variability	*before_after, area, fence, before_after *area, fence* before_after*	9	3213.57	0.00
			*before_after, area, fence, before_after *area, fence*area, fence* before_after*	10	3213.78	1.61
			*before_after, area, fence, before_after *area, fence*area, fence* before_after, fence*area* before_after*	11	3214.70	1.82
	BI	Mean	*before_after, area, fence, before_after *area, fence*area, fence* before_after, fence*area* before_after*	11	2006.58	0.00
		Variability	*before_after, area, fence, before_after *area,*	8	3393.22	0.00
			*before_after, area, fence, before_after *area, fence* before_after*	9	3393.67	1.14
			*before_after, area, fence, before_after *area, fence*area*	9	3393.45	1.58

Full and reduced models as a response of seasonal indices, with ΔAICc values. Shaded models were selected as final models.

Response			Predictors	df	logLik	ΔAICc
Dry season	NDVI	Mean	*before_after, area*	6	1750.61	0.00
			area	5	1749.59	0.03
			*before_after, area, before_after *area*	7	1750.88	1.50
			fence, before_after, area	7	1750.87	1.51
			fence, area	6	1749.84	1.54
		Variability	*before_after, area, fence, fence*area*	8	3178.14	0.00
			*fence, area, fence*area*	7	3176.77	0.71
			fence, before_after, area	7	3176.71	0.81
			fence, area	6	3175.34	1.54
	BI	Mean	*before_after, area, before_after *area*	7	2067.99	0.00
			*fence, before_after, area, before_after *area*	8	2068.37	1.28
		Variability	*before_after, area, fence*	7	3380.41	0.00
			area, fence	6	3378.83	1.13
			*before_after, area, fence, fence*area*	8	3380.78	1.29
			*before_after, area, fence, before_after *area*	8	3380.61	1.64
			before_after, area, fence, fence before_after*	8	3380.51	1.84

Appendix F

Detailed stakeholder responses to open-ended interviews.

High-Level Stakeholders

Year fenced	Land-use	Type of fence	Preferred level of greenness for grazing livestock	Other comments
2013	Growing and cutting grass throughout the season	Wood and wire, posts 2-m apart to allow sheep to pass through	4	River borders property line
2018	Grass dried standing (it is less green and preferred for cattle). Trees removed from grazing area.	Electric	3	River borders property line
2016	Half of fenced area is preserved until dry season; half is open to grazing	Wood and wire	5	River runs through property
2013	Grass saved in a bank until outside area is completely grazed	Wood and wire, 50cm spacing to keep out cattle	4 for sheep, 5 for cows	
2010	Grass dries standing, agriculture in part of fenced area, additional sown grass for cattle and planted trees	Wooden post and chain link	3	River along property border
2003	Cut down trees to make way for grass	Barbed wire	3	Bordered by two roads
2014	Grass is cut and dried, then fed to cattle, grass near the house is mowed. Land is cleared of trees.	Post and wire	3 for cows, 2 for sheep	Land irrigated by water pipe, bordered by two roads
2013	Agriculture	Wood posts and wire using local trees	3.5	Bordered by a seasonal river and perennial river
2015		Wood and wire, with 5m spacing between posts	3	This area is trying to remove fences because they are costly to maintain and harmful to wildlife

Local-Level Stakeholders				
Year fenced	**Land-use**	**Type of fence**	**Preferred level of greenness for grazing livestock**	**Other comments**
2012	Large trees are standing, small trees and shrubs are cut to make way for grass. Grass kept standing until dry season	Wood post and barbed wire	4	No water source inside fenced area, use nearby water source
2012	Grass bank until dry season. Land is rocky with many trees, with additional trees planted	Wood posts without wire	4	River is nearby, no water source on the property
2013	Planting trees inside fence, no cutting of grass, some agriculture	Wooden posts with metal mesh	4	River runs through property
2016	Planting trees, allows cattle to graze	Mixed; wood and metal posts, some wire mesh, partially electric	4	River through property
2016	Planting trees near residence, no cutting of trees, sharing grass grazing plots with neighbors	Electric with wooden posts	4	River between several properties
2015	Shared grazing area, no cutting of grass, planted trees near the school inside the fence	Electric with wooden posts	5 (this can make cows sick, but owner will use medicine if necessary)	River through property
2015	Shared grazing area, planting trees	Electric with wooden posts	4	Shared river with neighbor running through property
2017	Planting trees, allowing cattle to graze vegetation	Electric with wooden posts	4	River through property
2003	Cattle kept inside smaller fenced area within larger fenced area which is open and grassy	Electric	5	Dry area
2014	Grass with trees	Electric (originally a shrub barrier, fenced land to keep out wildlife)	4	Water source on neighboring property
2011	Three grass paddocks used for rotation of cattle	Electric with wood and wire	4	Water pond at center of paddocks
2015	Multiple grass paddocks for rotation of grazing cattle	Paddocks separated with wood and wire; outer fence is electric	5	River along border
2016	Multiple grass paddocks	Wood and wire fence	5	Property located inside conservancy
2015	Grass paddock for cattle, botanical garden and apiary	Wood and wire, intend to electrify to keep out wildlife	5	Grass health has improved, which improves the health of the animals (owner comment)
2012	Growing grass to preserve for dry season	Wood and wire	5	Water source outside fence
2017			5	Fence borders a road
2017			5	Fence borders a road
2017			5	
2015			5	
2013			5	Fence borders a road
2015			5	

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