QUANTIFYING DRIVERS OF SPATIAL-TEMPORAL TRENDS IN RANGELAND CONDITIONS IN NAROK, KENYA

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ABSTRACT

Range managers are faced with assessing conditions and trends of rangeland ecosystems that continually change in response to weather and management decisions. The overall objective of this study is to contribute to the realization of a robust rangeland monitoring and assessment framework as a basis for adaptive management for rangeland ecosystems by: optimizing the use of remote sensing data, Geographic Information System (GIS) and ground based data to assess and understand spatial-temporal changes of rangeland conditions, vegetation cover, animal populations as influenced by management within the conservancies of the Maasai Mara rangelands in Narok, Kenya. Specifically to 1) to map vegetation cover, 2) to compare the animal densities and land cover units, 3) to investigate the spatial temporal trends in vegetation cover for different conservancies, and 4) to examine the relationship between NDVI trend and change management over time.

This study used hypertemporal remote sensing MODIS Terra 16 day NDVI time series covering periods between 2000 to 2013 in mapping vegetation cover. ISODATA clustering and divergence statistics method together with NDVI statistics maps – standard deviation, median and trend were combined with field vegetation cover data to construct a legend for the map. The results revealed that land cover units can explain up to 79% and 80% of animal census derived tropical livestock units (TLU) across the study area, under different management regimes. Pairwise comparison of the cover units' trends between conservancies depicted statistical differences between Maasai Mara reserve and conservancies following declining trend in vegetation cover. There was correlation between animal density and cover r (53) = .21, $p<.05$. Breaks for Additive Seasonal Trend (BFAST) revealed that there was a magnitude of change ranging between 60% to 90% for the period between 2002 and 2008. The results corresponds with changes in management during which, a number of conservancies were established. The subsequent effect of this is seen in areas in the Loita plains, such as OlKinyie, Olare Orok, Naboisho and Siana conservancies where pressure of overgrazing can be seen as a result of large populations of livestock are pushed out of conservancies to the traditionally owned trust land.

Considering rangeland adaptive management choices, the study recommend feasibility in potentials, while considering limitations of hyper-temporal application for ecological monitoring. Long-term consistent monitoring is only possible with remote sensing.

Keywords: Spatial-Temporal, Rangeland conditions, remote sensing, Adaptive management.

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1. INTRODUCTION

1.1. Background

Rangelands monitoring and assessment is a global concern especially for researchers and land managers keen on rangeland ecosystem restoration, management especially when faced with changing global climate coupled with anthropogenic impacts that present new threats to ecosystem stability (Wylie, Boyte, & Major, 2012). Management decisions regarding rangelands are generally clouded with necessity and based on primarily expert knowledge and experience, whereas on the other hand, great efforts to use science to seek rangeland management solution is on rapid rise (J.E. Herrick, Bestelmeyer, Archer, Tugel, & Brown, 2006). Understanding ecological potentials of land, coupled with assessment of the current status of land relative to its ecological potential, should be integrated with monitoring data that explain changes in status over time.

Health of rangelands has strong bearing on the livelihoods of pastoralists as well as the lives of populations that suffer from resultant hydrological disturbances, dust storms, commodity scarcity, and eventual consequences of uprooted people (Harris, 2010). Sustaining ecosystem services provision and striking management balance is essential for livestock grazing and wildlife herbivores that characterize arid biomes worldwide (Karl, Herrick, & Karl, 2010). Consequently, range management occur in the context of climate variability, that requires spatially explicit delineation of ecological potential about current status and change over time (Wylie et al., 2012). Thus, to understand changes in land status and their courses, require the assessment of anthropogenic and climate-driven changes. Further, determine the link of how climate exacerbate or mitigate land use impacts (Karl et al., 2010). Spatial temporal integration, hence remain a fundamental challenge to assessing and interpreting land use and land cover change (Peters & Havstad, 2006).

There is evolution and application of different techniques for assessment and monitoring of rangeland ecosystems that include qualitative (Pellant, M., P. Shaver, D.A. Pyke, 2005) and quantitative (Jeffrey E Herrick et al., 2005) field methods, ground-based aerial photography methods and remote sensing methods. Many researchers (J.E. Herrick et al., 2006) in the recent past come up with "state and transition" model basing argument that vegetation existence may adapt different states, transitions driven mainly by management and climate, however transition back to previous state may not occur without addition of external inputs. In addition, in agro-pastoral areas, monitoring of forage species have proven that monitoring indicators of ecosystem functions is a pre-requisite to ensure ecological sustainability (Karl et al., 2010). Furthermore, total annual precipitation as a surrogate of plant productivity can now be effectively be used to account for timing effects, inter-annual variability, sequencing, and lag effects (Huxman et al., 2004) including precipitation spatial variation and redistribution (Gosz & Moore, Douglas I, Shore, Gregory A., Grover, 1995). Precipitation is the basic driving force for biomass availability in rangeland ecosystems, with high correlation with vegetation cover, making it a sensitive pointer of productivity levels in space and time (Bai, Han, Wu, Chen, & Li, 2004).

The Mara rangelands ecosystem is uniquely associated with high density and abundance of large herbivores that are both domesticated and in the wild that depend on the meagre rangeland pasture and forage for survival. However, pressures on rangelands such as human land use; tourism, subsistence and commercial farming of livestock and crops encroachment remain a challenge as observed by du Toit, Kock, and Deutsch, (2012), and Serneels and Lambin, (2001). The Mara were traditionally managed communally by seasonal movement and selective grazing, and Global Rangelands Knowledge System, (2014) noted that replacement of temporal grazing by intensive, year-long grazing of livestock has led to the alteration in rangeland dynamics. The project website, Mau Mara Serengeti Sustainable Water Initiative (MaMaSe), (2014), notes that the complexity has in the recent past (1980's) been exacerbated with rapid transition from communal and/or group ranches into private land through sub-divisions into individual parcels driven by population pressure and internal governance challenges. Hence, the ecosystem is under three different management zones, denoting different scales of operations as National Reserve, Private land – Conservancies, and the Traditional communal trust lands for grazing (Serneels & Lambin, 2001). Consequently, with increasing population and livestock pressure, climatic variability coupled with decline in precipitation can lead to land degradation, an increasing environmental challenges on the Mara region.

Assessment and monitoring of rangeland productivity is essential in shaping management objectives at different levels in the short, medium and long term that factors the carrying capacity for livestock production and wildlife survival hinged on forage availability. Diouf and Lambin, (2001) in a bid to assess dry-land degradation, used three parameter as; resilience of vegetation to droughts, decrease in rain-use efficiency and modification of floristic composition, where they tested remotely sensed indicators of vegetation, rainfall data and field measurements of biomass and floristic composition. They found that rain-use efficiency can best explain the measurement of land-cover modification for 10 year study period. However, this should be based on the precept of spatial, spectral and temporal resolution, taking into account the trade-offs in resolving power of these remote sensing systems that usually affect the quality, quantity and timeliness of acquired imagery (Rogan & Chen, 2004).

Some researchers have applied various remote sensing products at various spatial resolution scales by using Normalized Difference Vegetation Index (NDVI) as proxy of vegetation productivity (Pettorelli et al., 2006). Vegetation dynamics monitoring using remote sensing is associated with the strong coupling between visible and the Near Infra-Red (NIR) reflectance (Owe, de Jeu, & Walker, 2001) with the physiological condition of leaves and density (Anyamba, Small, Tucker, & Pak, 2014). NDVI is derived from the formula (NIR-Visible) / (NIR +Visible). A number of studies have used NDVI as a proxy for vegetation in African rangelands and elsewhere. Time series of high temporal remotely sensed imagery are increasing becoming available, for instance, from advanced very high resolution radiometer (AVHRR), ("NOAA Satellite Information System (NOAASIS)," 2013) has been used for estimation of total herbaceous biomass production in the Senegalese Sahel (Pettorelli et al., 2006). Notably, the recent availability of NDVI datasets from MODIS Terra (Moderate resolution imaging Spectro-radiometer) brings more robustness over AVHRR data and with the release of Global Inventory Modelling and Mapping Studies third generation (GIMMS3g) on overlapping period of 14years now (Fensholt & Proud, 2012). In addition, studies that investigate ecosystem potential indicator relationships with NDVI in rangelands have been extensively been explored (Pettorelli et al., 2005). Li, Da, Wang, & Song, (2006) in east China also made remarkable attempt in using multi-temporal NOAA-AVHRR to classify vegetation, and (Pettorelli et al., 2012) used NDVI to test impacts of climate change on the dynamics of net primary productivity in protected areas of Africa.

Integrated science driven range monitoring and assessment alternatives have been explored (J.E. Herrick et al., 2006). Identification of underlying effects of anthropogenic activities on the condition and functioning of ecosystems is realised through detection of changes in ecosystem characteristics (Sulkava, Luyssaert, Rautio, Janssens, & Hollmén, 2007). However, overcoming the imprecision of data that blur temporal trends derived from various spatial and temporal resolutions of rangeland monitoring and assessment methods remain a great impediment for integration adaptive management decisions (Sulkava et al., 2007). On the other hand, noting that spatial scale and its relations to ecological processes and range management is essential, estimation of trends should aim to integrate the length, temporal and spatial resolution of the time series, including quality of the data measured and applied statistical methods in order to get a comprehensive outlook of the rangeland condition at any scale (Parmentier, 2014).

Therefore, this study aims at optimizing application of long-term MODIS Terra NDVI time series trends and seasonal trend breakpoint to quantify the drivers of spatial – temporal trends of rangeland conditions. Explore the use of GIS in undertaking an assessment of rangeland condition by analysis of the spatial-temporal trend of vegetation cover, composition, herd populations and distribution as a basis for adaptive management for the Mara rangeland ecosystems.

1.2. Literature review

1.2.1. Trends in Rangeland Conditions

Range managers are faced with assessing conditions and trends of range ecosystems that continually change in response to weather and management decisions. The (ILRI, 1975) defines range condition as "the present health of range in relation to what it could be with a given set of environmental and managerial factors". It measures range deterioration and improvement in space and time. Rangeland trend is the direction of change in range conditions and soils. Trend is considered downward (declining) or upward (improving). A downward trend in range condition is when desirable species are replaced with poor species, coupled with a drop in in forage production and subsequent animal production. Additionally, when soil erosion is accelerated due to soil cover, exposing excessive bare surfaces, and a combination of these effects. Thus, ecological parameters used to measure range condition are: - specie composition, cover, erosion, and production. Different approaches have been developed in assessing rangeland conditions, however there are overriding commonalities that apply; these include the need to understand the natural potential of the land (Pellant, M., P. Shaver, D.A. Pyke, 2005). This involves determination of the kind of flora community that a particular combination of soil (depth, texture, soil limiting factors), climate and topography can support. A number of researchers have used these basis for undertaking rangeland monitoring and assessment work. In two studies, Tefera, Snyman, and Smit, (2007) studied rangeland dynamics and rangeland condition (Tefera, Snyman, & Smit, 2007b) based on different vegetation composition and soil characteristics in southern Ethiopia with respect to land-use and distance from water as influenced by different management regimes. A benchmark reference state is a pre-requisite as a basis upon which condition deterioration trend can be measured. In this regard, there is widespread understanding that an excellent range condition must be reconstructed deductively (Pellant, M., P. Shaver, D.A. Pyke, 2005).

1.2.2. Normalized Difference Vegetation Index (NDVI)

NDVI provide valuable information on vegetation biophysical properties such phenology and senescence. It is obtained as a ratio of red to near infra-red reflectance (Owe et al., 2001; Pettorelli et al., 2005). In rangeland assessment and monitoring, Olexa & Lawrence, (2014) used NDVI product associated with semi-arid rangelands of western United States to predict the performance and effects of land cover types and found accurate estimates for land cover/land use through the growing period, with varied inter-class performances. Reeves and Baggett, (2014) also found plausible results in identification of degradation of rangeland productivity capacity across northern and southern Great Plains of the United States.

1.2.3. Spatial-Temporal Assessment

Forbis et al., (2007) notes that with growth in landscape-scale management calls for development of multi-scale vegetation assessment that allows managers to comprehensively assess spatial patterns of vegetation condition across mosaics occurring within each major vegetation type. Consequently, Ward and Kutt, (2009) in their work to analyse potential of spatially explicit ecological indicators of disturbance as a basis for spatial variability in species diversity and abundance in the Australian savannah found that temporal mean and variance are useful indicators of disturbance. Whereas, S. Li, Verburg, Lv, Wu, and Li, (2011) in a study in Inner Mongolia, China, explored the spatial-temporal variation and driving factors of grassland degradation noted that monitoring and analysis at broad regional scales is needed. Olexa and Lawrence, (2014) adopted the use of recent advances in the blending complementary remote sensing data to provide spatial-temporal resolution and extents needed to assess rangeland conditions. They applied Spatial and Temporal and Adaptive Reflectance Fusion Model (STARFM) to Landsat TM and concurrent MODIS-Terra scenes with lots of success. Additionally, spatial and temporal characterization of time series to detect change, examine magnitude and direction of trend was tested on MODIS –Terra 16day NDVI in two ecological studies in Australia (Verbesselt, Hyndman, Newnham, & Culvenor, 2009). In this study, Breaks For Additive Seasonal and Trend (BFAST) was used to effectively detect change within the time series.

1.2.4. Land Use and Land Cover Mapping

Land cover and land use maps are essential platforms for inventorying assessment of ecological performance and monitoring (Khan, de Bie, van Keulen, Smaling, & Real, 2010). Remote sensing data available integrated with ground data can form the basis of classification method to be used. The two widely used classification methods are supervised and unsupervised algorithms (Leica Geosystems Geospatial Imaging, 2005). Supervised classification is dependent visual identification and prior knowledge about the area under study, on the other hand, unsupervised is more computer automated that depend on data itself for definition of classes, and usually used when less is known about the data before classification. Hagen et al., (2012) in their comparison study of ground measurement of vegetation and reflectance of satellite observed measurement in the western United States, used soil-adjusted vegetation index (SATV) to capture 55% of the variability to the Landsat-30m scale. Serneels and Lambin, (2001) on the other hand while studying the proximate courses of land use change in Narok, Kenya, used spatial statistical models to identify key driver of land use change. Proximity to permanent water, land availability, location near tourism market and vicinity to villages to gain access to social amenities were some of the drivers to land use change in the Mara –Narok region.

1.3. Research Problem

Rangeland condition related studies in the Mara rangelands have focused mainly on the migratory and non-migratory wild animals and livestock populations as drivers of rangeland deterioration (Ottichilo et al., 2000; Ndegwa Mundia & Murayama, 2009 and Serneels & Lambin, 2002). Other research attempts have looked at the population-climate nexus to degradation trend at regional levels (Pricope, Husak, Lopez-Carr, Funk, & Michaelsen, 2013). However, in the recent years, rapid emergence of visible physical land use changes need to be explored in space and time. Little is known about the spatial temporal trend of rangeland conditions of the Mara ecosystem in the last 15 years. Conceptually, as described schematically (Figure 1.1) the different management zones, which are considerably driven by the market (tourism) economy have adopted restrictive conservation regulations to remain both competitive and conform with certain conservation thresholds for instance payment for ecosystem services (PES) (de Leeuw et al., 2014). Nonetheless, the impact of some of these policies and regulations that touch on planned grazing, wildlife and livestock movement, fencing and human settlement impact on the quality and quantity of vegetation cover across the ecosystem. Historical hyper-temporal NDVI time series are information rich datasets that have possibilities to analyse and understand impacts of different management choices or lack of it in space and time. Using MODIS –Terra NDVI time series, the research study aims to attempt to address the following question: How did the Maasai Mara ecosystem land use and land cover change impact on the rangeland conditions and how trend in this condition was influenced by management regimes? The conceptual diagram (Figure 1.1) details the interaction between the rangeland ecosystem functions and factors that influence them and the different management systems.

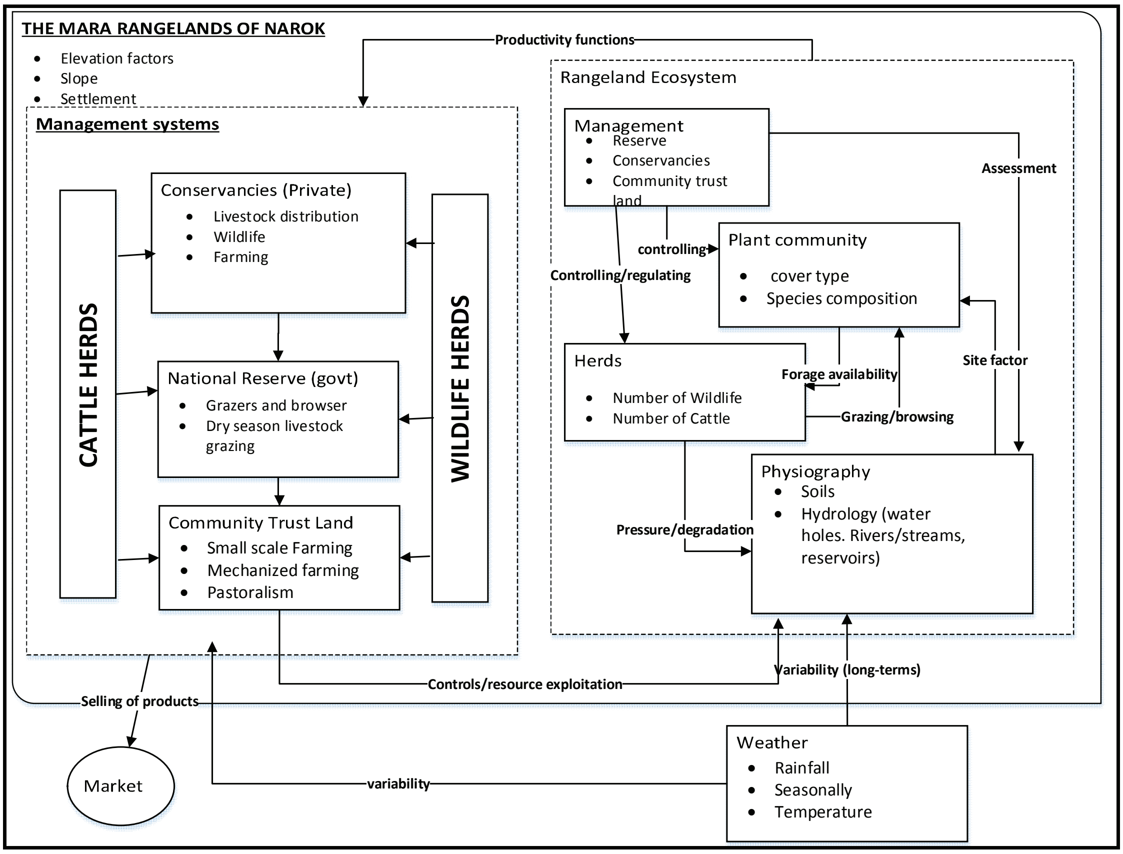


Figure 1.1 The conceptual diagram showing systems relationship analysis between the ecosystem drivers and the impacts of management zones depicted by three main land uses in the Mara Ecosystem – Conservancies, Traditional Trust pastoralism Land, and the National reserve

1.4. Objectives

1.4.1. General Objective

The overall objective of this study is to contribute to the realization of a robust rangeland monitoring and assessment framework as a basis for adaptive management for rangeland ecosystems by: optimizing the use of remote sensing data, Geographic Information System (GIS) and ground based data to assess and understand spatial-temporal changes of rangeland conditions, vegetation cover, animal populations as influenced by management within the conservancies of the Mara rangelands of Narok, Kenya.

1.4.2. Specific Objective

To address the main objective of this study, the following specific objectives shall be addressed:

i. To map vegetation cover of the Maasai Mara rangelands.
ii. To compare the animal densities and land cover units within Maasai Mara rangelands.
iii. To investigate the spatial temporal trends in vegetation cover for different conservancies.
iv. To examine the relationship between NDVI trend and change management over time.

1.4.3. Research Questions

i. What is the corresponding vegetation cover for different conservancies?
ii. What is the relationship between land cover units and animal densities in the different conservancies?
iii. What kind of relationships can be appropriate to explain spatial-temporal trend in different conservancies?
iv. Do the NDVI trend and breaks in trend correspond with change in management from 2000-2013?

1.5. Thesis Structure

Chapter 1 consist of background information about the study, objectives of research, research questions, and outline the thesis structure. Description of datasets, materials and methods used are detailed in chapter 2. Chapter 3 consist of results and interpretation of results. Chapter 4 contain discussion of results, and chapter 5 shall provide a brief summary of the study, conclusions and recommendations and finally the list of references.

2. MATERIALS AND METHODS

This chapter outlines the details of the study area, materials and data used in the study. It also contains the methods and tools as well as methods used for analysis in the study. It however, begins with providing a glossary of definitions of various terms and terminologies as used in this study.

2.1. Definitions

Degradation: Refers to temporary or permanent lowering of the productive capacity of rangelands – specifically forms of soil degradation, adverse human impact on water resources and deforestation.

Forage: This refers to herbaceous feeds available for grazing in form of pasture; and this excludes harvested feeds for animal feeding and browsing.

Foraging: The search for forage; as guided by numerous decision by herbivores as to where to graze (spatial choice) as well as what to graze (the plant species, plant parts chosen) as dictated by grazing sites.

Grazing Pattern: Foraging habits that different herbivores adapt based on numerous decisions and processes made by grazing animals at a variety of spatial and temporal scales, so as to achieve adequate forage and nutrient intake.

Grazing System: Defined as a specialization of grazing management that specifies periods of grazing and non-grazing.

Management System: In this context, refers to the application of different and/or similar management policies by different institutions on range units (of the Narok).

Payment for Ecosystem Services (PES): also known as payment for environmental services (or benefits), are incentives either in-kind or in cash payment offered to farmers or land owners in exchange for managing their land to provide some sort of ecological service (UNEP).

Physiography: This refers to abiotic and biotic factors that determine grazing distribution and influence range management decisions. Abiotic factors include: weather (temperature, precipitation, wind, storminess, etc.), soil characteristics, topography and landform features, elevation, aspect, water availability, salt availability and fencing. On the other hand, biotic factors include: plant communities, botanical composition, quantity of forage, quality/palatability of plants, shade and shelter, escape cover, brush or tree barrier, inter- and intra-specific animal behaviours, insect pests and human activity.

Rangeland: Land supporting mostly native (indigenous) vegetation that is either grazed or has potential to be grazed and is managed as a natural ecosystem. It excludes grazable wood land and grazable forestland (range without tree over storey).

Rangeland Condition: A generic term that relate to present status of a unit of range in terms of specific values and potentials. Synonymous with resource value rating (RVR) – the value of vegetation present on an ecological site for a particular use or benefit, usually established for each plant community capable of being produced on an ecological site.

Rangeland Trend: Direction of change in the plant community and associated components of the site from the climax or other desired plant community.

Tropical Livestock Units (TLU): Refers to a common unit (1 TLU) based on "Exchange Ratio" upon which different species of different sizes are compared and described in relation to a common unit, thus, used to describe livestock numbers of various species as a single figure that expresses the total amount of livestock present – irrespective of the specific composition (FAO).

2.2. Study Area

2.2.1. Location

The Mara Ecosystem of Narok is located in the south western Kenya (Figure 2.2). It lies approximately between attitude 10 00' and 2000' south longitude 340 45' and 360 00' east and covers approximately 6,500 square kilometres. To the south, the area is bound by the Kenya-Tanzania international border, to the west is the Siria escarpment (Esiot Olololo), agriculture and forest to the north, and to the east is the Loita plains and hills to the south-east. The ecosystem is intersected with a network of streams and river draining into the Mara River (Olson et al., 2001).

2.2.2. Climate and Vegetation

The region experiences bimodal rainfall, with June to mid-October as long dry and January to February as short dry. Annual rainfall ranges from 800m to 1,200 mm with a northwest to south east declining gradient (Ndegwa Mundia & Murayama, 2009). The local precipitation pattern however mixed up the bimodal behaviour in rainfall conditions can be seen in Figure 2.8. Commonly referred to as "the Mara triangle" divided into three main range units as characterized by biogeography and climate, at altitude 1,600m above the sea level. These units are the Mara rangelands and the Mara Reserve, which are mainly composed of *Themeda spp* grass, and the Loita Plains composed of dwarfs shrubs and *Acacia drapanolopium*, grassland, and lastly the Saina Plains – mainly undulating hills and plains supporting croton bush and other bushy species interspersed with grasslands (Ottichilo et al., 2000). The vegetation cover encountered during field work are shown in Figure 2.1 below.

Figure 2.1 Vegetation cover types in the Mara Ecosystem. The first panel picture taken in sample number 7, shows sporadic high shrubs occasioned with grasses and bushes in degraded rangeland. Panel two picture taken in sample number 8 shows dwarf shrubs and grass cover – these areas are grazed mainly by sheep and goats. (Pictures courtesy of Author)

2.2.3. Land cover

Various maps available prepared for the study area in the past are a challenge to operationally utilise, as they pose limitation on spatial change occurrence in time and currency. Additionally, typically, these maps have little agreement with one another, underlying reasons are that local precipitation patterns on vegetation were misinterpreted as being densely vegetated, which was mainly triggered by the use of one-time snapshot of imagery, and thus a reliable land cover map is still missing. For this research, based on its contextual information, the Maasai Mara safari map was used for general reference.

2.2.4. Soil and Geology

The Mara rangeland soils are determined by local geology, topography and rainfall. Three distinct broad soil categories can be distinguished; namely, the mountains, plans and the swamps. To the north, the mountains have rich volcanic soils suitable for intensive agricultural production as wheat, barley and zero grazing. The soils here are characterised with well-drained dark-brown ando-calcaric eutric regosols (volcanic soil). The Maasai Mara National Reserve and areas around Shartuka, and Kapkimolwa plains have the deep, dark-greyish soils (verto-eutric and planosols) (GoK, 1964).

The entire project area is characterised with surficial deposits, in some areas, quaternary lacustrine and fluviate unconsolidated sediments of pleostocene age. Outcrops of quartzite and muscovite occur sparsely in the region. Along the road linking Ngore Ngore to Aitong, there occurs remnants ridges, reddish brown gravels and sandy soils invariably formed from the basement rock complexes that precede coarse scree of rocky outcrops (GoK, 1964). Previous mapping attempts of soils in the Mara are still very small scale (1:1000 000).

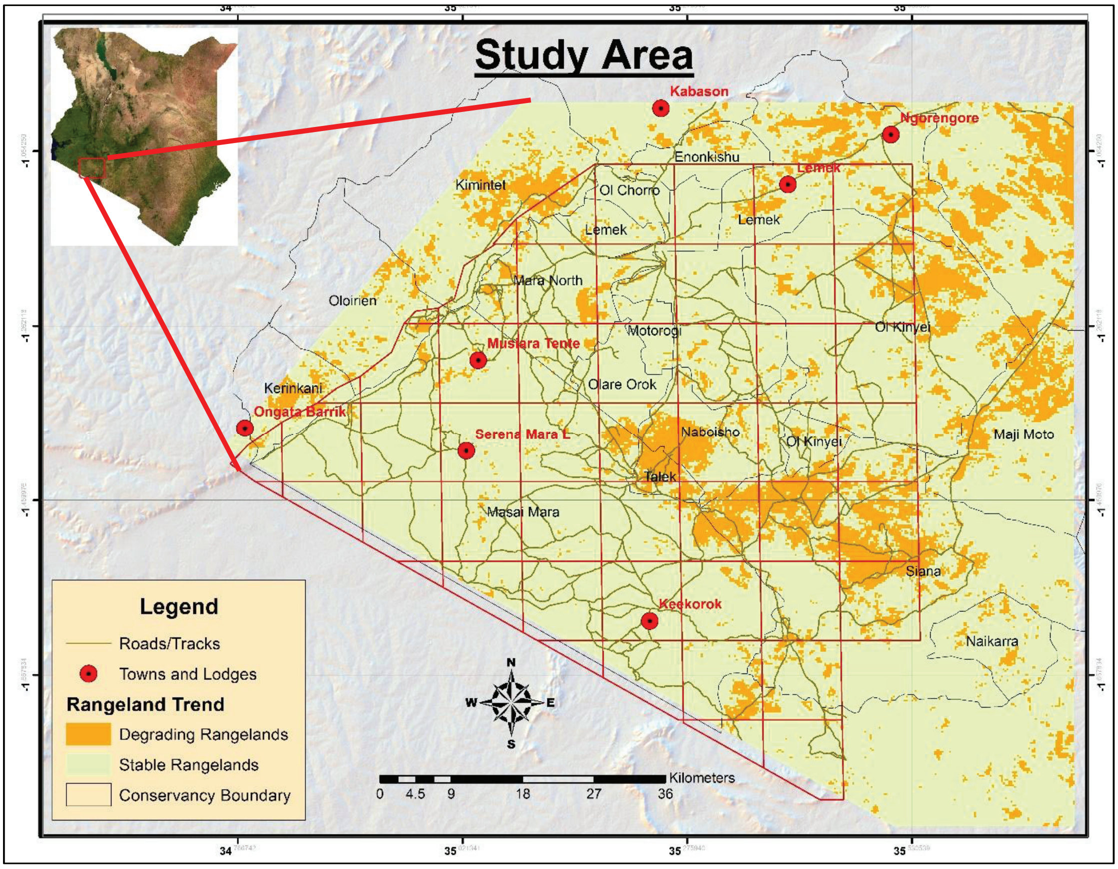


Figure 2.2 Map showing the location of study area, located in the South Western part of Kenya in the Mara rangelands ecosystem. Trend map was used in the background see section 2.7.3 for more details.

2.2.5. The Mara Rangeland Management and Governance Structures

Land privatization pursuit has been on in the Mara rangelands since Kenya got her independence in 1963. Nonetheless, to date, the land under Maasai Mara national reserve remained under the custody of the government for wildlife conservation and tourism. In the perimeter of the reserve, group ranches emerged soon after courtesy of "Land Group Representative and Land Adjudication Act" of 1968. Group ranches constituted a group of families jointly register formal title deed, with opportunities for credit for land development. Management was vested on management committees with first group ranches formed in 1970s. However, the adjudication process was faced with a number of governance problems, including inequity and allocation of large land areas to people from outside Maasai community. The distrust led to subsequent collapse of the group ranch in the 1980s and 1990s, with land sub-divided into individual private land parcels held by those who formerly were members of group ranches. For instance the following group ranches were subdivided; Lemek and Koyiaki Group ranches and later converted to conservancies, with individual land parcel holders as members. Still a vast area in the Mara ecosystem is still managed as communal grazing areas.

The market economy coupled with the prevailing government policy has shaped the management practice in the Mara ecosystem. The emergence of payment for ecosystem services in conservation efforts in the rangelands of Narok plays a decisive management drive on adaptive formalization of management systems in the ecosystem. Thus, categorised into three distinct different management zones as: the conservancies, private conservancies and traditional communal trust lands as briefly described below.

a) Conservancies

The conservancies are governed as corporate bodies managed privately, complete with established offices. The governance structures entail representation from the land owners who are in formal contractual membership with conservancies, tourism partner and management experts. During field work, obtaining formal strategic management plans for various conservancies in the ecosystem was difficult. In addition, the conservancies have an umbrella management platform that bring all conservancies together, called Maasai Mara Wildlife Conservancies Association (MMWCA). The organogram alongside (Figure 2.3) shows the components of the governance system. The conservancy council is the supreme body, which draws its membership composition from all the conservancies; as three land owners, three tourism partners and/or investor. Co-opted members include Management experts from the conservancies, County Government, Kenya Wildlife Service and NGOs operating in the ecosystem. The council then elect the Executive Board that consist of three land owners, three tourism partners and three independent agencies. The Executive Board establishes a Secretariat, which is headed on a day to day by a chief executive officer. The association gets its operation revenues from membership fees pegged at KES 1,000.00 (one thousand Kenya Shillings) per bed per year, whereas conservancies with 20 beds and below, subscribe with KES 20,000.00 (twenty thousand Kenya Shillings) per year.

Each conservancy has grazing management plan – governed by by-laws and policies as instituted internally, with more or less regulations and supervision by the association. Great influence on the kind of policy implemented comes from composition of membership, as well as the typology of operation in each conservancy (see Table 2.1). Settlement is prohibited in the conservancies, however, closer look at google images covering the project areas shows dotted settlements and bomas across the conservancies. All the conservancies have strict rules that restrict grazing and browsing of sheep and goats, only cows are allowed. During low tourism months of April to June and between November to January, grazing is allowed on core conservation areas. The conservancy management open designated routes to grass pastures on two weeks rotation. Different conservancies have regulations on extents herds can go, for instance, Mara North Conservancy have invested on mobile metallic cow bomas they offer to their members during such periods. On the other hand, during high tourism season, between July to October and months between February to March, grazing is not allowed in the core conservation areas, thus pushing the pastoralists and their herds on the peripheral areas.

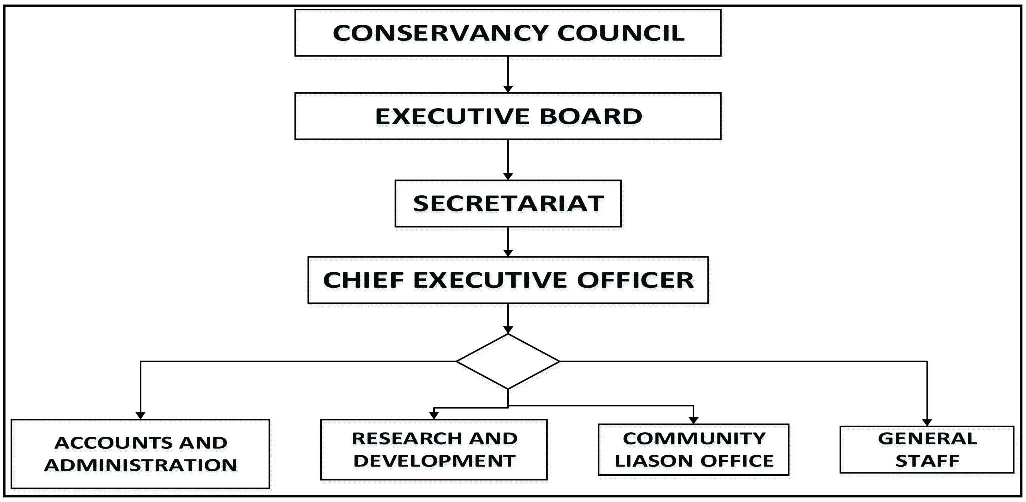


Figure 2.3. The organogram of the governance structure of the Maasai Mara Wildlife Conservancies Association.

Summary of Conservancies in the Mara Rangelands of Narok

Table 2.1 outlines the details of conservancy typology in Narok. Conservancies are greatly driven by either tourism market economy on one hand and payment for ecosystem services (PES) (refer 2.1) in some conservancies, or a hybrid of the two.

Conservancy	Year Est.	Area in Ha	Typology of Conservancies in Narok			
			Production System		Land Tenure Category	Project Type
			Livestock	Wildlife		
Enonkishu	2010	6,566	√		Private	Tourism Market
Olchoro	2009	6,879	√	√	Private	Tourism Market
Lamek	2007	6,860	√	√	Private	Tourism Market
Mara North	Jan 2009	30,955	√	√	Private	Program – (PES)
Olare Orok	2006	9,720	√		Private	Tourism Market
Motorogi	2006	5,466	√	√	Private	Program – (PES)
Naboisho	March 2010	20,946	√		Private	Program – (PES)
Olkinye	2005	4,856	√	√	Private	Tourism Market
Siana	2010	12,545	√	√	Private	Tourism Market

b) Traditional Communal Grazing Areas (Trust Land)

The areas that cover the Loita plains, extending towards the north east are generally open grazing areas that are managed by Maasai pastoralist communities. In addition, land outside the conservancies, including the fringes of the conservancies are managed as communal grazing areas. Most of the households that own land in the conservancies have their homes (manyattas) in these areas. Large populations of sheep and goats are found in these areas. Cattle grazing is communal, with frequent occurrence of mixed grazing, as wildlife from the national reserves and conservancies compete for forage with domestic animals. These areas are highly degraded.

c) The Maasai Mara National Reserve

The Maasai Mara National Reserve covers 1,510 km^2 administered under the County Government of Narok (Kenya Constitution 2010) since 1961. It's an extension of Tanzania's Serengeti National park. On the outskirts perimeter of the reserve, there large private conservancies as described in (a) above (See Figure 2.2). Consequently, gradual loss in traditional grazing land, coupled with grazing restrictions that various conservancies have come up, have subjected the reserve to pressure, as alternative pastures is sought in the reserve especially during dry season. The land use in MMNR is predominantly preserved for wildlife tourism, however, illegal cattle grazing still persist.




2.3. Materials and Methods

Materials used in this research study are outlined below. They include historical satellite data covering study period, remote sensing and GIS application software, as well as field equipment. A generalised overall flow chart of the steps undertaken in the research study is outlined in Figure 2.5.

2.3.1. Software and field tools

The following remote sensing and GIS application software were used in pre-processing and processing of the data and subsequent analysis and production of the thesis research report.

- ArcGIS 10.3
- ERDAS IMAGINE
- R Studio and Spatial libraries
- Statistical Package for Social Sciences (SPSS) version 22.
- Google Earth Engine - Web Earth Observation Monitoring (webEOM)[1]
- Mendeley reference manager software
- IPaq (mobile GIS)

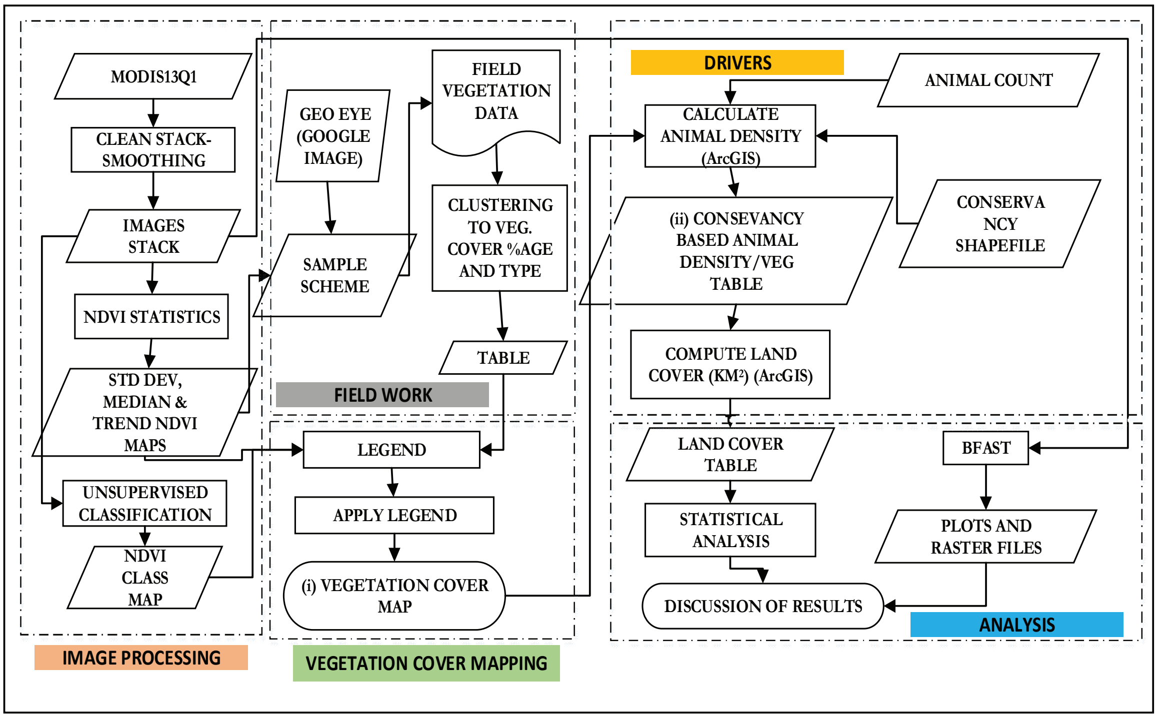


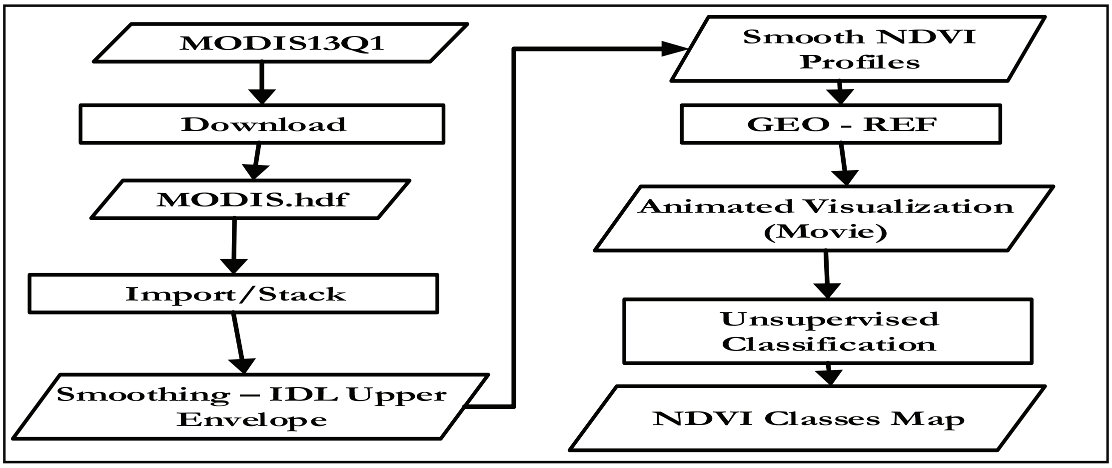
Figure 2.5 Flow chart showing the step by step of operations undertaken in all the stages of the research study.

[1] The Earth Earth Observation Monitor (EOM) is a product based on the Siberian Earth System Science Cluster (www.sibessc.uni-jena.de) established at the department of department of Earth Observation at the Friedrich-Schiller University Jena (Germany) – (http://www.earth-observation-monitor.net/index.php).

2.4. Methods

2.4.1. Image Processing

The flow chart below (Figure 2.6) outlines the operations that were undertaken to on the satellite data that was used in the study. The basic image processing were carried out by the MaMaSe project team.



2.4.2. Modorate resolution imagine Spectro-radiometer product - MODIS13Q1

Moderate resolution imaging Spectro-radiometer (MODIS) Terra vegetation index, version 5, product – MOD13Q1, 16 days 250 m, obtained using NASA web facility archive at http://reverb.echo.nasa.gov/. The dataset obtained span period between 18th Feb 2000 to 2nd Dec 2013 (317 images with 23 images per year). The projection is sinusoidal on the WGS 84 spheroid. The tile identifier for research area of interest is h21, v09.

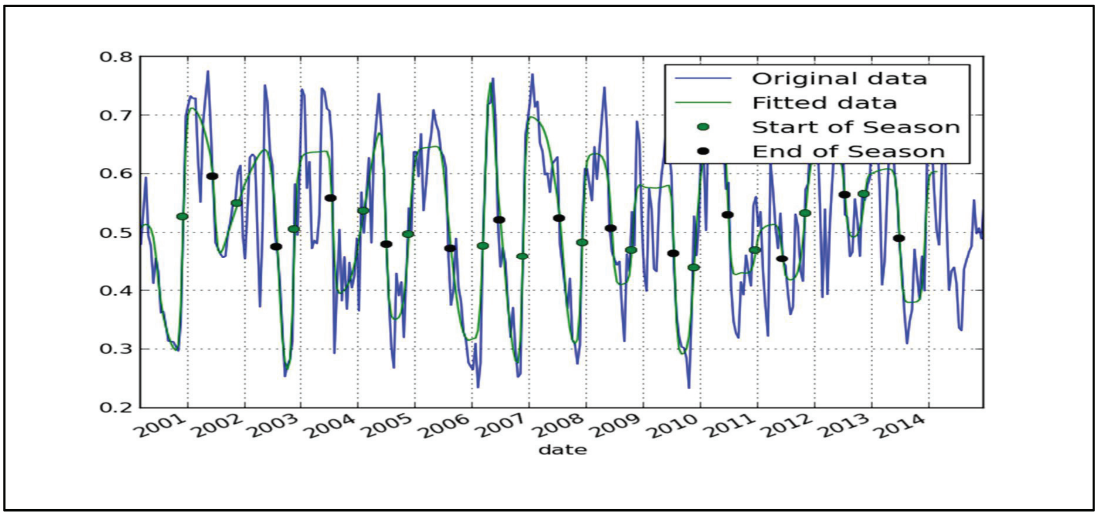
2.4.3. Pre-processing of MODIS and Field-work Preparations

The NDVI images are based on 16 day Maximum Value composite (MVC) cycle come with NDVI values coded from -3,000 to 10,000, thus requires rescaling. The reflectance's of red (band 1 – 620-670nm) and near infra-red (band 2 – 841-876nm) were used to determine daily NDVI. To rescale MODIS NDIVI-data to DN values of between 0-255, a linear interpolation formula: Y= a+bX; where Y is the DN, a=212.5, b=42.5 as shown in Table 2.2 is applied (Ali, de Bie, Skidmore, Scarrott, & Lymberakis, 2014, Thi & Ha, 2013). The information was obtained from the metadata of the product, and coded in ERDAS Imagine. The missing values are substituted with zero and 85 is the start of photosynthesis activity.

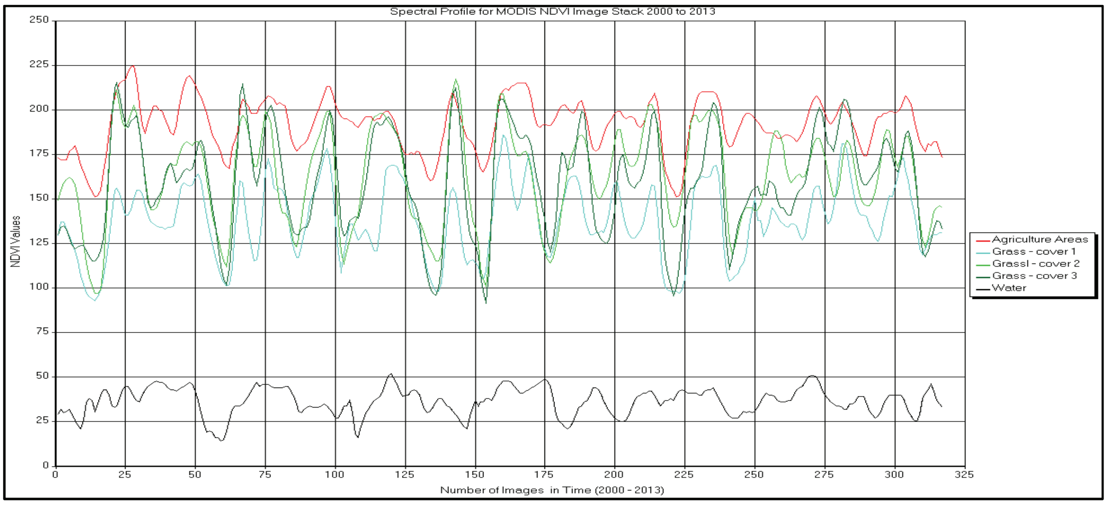
Table 2.2 Table of NDVI values obtained from the metadata of the MOD13Q1 product.

Linear Interpolation: Y = a+bX		
Source	Target	Label
-3000	0	Missing value
-2000	0	Low of range
10000	255	High of range
2000	85	Value where vegetation starts
0	42.5	
b	212.5	
a	42.5	

The output from the process was then processed following Adaptive Savitzky Golay filter (ASAVGOL) and fitting functionality so as to factor for outliers (Figure 2.7), that pose noisy and non-uniformity in NDVI time series data sets (Ali et al., 2014).



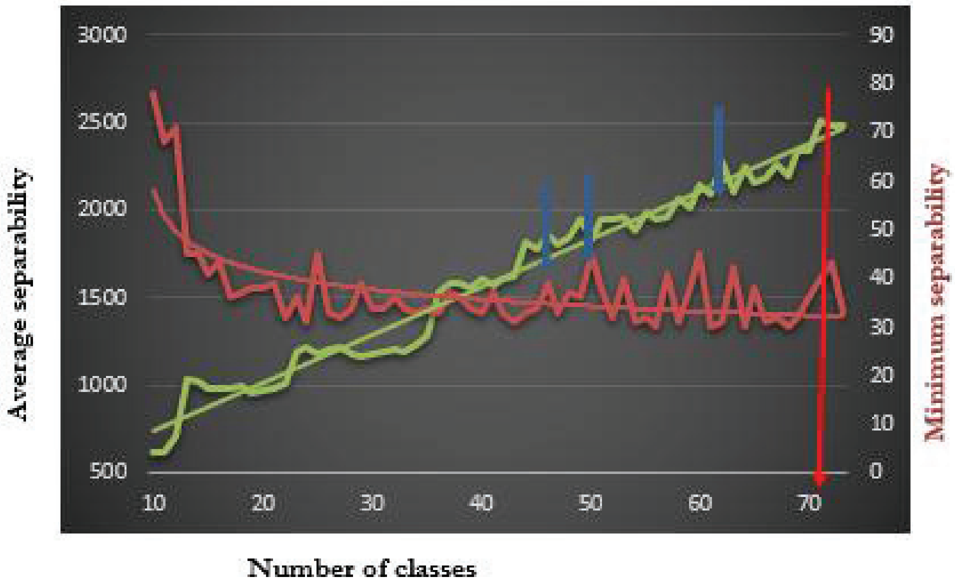
The visual inspection of the spectral profiles was done in ERDAS to obtain a dynamic intermediate legend of greenness profiles (Figure 2.8).



2.4.4. The ISODATA clustering technique and cluster separability indices.

The Iterative Self Organizing Data Analysis Technique (ISODATA) method of unsupervised classification (Leica Geosystems Geospatial Imaging, 2005) was used. It applies spectral distances in the sequential method, but iteratively classifies the pixels, redefines the criteria for each class, and classifies again so that spectral distance pattern in the data gradually emerge. The method is more feasible when using hypertemporal datasets; since the feature space encapsulates many bands (time periods), as compared with RGB input for supervised classification.

ISODATA algorithm was used to classify 100 classes, followed by evaluation of divergence statistics. The graph below (Figure 2.9) shows the plotting of average and minimum separability as the classes' progress.



There are no clear peaks along the average divergence separability. Small peaks appear with corresponding low peaks on minimum separability values.	No. of classes			comments			71 classes selected giving room for merging some clusters based on NDVI profile spatial location
		avg	min	avg	min	verdict	
	47	1898	40	low	ok		
	50	1700	47	ok	low		
	62	2355	30	Still low	low		
	71	2500	45	ok	ok	select	

Figure 2.9 separability statistics for determining the optimum number classes for NDVI profiles.

Ali et al., (2013) describes clustering as an unsupervised classification of patterns, which include observations, data items, or feature vectors, into groups or clusters or classes. Settling for an optimum number of clusters during clustering process, is aimed at a threshold upon which a validation index is lowest (or highest). Divergence index calculated from for any combination of image bands as the validity index to provide objective measurement of clustering results, with its value used to choose optimum number of clusters of the clustering algorithm. Separability value of divergent index of more than 24 is generally recommended (Khan et al., 2010).

2.4.5. MODIS Terra NDVI time series Statistics

Natural environments portray irregular NDVI patterns, both spatially and temporally, as compared to human influenced environments, such as agricultural fields. The effect of short term rainfall anomalies is manifested on vegetation cover that formed the basis for maps produced in the past. Exclusion of short term precipitation anomaly on NDVI pattern observed for the project area, is achieved by long-term patterns of NDVI intermediate legend based on: a) standard deviation, b) Median and c) Trend (probability of change).

a. Standard Deviation map of MODIS NDVI time series

Standard deviation values were generated in ERDAS IMAGINE from the stack of MODIS Terra NDVI covering the project period. The maps of standard deviation, median and trend followed the principles used in creation of absolute accurate thematic maps (choroplethic map) as developed by George Jenk (MacEachren, 1992) . To obtain desired classes, natural breaks (jenks) classification was used to cluster standard deviation values through iterative process. The algorithm divides the dataset was into groups of 10 interval breaks to determine the smallest in-class variance was achieved. This involves four main steps as follows:

i) Computation of the sum of squared deviations between classes (SDBC)
ii) Calculation of the sum of squared deviation from array of mean (SDAM)
iii) Obtain the sum of the squared deviations from the class (SDCM), by computing the difference between SDAM and SDBC.
iv) Inspection of each SDBC, to move a unit with largest value to the class with lowest SDBC.

The iterative process goes on new class deviations until the sum of the within deviations reaches minimum value. Eventually, the GVF statistics (good of variance fit) is calculated. GVF is obtained by: (SDAM-SDCM)/SDAM. GVF ranges from 0 (worst fit) to 1 (perfect fit). Histograms aids in the visualization of the classifications was used in the process.

Using google image, relevant classes of interest for the study were identified as woody vegetation, degraded rangelands and pasture, good to very good rangeland and pasture and lastly agricultural fields. The resultant map Figure 2.10 therefore puts more emphasis clusters of interest for the study. This was done for respective standard deviation, median and trend maps as shown below:

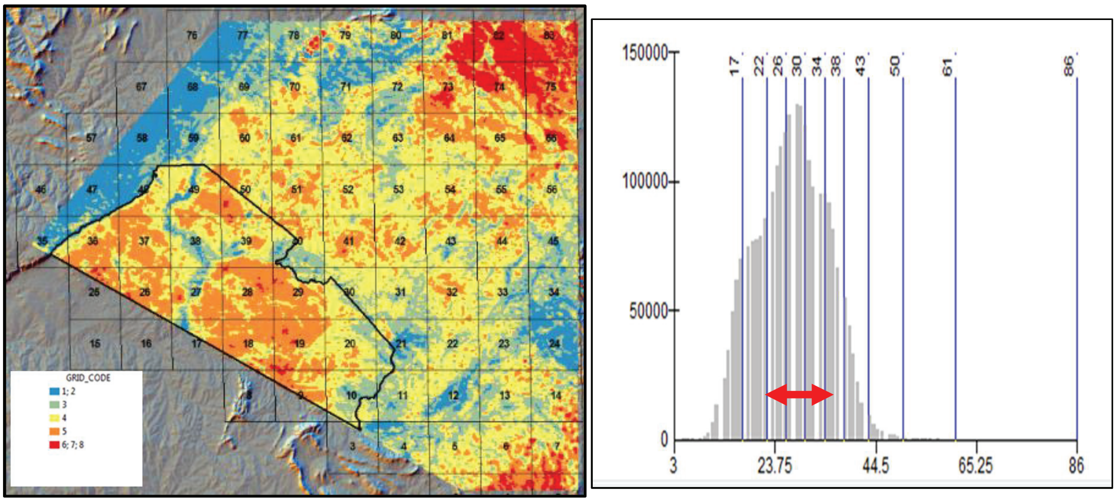
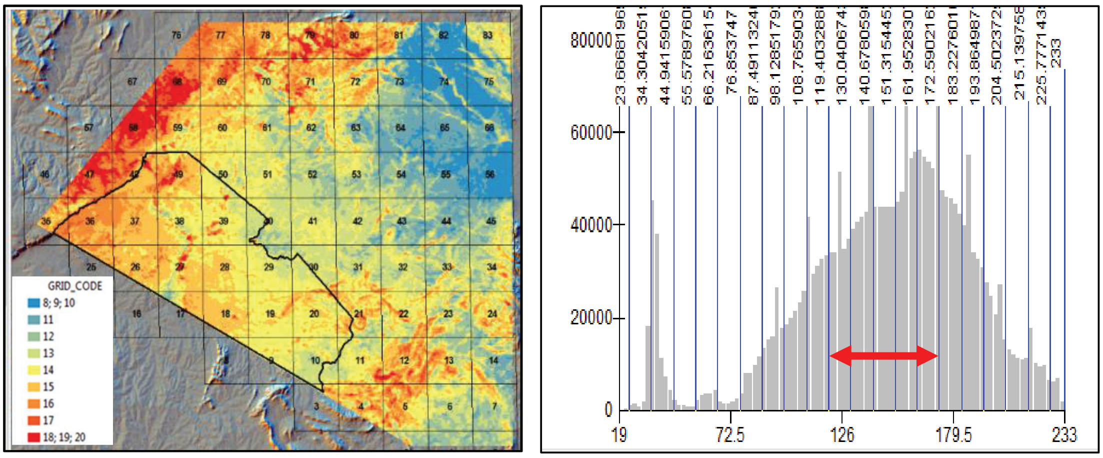


Figure XXXX: The first panel shows the standard deviation classes, with relevant classes; 1-2 relates to woody

b. Median values of MODIS NDVI time series

The median classes were made based on the same algorithm for classification used in standard deviation classes. However, standard deviation classification method was used for classification. Google image was used to identify relevant classes of interest. Figure 2.11 shows the classes that were of interest for the study. The histograms show the breaks based on standard deviation classification of median.



c. Trend values of MODIS NDVI time series.

Trend map was created following the algorithm described for standard deviation map. However, it further estimation on change probability was done using ITC's integrated data language (IDL). The processing involved computing mean values by polygon and decade, followed by a comparison of established range of pooled standard deviation around NDVI values ($NDVI_{d,p}$ +/-$SD_{d,c}$). In this case, the change probability was summed to produce degrading rangeland and pasture and conversion to agricultural land (Figure 2.12). On the other hand, pixels in areas that did not show change, were considered to be stable rangelands, pasture or agricultural lands.

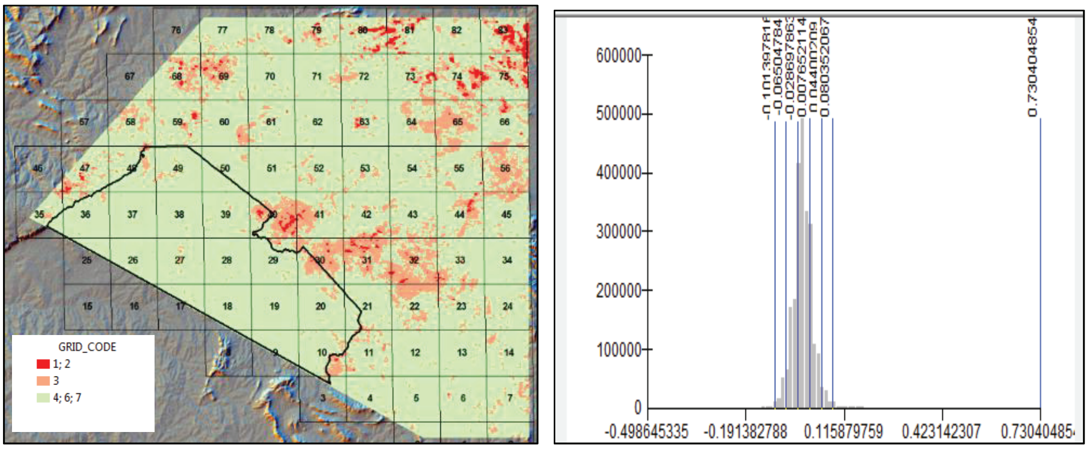


Figure 2.12 Classes 1 and 2, including 3 relate to degrading rangelands and/or conversion to agricultural land. Classes 4 and higher refers to relatively stable rangelands, pasture and agricultural fields. The second panel shows the histograms of classified NDVI values.

2.4.6. Sample Design

The study area was stratified following NDVI maps of classes of trend, standard deviation and median described in section 2.4.5. The three images were crossed with a classified google image, then random polygons were be generated on the strata's of interest across different management zones in the ecosystem. The three maps layer exclude the influence of local and short duration precipitation on vegetation. Potentially, crossing (5x9x2) of the maps produces approximately 80 possible sample clusters (see Figure 2.13). However, clusters representing "woody" classes were not sampled. Thus, random stratified 50 sample polygons were generated following criteria of:

- Area larger than 20Ha, within 500m off the road,
- Within area of interest, not intersecting with fields.

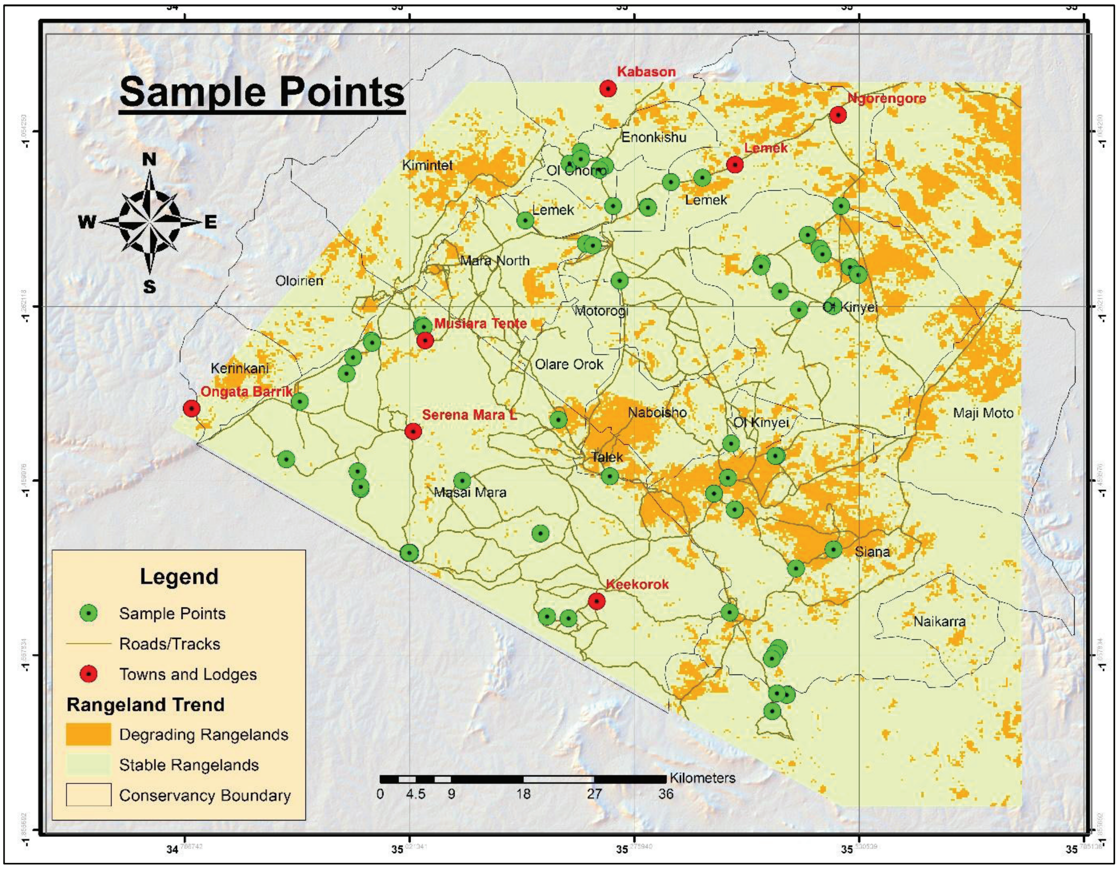


Figure 2.13 The sample scheme of 50 polygons randomly distributed across the Mara Ecosystem in three management zones (National Reserve, Conservancies, and the Traditional grazing Trust land)

2.5. Field Work

2.5.1. Field Vegetation Data

Vegetation data collection was done between dates 7th to 30th October 2014. A comprehensive field data sheet (see appendix B) was used to record detailed information for each sample unit in a sample polygon. In each sample polygon, a sample plot of approximately 10m by 10m was selected as representative for the whole polygon, representative of a 250m pixel. This was termed as "homogeneous sample polygon". In instances where sample polygons had variations that were distinguishable, sample plots were done on two or three variations in percentage proportions that sum up to 100%. This was termed as "Complex sample polygon". Vegetation cover was recorded in percentage composition per sample plot.

Each sample plot the following variables were recorded:

- Sample unit: the code identifying the polygon unit and sample number
- Geographical coordinate obtained from a GPS as well as the GPS number
- Cover percentage (trees, shrubs, herbs, grass, litter, bare, stony)

2.5.2. The Mara Rangeland Management – A Spatial Temporal Context

a) Management Policy Choices

Spatial temporal rangeland conditions of the Mara is highly characterised by very variable climatic conditions (Toxopeus, 1999). This drive the pastoralists (Maasai) to maximize on movements to take stock to favourable areas for grazing as forage decline in one area. As the rangeland in the Mara keep on getting sub-divides, coupled with restrictive movement policies by the conservancies, grazing is restricted to the boundaries of either private land, or fringes of allowed grazing zones in the constituency. In order to objectively depict and display the spatial temporal variation of impact caused by grazing of livestock and wildlife, qualitative data was collected concerning animal distribution and density during high and low (wet) season and high (dry) season, conservancy grazing strategies, fencing, and forage availability (Table 2.3).

Key informants were identified from the management of conservancies, land owners, and field Kenya Wildlife Service personnel. A total of 15 interviews were conducted. Using a checklist of questions (see annex B section B), information about rangeland modification undertaken by different management zones, policy choices on grazing, fencing, and movement of cattle and wildlife, management concepts, water access and water improvement was collected and recorded.

Different kinds of rangeland modifications that have emerged among and between the conservancies in the recent past were recorded. These included incidences of induced grazing, presence of planned grazing annually, as well as establishment of grazing corridors/zones. Spatial records about the location of the modifications were scanty during the field visit, however, the managers interviewed confirmed positive or otherwise their continued efforts to effect these changes (Table 2.4).

Water scarcity challenge in Mara rangelands have been encountered with sinking of more boreholes, opening of dams to harvest surface run-off from flash floods. These interventions are aimed at supplementing natural water sources such as river Mara, and its tributaries (Table 2.5). Up to date water points for the entire study area could not be obtained, except for some conservancies: - Naboisho, Mara North, Telek, Siana, Ol Kinyei, Olare Orok, Motorogi and a small portion of the Masai Mara National Reserve.

Table 2.3 Management policy choices on grazing and livestock movement that are effected by different conservancies during different seasons of the year that correspond with low tourism season (coincides with wet climatic season) and high tourism season (coincides with dry climate season).

Conservancy	Restriction of Livestock Movement	Fenced Land Presence within	Preservation Grass-Banks	Grazing Permission	
				Low season (AMJ-NDJ)	High Season(JASO-FM)
i. Enonkishu	0	1	1	1	1
ii. Olchoro	1	1	1	1	0
iii. Lamek	1	1	1	1	0
iv. Mara North	1	0	1	1	0
v. Olare Orok	1	0	1	1	0
vi. Motorogi	0	0	1	1	0
vii. Naboisho	0	0	1	1	0
viii. Olkinye	1	1	1	1	0
ix. Siana	0	1	1	1	0
x. Masaai Mara Reserve	0	0	0	0	0
Key: 1 – Enforced,		**0 – Not Enforced**			

Table 2.4 the presence of rangeland modifications undertaken by different management of conservancies.

Conservancy	Rangeland Modifications		
	Grazing Induced Modifications	Planned Grazing	Grazing Zone
i. Enonkishu	1	1	1
ii. Olchoro	1	1	1
iii. Lamek	1	1	0
iv. Mara North	1	1	1
v. Olare Orok	1	1	1
vi. Motorogi	1	1	1
vii. Naboisho	1	1	1
viii. Olkinye	1	1	1
ix. Siana	1	1	0
x. Mara Reserve	1	0	0
Key: 1 – Enforced,	**0 – Not Enforced**		

Table 2.5 Water improvement and access status by different conservancies

Conservancy	Artificial Water Points	Rivers and Streams	Rainwater Harvesting
i. Enonkishu	1	1	0
ii. Olchoro	1	1	0
iii. Lamek	1	1	1
iv. Mara North	1	1	1
v. Olare Orok	1	1	1
vi. Motorogi	1	1	1
vii. Naboisho	1	1	1
viii. Olkinye	1	1	1
ix. Siana	1	1	1
x. Mara Reserve	1	1	0

Key: 1 – Present, 0 – Absent

b) Change in management

The gradual and continuous changes in the management of the Mara ecosystem from group ranches to private land ownership and eventually into conservancies have been documented by researchers (Serneels & Lambin, 2001). All the conservancies under study area were established from 2005, however, previously, they were managed as group ranches. To objectively determine the impact of change in management and relate this with rangeland trend, arbitrary intervals of 3 year was chosen starting from 1997 to coincide with the immediate previous general election. Thus, the intervals used were shown in Table 2.6 below.

Table 2.6 Phased sequence in change management in time between 1997 – 2013.

		INTERVALS				
Conservancy	Year Est.	A	**B**	**C**	**D**	**E**
Enonkishu	2010				√	
Olchoro	2009					
Lamek	2007			√		
Mara North	Jan 2009				√	
Olare Orok	2006			√		
Motorogi	2006			√		
Naboisho	March 2010			√		
Olkinye	2005			√		
Siana	2010				√	

A (1997-2000) B (2001-2003) C (2004-2007) D (2008-2011) E (2012-2013)

Basing on the intervals of years for assumed change in management, the outcome of BFAST trend (refer to section 2.9) on time series were compared to check when the breaks occur, and the coincidence in time confidence interval for abrupt change.

2.5.3. Secondary Data

Additional data obtained from relevant agencies and actors in government and private firms to be used in the study. These are outlined in the Table 2.7 below, and already reported in section 2.5.2.

Table 2.7 showing a list of secondary data sourced from different actors in government offices in Kenya and private actors (conservancy managers).

Data	Source	Format type	Unit of measurement
Management Objectives			
• **Fencing policy**	Conservancy Managers/Field work	Binary	0-1
• **Rangeland modifications**	Conservancy Managers/Field work	Binary	0-1
• **Tourism**	Conservancy managers	Binary	0-1
• **Settlement (bomas)**	Digitized from Google	Shape file	Points
Wildlife and Livestock Census Data	DRSRS	Shape file/dbf	Grid/points

Animal counts data that covered the project area was obtained from Department of Remote Sensing and Remote Survey (DRSRS), ministry of environment and Natural resources in Nairobi. The data were collected using aerial count for both livestock and wildlife, undertaken in 2010. The Metadata on this data was not comprehensive enough, however the shape file of counting grid, the attribute table had counts for different species of animal codes recorded for each grid. Additional excel sheets with list animal species and their codes. Details about exact flight dates were not obtained on time. The animal counts were recorded and mapped as point files in ArcGIS for square grids measuring 5km by 5km.

The shape files were projected. Further analysis on the data was performed in R-Studio, to calculate the spatial distribution and density based on different management units. Only grazers and browsers were used in the study. These included: buffalos, cattle, donkeys, eland, elephant, grant gazelle, impalas, kongoni, Thomsons gazelle, waterbuck, warthog, wildebeest and zebras. Calculation of tropical livestock unit were also done based on this data set.

2.6. Vegetation Cover Mapping

2.6.1. Legend Construction

Field vegetation survey data from all sample plots were entered in Microsoft Excel from the field data sheets (see 2.5.1). Using weighted percentage, data records from complex polygons were combined to obtain a representative percentage cover for the whole polygon, with a basis for corresponds with 250m resolution (MODIS Pixel size). Trees and high shrubs cover percentage were generalized into one class, while low shrubs cover was a class of its own and were excluded in further analysis. The percentage covers for herbs and grass, bare soil, litter and stones were derived so that their sum equals to 100%.

The vegetation cover percentages that constituted the final legend followed the system used by Reed, Anderson, Dempewolf, Metzger, and Serneels, (2009) in land cover classification in Mara Serengeti Ecosystem. Grass and herb cover percentage offered the basis for hierarchical due to normal distribution as compared to other variables. Therefore, other specific classes as bare soil, low shrub, and trees and high shrubs were telescoped inside grass and herbs class.

Using ArcGIS, the table was joined with NDVI raster 71 classes as outlined in section 2.4.4, Median NDVI classes, Standard Deviation, and Trend maps. Based on these, legend was generated. Visual counter checking on google earth image based on the 71 classes, only raster classes that were relevant for study were used for vegetation mapping, thus included: 18, 25, 35, 39, 48, 52 and 57. Only raster classes that were confirmed with google earth images were given definite class. Field vegetation cover data were averaged for each cover variable and joined with the raster classes, median, standard deviation, and trend maps. The joined table was sorted to correspond with sampling units resulting in 6 distinct map units.

The resultant table was clustered based on raster classes, map units are delineated based on median and standard deviation classes' combinations. Field data are integrated with GIS data and analysed give further classes within classes, as well as overlaps between map units based on cover percentages among vegetation types.

2.7. Data Analysis

After mapping vegetation cover for the Maasai Mara ecosystem, the next step was to evaluate and statistically test the significance of drivers based on available input data. Livestock and wildlife count [as Tropical Livestock Unit (TLU)] density pressure was used. Analysis and quantification in relation to the range condition in space and time was done. Statistical analysis were executed in MS Excel, SPSS and R environment using spatial temporal packages.

2.7.1. Area estimation of mapped land cover units

The map units of vegetation cover obtained in section 2.6.1 were described based on percentage cover collected from the field. Using ArcGIS calculation of each cover type per conservancy was done. According to (FAO, 2006) rangeland condition assessment follows estimation of available forage and land cover. Considering the density modifiers for range conditions based on grass/herb cover predicted for the study area as: degraded (2-19%), degrading (20-49%), healthy (50-79%) and Stable (80-100%). Therefore to obtain forage cover for the project area, field data on estimates for forage cover was used, by summation of herbs and grass cover percentages to compute prediction coefficient for the study area. The herb and grass cover percentage was regressed with standard deviation, trend, and median NDVI values. The grass/herb map was crossed with the vegetation cover map. Then, actual cover area estimates in square kilometres (sq. km) for the different class variables calculated for the corresponding conservancies

2.7.2. Animal Count by Conservancy and Cover Type

a) Tropical Livestock Units

Spatial density distribution analysis of animal count was done based on both counts per unit area and tropical livestock per unit area. Tropical Livestock Unit (TLU) concept provides for a standardized quantification of wide range of different livestock types and sizes (FAO, 1999). The unit of measurement – 1 TLU is based on an exchange ratio upon which different species of different sizes can be compared and described in relation to the common unit. The best means of comparison to estimate this ratio is the ratio of metabolic weights, basing the argument of the fact that food consumption requirement for heat production among smaller animals per unit of body size is higher as compared to larger animals (Vallentine, 2000). The body weight of 250kg for one cow is the standard measure for one Tropical Livestock Unit (1 TLU).

The wildlife and livestock census data described in section 2.5.3, was converted into TLUs, using the species listing (see appendix E) of daily dry matter intake of grass of free ranging herbivores in relation to life body weight during dry season in the Amboseli Biosphere Reserve by Toxopeus, (1999). The FAO reference table of exchange ratio for livestock in TLU units based on metabolic weight is available in the appendix D. Computation of TLUs density was done for the grazers in the Mara ecosystem. Total number of each species of grazers was calculated for the conservancies that had total counts falling within their boundary. The totals for each grazer species was multiplied with the live body weight (Appendix E) and divided with 250kg, the weight for equivalent of 1 TLU (see appendix), so as to obtain the number of TLUs per species. A chi-square test was performed on the sums of TLUs per conservancy with vegetation cover units per conservancy to establish association between them.

b) Animal density vs cover estimation

Using ArcGIS, kernel density was computed for entire study area, based on the point grids used during the counts. Only animal counts of grazers that included: buffalos, cattle, donkeys, eland, elephant, grant gazelle, impalas, kongoni, Thomson's gazelle, waterbuck, warthog, wildebeest and zebras were used for the computation. A kernel density estimation values were extracted for a correlation analysis.

2.7.3. Rangeland Trend map

Using the NDVI trend values, a comparison between stable areas and stable areas was done and tabulated. Am rangeland condition map depicting trend was constructed. This was further evaluated based on different conservancies. Visual interpretation was done on the raster files and plots generated of spatial temporal outputs of BFAST and the trend map generated as outlined in section 2.9.

2.7.4. Management factors and rangeland condition

Coping with climatic variability to sustain productivity of the rangeland remain a great challenge. This often determine the distribution of both water independent and dependent animals across different seasons (Toxopeus, 1999). Therefore, the conservancies in the Mara ecosystem have to develop adaptive management options on grazing strategy and water access that meet both the corporate needs and range conditions.

Secondary data was obtained on water points (streams, rivers, dams, boreholes) and, settlement (bomas) was were analysed in relation to TLU density, and land cover analysis to quantify variation between stable and degrading areas between and among conservancies.

2.8. Statistical Analysis

2.8.1. Regression statistics

A simple linear regression of tropical livestock units per conservancy as dependent variable was executed with each map unit of vegetation cover in area per conservancy as independent variable as expressed in the equation below.

$$TLU = (\, \beta_0 + \beta_1 U1 + \beta_2 U2 \dots\dots\dots . \beta_6 U6)$$

Where; TLU is the response variable, where areas U1, U2…U6 are the map units of land cover area in square kilometres.

ANOVA was used to statistically test the significant difference between map units variables.

2.8.2. Cover comparison for different conservancies

A comparison of forage cover between the conservancies was undertaken. 220 random values were extracted from the entire conservancy to obtain forage cover predicted. Lemek (n = 28), Mara North (n = 19), Maasai Mara (n = 24), Ol Kinyei (n= 24) and Siana (n = 44). Forage cover were compared using non parametric *Kruskal-Wallis* H test in SPSS. To confirm when the forage data followed normal distribution, *Shapiro Wilk test,* $p<0.05$ was performed. A pairwise comparison were then performed based on Dunn procedure, followed with Bonferroni correction for multiple comparison at significance level $p<0.05$.

2.8.3. Relationship between animal density and cover

Pearson correlation between animal density and forage cover was performed to measure the strength of linear association between the variables. Computed TLU was also correlated with conservancy area.

2.9. NDVI Spatial Temporal Trend Analysis

The method follows the work of Reeves and Baggett, (2014). A reference condition (status) is needed to evaluate the trend of maximum value composite (MVC) during the study period. A mean maximum NDVI response between the study periods, was computed at each pixel to be used in trend analysis. An iterative evaluation of the status of each pixel was performed in targeted strata across the rangeland, with exclusion of pixels located at base plot locations of known biophysical properties in the same ecological subsection. This forms the reference condition to compare with target pixels.

Breaks for Additive Season and Trend (Verbesselt et al., 2009), R-package was used to decompose and analyse the NDVI time series into trends and seasons to characterize and detect trend within time series.

2.9.1. Decomposition model

Iterative model that fit pairwise linear trend and seasons was applied (Verbesselt et al., 2009). The model:

$$Y_t = T_t + S_t + e_t, \;\; t = 1, \dots\dots, n \tag{1}$$

Where;

$\boldsymbol{Y_t}$ is the observed data at the time t
$\boldsymbol{Tt}$ is the trend component,
$\boldsymbol{S_t}$ is the seasonal component and
e_t is the remainder component (variability unexplained)

The variation in the data that is beyond that found in either seasonal component or trend component are treated are remainder component. Thus, considering operation in presumption that T_t is pairwise linear, with break points $t\frac{*}{1}, \dots\dots, t\frac{*}{m}$ and define $t\frac{*}{0} = 0$, hence:

$$\boldsymbol{T_t = \alpha_j + \beta_j t} \tag{2}$$

For $\boldsymbol{t\frac{*}{j-1} < t \leq t\frac{*}{j} \; where \; j = 1, \dots\dots, m}$. Magnitude and direction of trend change are derived from the intercept and slope of consecutive linear models, $\boldsymbol{\alpha_j}$ and $\boldsymbol{\beta_j}$. The difference between Tj at t*j-1 and t*j derives the magnitude of abrupt change at break point. Thus;

$$\boldsymbol{Magnitude = (\alpha_{j-1} - \alpha_j) + (\beta_{j-1} - \beta_j)t} \tag{3}$$

Hence, β_{j-1} - β_j are the slopes of gradual change before and after a break. Seasonal components are also used in this study, however they are computed simultaneously. They are fixed between the breaks, however they vary across the break points, and occur at different times from the break points detected in the trend component. Hence, let seasonal breaks be given $t\frac{\#}{1}, \dots\dots, t\frac{\#}{p}$, and define $t\frac{\#}{1} = o$. Then for by $t\frac{\#}{j-1} < t \leq t\frac{\#}{j}$, it is assumed that;

$$\boldsymbol{S_t} = \{\boldsymbol{\gamma_{i,j}} - \sum_{\boldsymbol{i=1}}^{\boldsymbol{s-1}} \boldsymbol{\gamma_{i,j}} \quad \frac{\boldsymbol{if\ time\ t\ is\ in\ season\ i,\ \ i = 1, \dots s-1}}{\boldsymbol{if\ time\ t\ is\ in\ season\ 0},} \tag{4}$$

S is the seasonality period – for instance the number of observations per year, while $\gamma_{i,j}$ denotes the effects of season *i*. therefore the sum of the seasonal component, S_t across s successive times is zero for $t\frac{\#}{j-1} < t \leq t\frac{\#}{j}$, and hence eliminates seasonally induced breaks occurrence of changes in trend.

2.9.2. Iteration Algorithm for breakpoints detection in trend

The procedure was started with estimation of the initial seasonal component **($\check{S}_t$)** by using the Seasonal Trend procedure –STL method (Cleveland, Cleveland, McRae, & Terpenning, 1990), considering all seasonal sub-series from February 2000 on a monthly basis to December 2013. STL decomposes the NDVI time series into trend, seasonal and remainder components following Locally weighted regression smoother (LOESS). Then the following steps were pursued.

Step 1. Testing the occurrence of breakpoints in the time series using Ordinary Least Squares (OLS) residual-based Moving Sum (MOSUM) – (p<0.05), the number and positions of trend break points $t\frac{*}{1}, \ldots\ldots, t\frac{*}{m}$ estimated from the seasonality adjusted data, $Y_t - \check{S}_t$

Step 2. Using regression equation **(2)** the trend coefficients α_j and β_j for j = 1 were computed, thus setting the trend estimates to $\boldsymbol{TT_t = \alpha\alpha_j + \beta\beta_j t}$ for $\boldsymbol{t = t\overset{*}{_{j-1}} + 1, \ldots\ldots, t\overset{*}{_{j}}}$.

Step 3. Estimation of the number and position of break points $t\frac{*}{1}, \ldots\ldots, t\frac{*}{p}$ from the detrended $Y_t - TT_t$ data based on indication of OLS-MOSUM test (step 1).

Step 4. Using regression equation **(4),** the seasonal coefficients**,** $\boldsymbol{\gamma_{i,j}}$ for $\boldsymbol{j = 1, \ldots\ldots, m}$ and $\boldsymbol{i = 1, \ldots\ldots, s-1}$ based on M-estimation, thus, setting the seasonal estimates to $\check{S}_{\boldsymbol{t}} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{s-1}} \boldsymbol{\gamma\gamma_{i,j}\ (d_{t,i} - d_{t,0}}$ for $\boldsymbol{t = t\overset{\#}{_{j-1}} + 1, \ldots\ldots, t\overset{\#}{_{j}}}$ **.**

The four outlines steps are iterated until stable number and position of breakpoints are realised. This insinuates that in a year, which has 23 observations (of 16 day NDVI images), only significant change detected is registered and the time span of change estimated based on confidence interval.

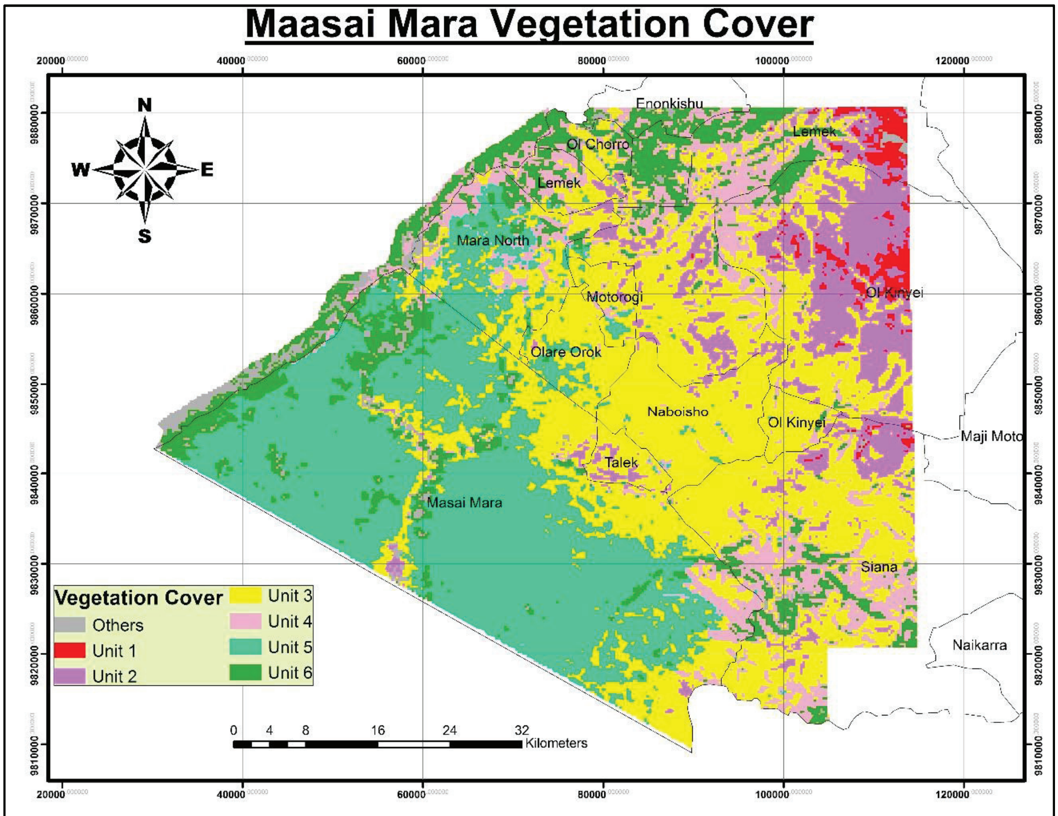
The raster files and plot results are visually interpreted and compared with spatial analysis.

3. RESULTS

This section presents the results of the study, outlines the statistical tests and tabulation of results.

3.1. Vegetation Cover Map

To map vegetation cover for the Maasai Mara in Figure 3.1, three different NDVI maps of standard deviation, median and trend were used together with the field vegetation data.



						% age Vegetation Cover						
Map Units	Raster Class	Median	SD	Trend	Tree	High Shrub	Low Shrubs	Herbs	Grass	Litter	Bare	Stony
1	18	10	3,4,5	3,4	0	5	2	0	31	0	67	0
2	25	11,12	2,3,4,5	3,4	1	6	1	1	57	0	41	0
3	35	12,13,14	2,3,4,5	3,4	1	8	1	1	37	1	59	2
4	39	13,14,15	2,3,4,5	3,4	2	22	1	2	46	0	51	1
5	48	12,14,15,16	3,4,5,6	3,4	0	1	1	0	70	20	9	0
6	52,57	15,16,17,18	2,3,4	4	14	54	5	2	26	19	43	4

The legend constructed from different vegetation cover type percentages obtained from field and the corresponding MODIS NDVI classes and corresponding Median, SD and trend into map units 1, 2, 3, 4, 5 and 6.

Standard deviation, median and trend map described in section 2.4.5 formed the basis to delineate different vegetation cover map unit to another based on NDVI class characterization that render differences between ecological units and cover characteristics. Field vegetation data were used to describe the cover type and the cover percentage. The map units are described below:

a) Map Unit 1.

The map unit is 67% bare, with 31% grass cover and are generally located in the regions that have generally been converted into agricultural fields, based on field visit. This was found to support the argument for the MODIS NDVI map images of SD, Median and trend that these pixels represent rangelands that are either degraded or with complexes of pixels with "good to very good" pastures based on SD. Following trend and median map, the pixels are classified as agricultural fields. These areas were described as degraded rangelands in agricultural fields located in the north eastern part of the study area.

b) Map Unit 2

In this map unit, there is 57% grass cover, 41% bare cover, with scattered high shrubs that account for 6%. This explains why the pixels classified as SD has complexes of both values considered as degraded (2 &3) and mixels of good rangelands (4&5). Based on field visits, these areas have pockets of wheat farms, fenced off from large tracks of good rangeland pastures. Based on this combination, generally, this map unit was described as degrading rangelands.

c) Map Unit 3

The map unit 3 is spatially spread right from the centre of the study area in Naboisho, and spread north in Motorogi and Lemek and to the south east in Siana. These are degraded rangelands with 59% bare cover, and 37% grass cover, dotted with 8% high shrubs. According to SD map, there are pixels with both graded and good pasture in the map unit – classes 2 & 3, and 4 & 5 respectively. Trend map depict pixels with stable rangelands as well. This map unit was described as degraded rangeland.

d) Map Unit 4

Map Unit 4 has 46% grass cover with 22% high shrubs and 51% bare. What differentiate this map unit from the unit 3 is median class 15. Pixels classified as class 15 are of higher order which relates to higher shrubs that are relatively stable covers. This can be described as shrubby grassland. The bare cover is slightly lower as compared with unit 3, hence was generally be referred to as degraded shrubby grassland.

e) Map Unit 5

These are areas with highest grass cover at 70%, with 9% bare cover. Spatially the area with this cover are located in the Mara Triangle, and slightly spread over to Mara North conservancy. They are have higher order of median class and high standard deviation of 16 and 6 respectively. This map unit was described as stable dense rangeland.

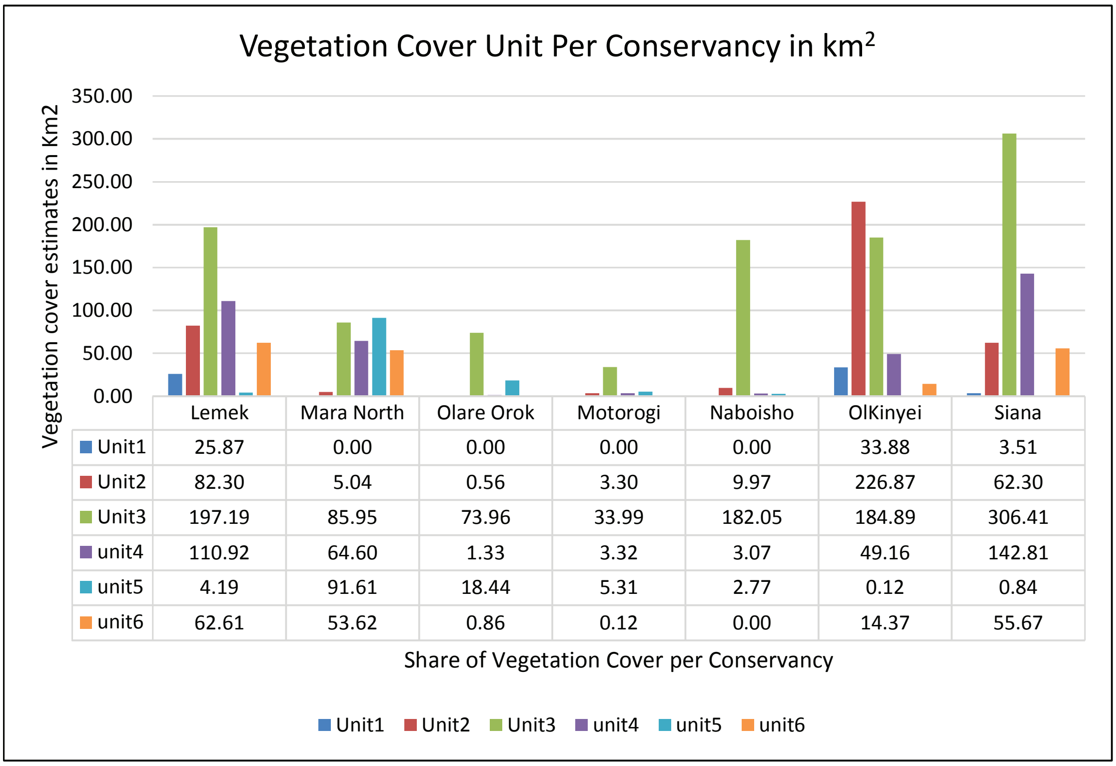
f) Map Unit 6

The map unit represent areas with high stability, as depicted with trend map class 4, high median classes and low SD classes. The cover is characterised with 54% high shrubs, 14% trees, 26% grass cover. The 46% bare cover was mostly found under the tree and shrub canopies. The unit was described as open shrub land.

3.2. Quantifying Drivers, Analysis and Evaluation Results

3.2.1. Vegetation cover area estimates

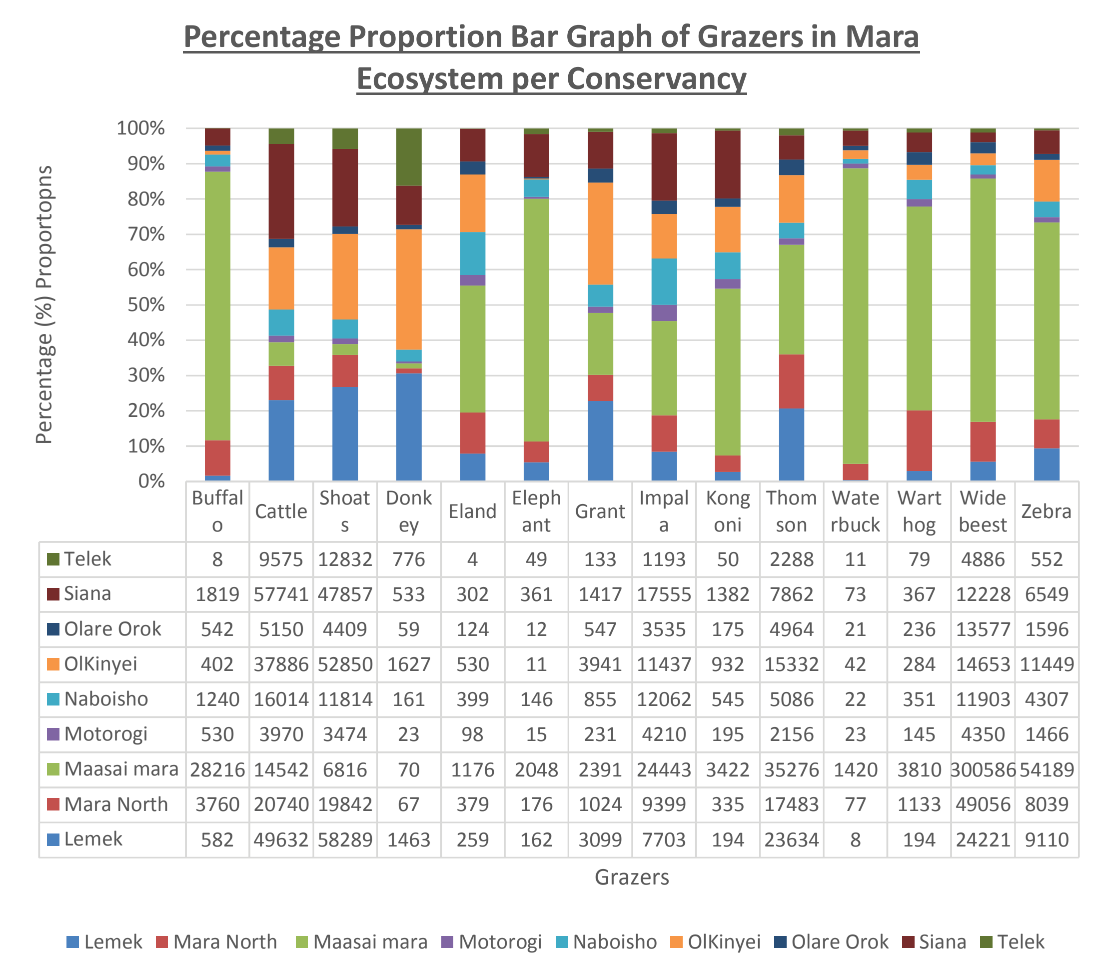
The result of computation of vegetation cover map units described in section 3.1 in square kilometre per conservancy are tabulated and graphically represented in Figure 3.2. The cover units represent different types of vegetation and range condition status for each conservancy. Unit 3 which was described as degraded rangeland is widespread across the 6 conservancies under study.



	Lemek	Mara North	Olare Orok	Motorogi	Naboisho	OlKinyei	Siana
Unit1	25.87	0.00	0.00	0.00	0.00	33.88	3.51
Unit2	82.30	5.04	0.56	3.30	9.97	226.87	62.30
Unit3	197.19	85.95	73.96	33.99	182.05	184.89	306.41
unit4	110.92	64.60	1.33	3.32	3.07	49.16	142.81
unit5	4.19	91.61	18.44	5.31	2.77	0.12	0.84
unit6	62.61	53.62	0.86	0.12	0.00	14.37	55.67

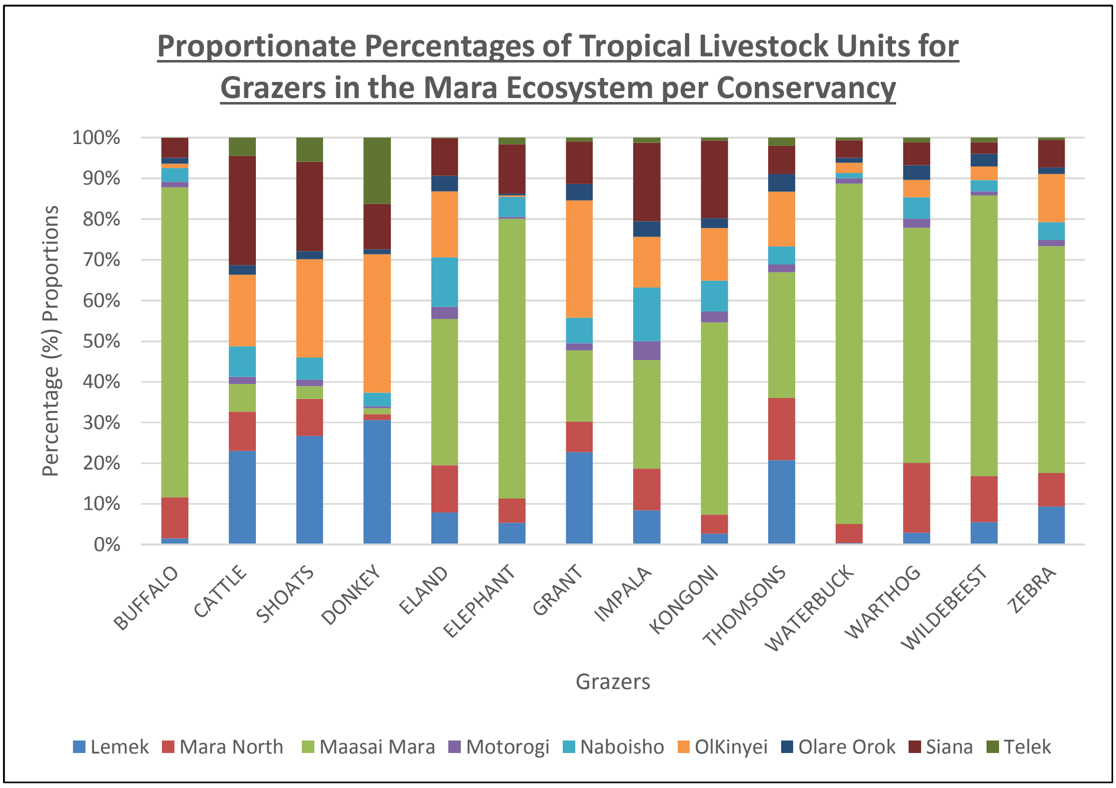
3.2.2. Animal Density by Conservancy and cover type

Figure 3.3 and Figure 3.4 are the results of animal counts and TLUs of grazers in percentage proportion per conservancy respectively. The graphs show the distribution of different species of herbivores that forage on the available biomass during the times of count in 2010. There is a variation in TLUs in comparison with animal count. Maasai Mara reserve has the highest number of wildlife grazers comparatively especially for buffaloes, elephants, waterbucks and wildebeests. However, cattle, sheep and goats were also found in the reserve in small proportionate percentages of less than 10%. The conservancies restrict grazing periods based on tourism seasons, nonetheless, cattle, sheep and goats which compete with wildlife for forage are variously distributed across different conservancies for instance, Siana has the highest number of cattle and shoats, followed by Lemek and OlKinyei.



	Buffalo	Cattle	Shoats	Donkey	Eland	Elephant	Grant	Impala	Kongoni	Thomson	Waterbuck	Warthog	Wildebeest	Zebra
Telek	8	9575	12832	776	4	49	133	1193	50	2288	11	79	4886	552
Siana	1819	57741	47857	533	302	361	1417	17555	1382	7862	73	367	12228	6549
Olare Orok	542	5150	4409	59	124	12	547	3535	175	4964	21	236	13577	1596
OlKinyei	402	37886	52850	1627	530	11	3941	11437	932	15332	42	284	14653	11449
Naboisho	1240	16014	11814	161	399	146	855	12062	545	5086	22	351	11903	4307
Motorogi	530	3970	3474	23	98	15	231	4210	195	2156	23	145	4350	1466
Maasai mara	28216	14542	6816	70	1176	2048	2391	24443	3422	35276	1420	3810	300586	54189
Mara North	3760	20740	19842	67	379	176	1024	9399	335	17483	77	1133	49056	8039
Lemek	582	49632	58289	1463	259	162	3099	7703	194	23634	8	194	24221	9110

Tropical livestock units proportionate distribution results are reported in Figure 3.4. The animal counts when converted into TLUs portray a different picture for comparison. Maasai Mara reserve was reported to have highest TLUs of buffaloes, elephant, eland, waterbuck and wildebeest. On the side of the conservancies, cattle, sheep and goats played a significant count for Lemek and OlKinyei conservancies followed with Siana.



3.2.3. Relationship between animal derived TLU and vegetation cover units

Simple linear regression was used to explain tropical livestock units based on each of the vegetation cover units area described in section 3.2.2. Summary of the regression results are in table Table 3.1.

Table 3.1 The results of simple regression analysis

Variable explained	Vegetation Cover Units	F-calc	F-sig	R^2
TLU1	Unit 1	1.65	0.26	0.25
TLU2	Unit 2	1.42	0.29	0.22
TLU3	Unit 3	4.58	0.90	0.48
TLU4	Unit 4	19.00	0.01	0.79
TLU5	Unit 5	0.23	0.65	0.04
TLU6	Unit 6	20.43	0.01	0.80

Regression results for the six vegetation cover show that they are significantly different. However, unit 4 with R2 = .79 and Unit 6 with R2 = .80 explain the highest number of TLU as compared to other units. Unit 6 is predominantly high shrubs at 54% with 14% tree cover, on the other hand unit 4 appropriately insinuate presence of grazers.

To quantify forage cover and compare the differences between conservancies, a multiple regression analysis was run to obtain coefficients for map prediction. The results of the regression indicated the three predictors – median, standard deviation and trend NDVI values explained 37.8% of the variance (R^2=.34, $F(3,49)=9.90$, $p<.05$).

Therefore, the coefficients were applied in ArGIS to predict a grass/herb values using the equation.

$$\text{Grass/Herb} = -56.98430 + (0.03662 * \text{Median}) + (3.79683 * \text{Std Dev}) + (9.48018 * \text{Trend})$$

The result showed that there was statistically significant difference in grass-herb forage cover among the conservancies. Conservancies *Kruskal-Wallis* chi-squared = 41.88, df = 4, p=0.00. As a subsequence, a pairwise comparison was performed using Dunn procedure (Dunn, 1964). A Bonferroni correction for multiple comparison with significance at $p<0.05$. The analysis of different conservancies revealed statistically differences between Maasai Mara and four conservancies namely: Siana, Olkinyei, Mara North and Lemek. On the other hand, the following conservancies were not statistically different: Mara North and three conservancies namely; Lemek, OlKinyei, and Siana in one part, as Siana was now with Lemek, Mara North and OlKinyei, lastly OlKinyei and Lemek

Table 3.2 pairwise comparison (Dunn, 1964).

Pairwise	Z score	P value
Mara North – Lemek	0.36	1.00
Maasai Mara – Lemek	-2.98	0.01
Maasai Mara – Mara North	-2.97	0.02
Ol Kinyei - Lemek	0.36	1.00
Ol Kinyei –Mara North	-0.06	1.00
Ol Kinyei – Maasai Mara	3.72	0.00
Siana – Lemek	1.58	0.57
Siana –Mara North	1.00	1.00
Siana – Maasai Mara	5.75	0.00
Siana – Ol Kinyei	1.29	0.99

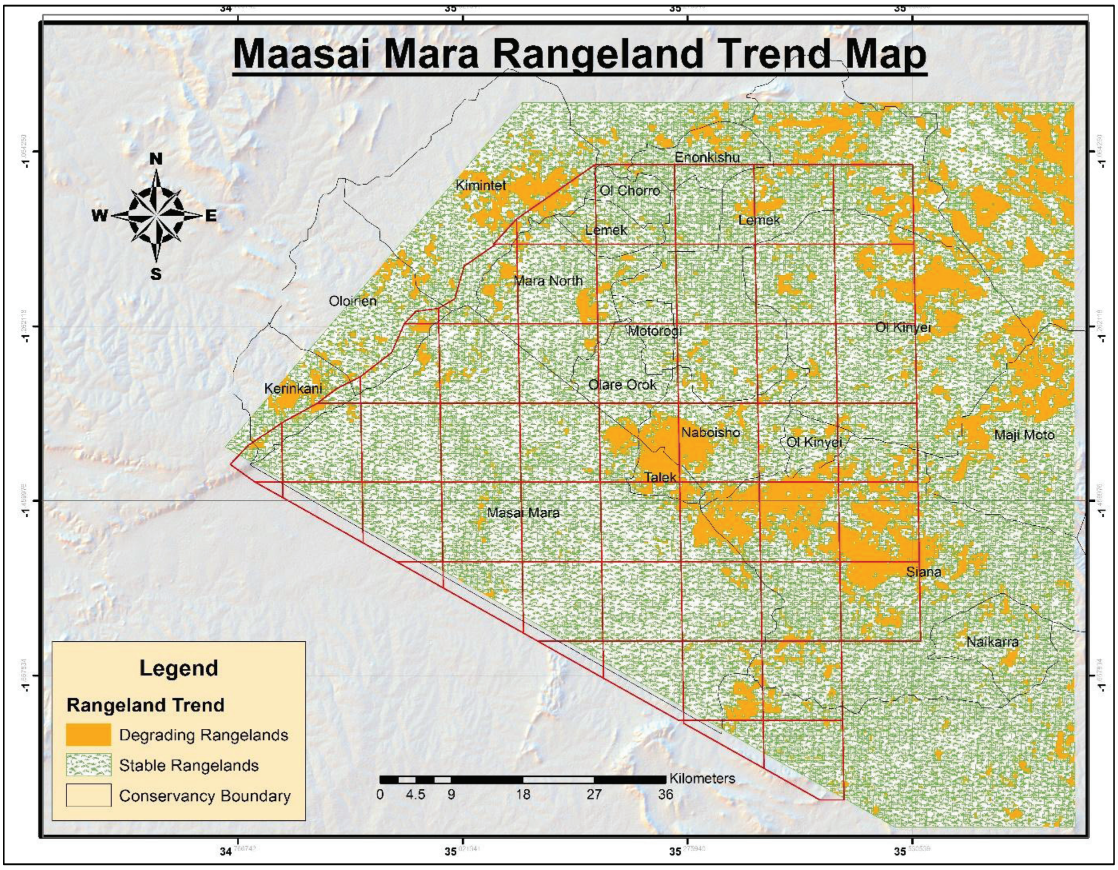
Using kernel density of grazers, the correlation between animal density and forage cover revealed a test score that were correlated, $r(53) = .21$, $p<.05$. The results show that there was a positive correlation (Table 3.3)

Table 3.3 Correlation score for animal density and forage cover.

		Animal Density	Forage
Animal Density	Pearson Correlation	1	.214
	Sig. (2-tailed)		.123
	N	53	53
Forage	Pearson Correlation	.214	1
	Sig. (2-tailed)	.123	
	N	53	53

3.2.4. Trend Map

As shown from result 3.2.3, Unit 4 reliably explains vegetation relationship with TLU per square unit. The trend map shows a corresponding degraded areas as compared with stable areas Figure 3.5. The result show that the degraded and degrading rangelands correspond with Unit 4.



3.3. NDVI Spatial Temporal Trend Analysis

3.3.1. NDVI time series decomposition

The result of decomposition of the MODIS Terra NDVI time series for the study area is shown in Figure 3.6. The result of the decomposed time series was categorised into seasonal, trend, and the random (remainder) components. Seasonal component was estimated from the mean of all seasonal subs-series. The observed series is the sum of the seasonal trend, and the remainder components. Trend magnitude ranged from 0.45 units to 0.55 units. Temporally, there was a slump dip between 2005 to 2010.

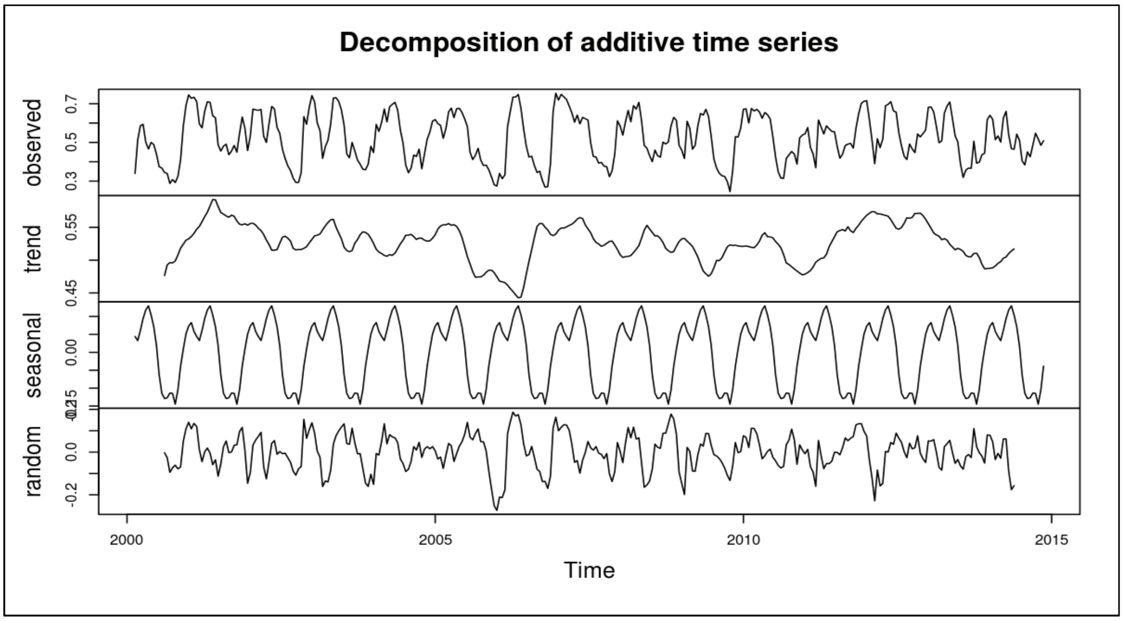


Figure 3.6. The seasonal time series decomposition of MODIS Terra 16 day NDVI for Maasai Mara rangeland ecosystem.

3.3.2. NDVI time series breaks in trend

Breaks for Additive Seasonal Trend analysis on the NDVI time series yielded estimates of time and magnitude of spatial changes. The results are shown for the four parts of the Maasai Mara ecosystem are shown in Figure 3.7. The amount of seasonality and trend breaks range between 0 (low) to 1 (high), on the other hand, the corresponding year of first breaks in seasonality and trend are also provided in the same chart.

The results shows that the occurrence of trend breaks do not relate with seasonal breaks the spatial and temporal distribution. In addition, the magnitude of change in trend for large portions of the study area range between 0.6 to 1, that occurred between 2002 and 2008.

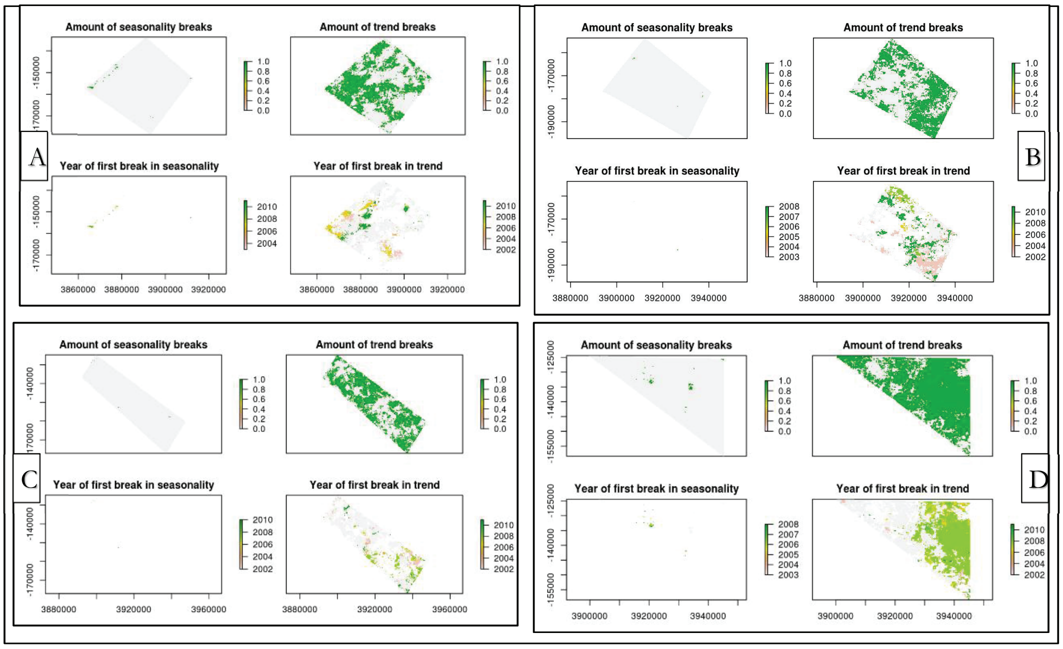
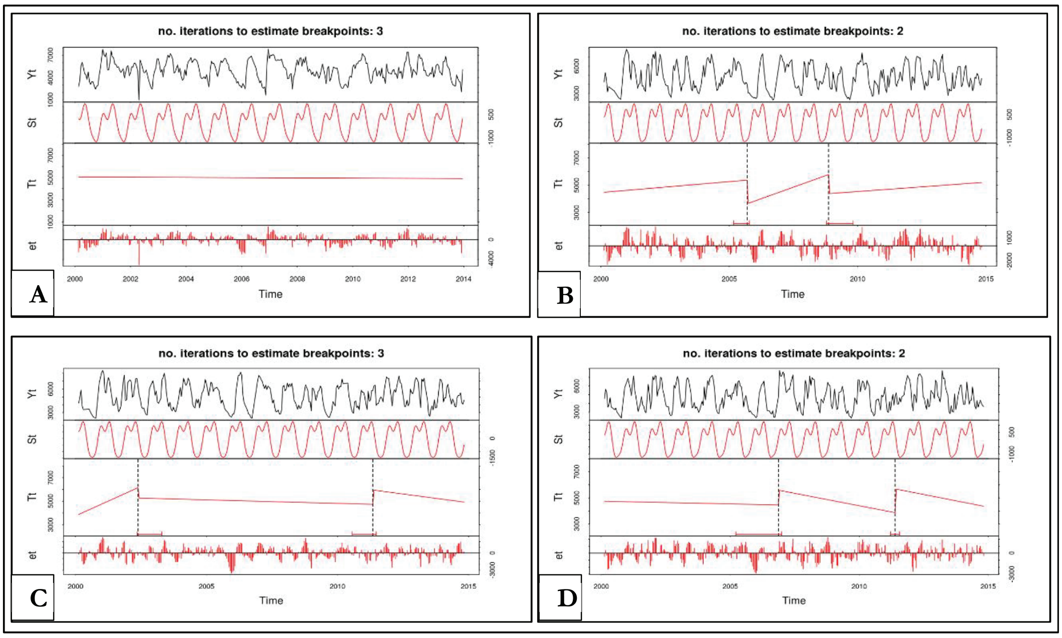


Figure 3.7 BFAST application outcomes A – south west Maasai Mara reserve, B – south east Maasai Mara reserve, C – the middle area (conservancies) and D northern area (conservancies)

The results for breaks in trend of the time series are shown in Figure 3.8. Panel A shows results show trend without breaks. For panel B, C, and D there are two breaks at different period in the time series.



The abrupt changes were detected in the trend component of the time series. The length of period of change is represented by confidence interval before or after the change, based on the fact that in natural environments, change occur gradually. The corresponding time of abrupt change, and the confidence interval in short red line, direction and magnitude of abrupt change and slope of the gradual change are shown in the estimated trend component Table 3.4.

Table 3.4 Table showing corresponding management change period with the breaks on trend.

		INTERVALS				
Conservancy	Year Est.	A	**B**	**C**	**D**	**E**
Enonkishu	2010				√	
Olchoro	2009					
Lamek	2007			√		
Mara North	Jan 2009				√	
Olare Orok	2006			√		
Motorogi	2006			√		
Naboisho	March 2010			√		
Olkinye	2005			√		
Siana	2010				√	

A (1997-2000) B (2001-2003) C (2004-2007) D (2008-2011) E (2012-2013)

4. DISCUSSION

Optimal application of remote sensing data were used in quantification of drivers of spatial-temporal trends in rangeland conditions in Narok. This follows the assumption that hypertemporal NDVI obtained from 16 day MODIS – Terra provided rich information that characterised drivers of change in spatially heterogeneous natural ecosystems. To objectively map vegetation cover, it was presumed that deriving and classification standard deviation, median and trend values of hyper-temporal NDVI robustly excludes the effects of highly variable short term precipitation on the vegetation cover. Therefore, maps of classes of NDVI standard deviation, median and trend formed the basis for mapping of vegetation spatial variation in the Maasai Mara ecosystem. The study focused on vegetation cover and their change as influenced by management factors and animal density. Further analysis on these drivers of change on cover were evaluated and introduced as qualitative data for the variation in change among and between different conservancies.

Result showed significant differences in cover between some conservancies, but not in some. There was a positive correlation in animal density and forage percentage across the study area.

4.1. Vegetation Cover Mapping

The map of vegetation cover of Maasai Mara ecosystem Figure 3.1 effectively integrates the application of ISODATA clustering of NDVI together with classes of NDVI standard deviation, median and trend. Delineation of mapping units made possible by field vegetation data. The use of ISODATA and separability statistics for heterogeneity cover mapping has been applied by various researchers to map land cover and land use change Thi and Ha, (2013), Ali et al., (2013). Such maps are relatively accurate and effectively delineated covers that experience cover patterns especially the agricultural fields. On the other hand, mapping vegetation cover heterogeneity of natural ecosystem in the tropics that experience high variability in rainfall patterns require approaches that exclude such noises (Reed et al., 2009).

We confirmed that integration of ISODATA clustering and separability statistics refer 2.4.4 with standard deviation, median and trend NDVI map components, effectively excluded the effects of short rains precipitation on vegetation cover mapping. Applying field vegetation data with remote sensing data to construct the legend for mapping enable reliability and robustness of the maps produced using this approach.

4.2. Quantifying Drivers, Analysis and Evaluation

4.2.1. Vegetation cover estimates

Spatial variation of different vegetation covers mapped across different conservancies in the Maasai Mara ecosystem as shown in 3.2.1 portrays different levels of range conditions. Proportionate cover per conservancy are associated with levels of grazing pressure, land use type proximity as well as climatic variations. The results are comparable with the findings of Serneels and Lambin, (2001) that found that vegetation cover change to other land uses such as agriculture and establishment of lodges is controlled by proximity to agro-produce markets, nearness to tourism market respectively. This explains the spatial location of vegetation cover unit 1- which are described as degraded rangelands and agricultural fields, located to main road access to markets. OlKinyie and Lemek conservancies are the most affected with emergence of rangeland conversion into agricultural lands. In addition, conservancies that are adjacent to the national reserve, due to its proximity to tourism market access, have put in place strict management regimes to protect the natural vegetation cover to retain wildlife and reduce competition for forage with livestock's within their areas of jurisdictions. This explains why, Mara North for instance enjoys a stable vegetation cover – unit 4 and 6.

4.2.2. Animal density by conservancy and cover type

There was statistically difference in vegetation cover *Kruskal-Wallis* chi-squared = 41.88, df = 4, p=0.00. The result of pairwise comparison between some conservancies (Table 3.2) depict the trend in cover between the conservancies. In as much as some conservancies are statistically similar, the differences can be attributed to management changes over the past years and their impacts on the vegetation cover. There is general agreement in previous studies that the closer a conservancy is to the Maasai Mara reserve, the more the similarities in cover the reverse is true for conservancies that are further (Serneels & Lambin, 2001). On the other hand, the comparison depicts conservancies that are on the migratory corridor, and vegetation similarities between them, for instance Mara North and Lemek.

There was significant correlation, $r(53) = .21$, $p<.05$ between animal density and vegetation cover (Table 3.3). This revealed the nomadic nature of pastoralists, prompting grazers to more towards vegetation cover units that have significant pasture and water.

4.2.3. Relationship between animal derived TLU and vegetation cover

The dependence of animal density on vegetation cover variability and trend was found to be different among the conservancies under study across the Maasai Mara ecosystem. Results of simple linear regression in Table 3.1 show that vegetation cover unit 4 – explained 79% of the tropical livestock units, cover unit 6 explained 80%, however can be used with limitations because, the cover is generally open shrub land. Results of simple regression of unit 4 with sheep and goats TLU show that 66% can be explained.

The results were found to statistically significant considering the cover unit 4 is considered shrubby grassland with 46% grass cover and 51% bare. We compare these results with the work of Ottichilo et al., (2000) that found that land use and vegetation changes are major contributors of decline in population trends of large non-migratory wild herbivores and livestock in Maasai Mara. Some researcher have found animal density pressure on land is attributed to water points and palatability status of forage species composition found in an area (Tefera et al., 2007a). The Maasai pastoralist are entirely nomadic, thus move with their livestock in search of water and pasture, thus the correlation found with vegetation cover and animal density. Grazing gradient is used to explain this tendency in both studies in the Borana rangelands in Ethiopia (Tefera et al., 2007a, 2007b).

4.2.4. Trend map

Visual inspection of the trend map comparing the stable rangelands against degrading rangelands indicates that areas with significant degradation correspond with cover unit 4 and cover unit 3 (refer to section 4.2.3). Notably, these are areas with high TLU density. Siana, Lemek and OlKinyei conservancies for instance are reportedly with the highest number of sheep and goats TLUs. Several researchers have established the relationship between degradation and high shoat's density in rangeland conditions (Stavi, Lavee, Ungar, & Sarah, 2012, Lorent, Sonnenschein, Tsiourlis, Hostert, & Lambin, 2009). The result realised in this map insinuates that trend map provide indications of management decisions on grazing of livestock especially sheep and goats and their impacts. Additionally, this provides spatial trend of the degradation spread in future based on historical trend.

4.3. NDVI Spatial Temporal Trend Analysis

The results for spatial temporal analysis of MODIS –NDVIS time series in form of plots and files (refer to section 3.3). BFAST has reliable capability to estimates of time and magnitude of changes are comparable spatially with field vegetation data that formed the basis for the Maasai Mara ecosystem vegetation map described in Figure 3.1 and trend map discussed in 4.2.4. BFAST revealed for the magnitude of change ranging between 60% to 90% for the period between 2002 and 2008. The results corresponds with changes in management during which, a number of conservancies were established. The subsequent effect of this is seen in areas in the Loita plains, such as OlKinyie, Olare Orok, Naboisho and Siana conservancies where pressure of overgrazing can be seen as a result of large populations of livestock are pushed out of conservancies to the traditionally owned trust land. A number of authors have used BFAST to study change detection in forest ecosystems, as well as separation of vegetation senescence periods at both local and regional scales with reliable results, Jong, Verbesselt, Schaepman, amd Bruin, (2012) realised 15% of significant browning at global scale using BFAST. Additionally, (Verbesselt et al., 2009) applied BFAST to MODIS 16 day time series for forested area in south eastern Australia in detecting spatial temporal change in comparison with actual forest inventory data.

5. CONCLUSIONS AND RECOMMENDATIONS

Hyper temporal remote sensing is able to consistently provide rich information for reliable ecological monitoring over large areas. Vegetation mapping in natural ecosystems in the tropics where climatic variability is high, minimizing noise remains an impediment that is effectively overcame by analysis of historical hypertemporal remote sensing data. Variety of approaches can be used to achieve reliable NDVI patterns for different vegetation cover types that effectively guide undertaking efficient ground truth data collection that is efficient, and reliable for intended mapping purposes. Therefore the appropriate method should incorporate mechanisms that exclude the effects of precipitation variability on vegetation, the threshold should be based on the nature of the environment and the vastness of the area of the study, including the length of period under consideration.

This paper explored drivers of spatial – temporal trends in rangeland condition, and their association with management choices of different conservancies found in the Maasai Mara ecosystem. Using MODIS – Terra 16 day NDVI time series for period covering 2000 to 2013. The vegetation mapping result provide a robust platform for management of the conservancies to take reliable inventory of the vegetation cover status in the ecosystem. These status reflect different stages in the rangeland condition that overall ecosystem can gauge the productivity trend for the coming periods. The supplementary information provided by the trend map is a pointer to that direction on rangeland condition status. Animal count derived tropical livestock units was used as the basis to explain the spatial temporal vegetation cover types, revealed that there is a strong evidence that different conservancies are at different levels of stages in range condition status. Additionally, application of BFAST provides real-time multi-purpose monitoring tool that can be essential for managers in the ecosystem for planning field verification of abrupt cover change, to supplement spatial – temporal analysis.

The study results highlight the potentials and limitations of hyper-temporal application for ecological monitoring. Long-term consistent monitoring is only possible with remote sensing, however, effective analysis of the conditions is only possible when ground data is collected and stored in the correct and consistent format. Depending on the scale of operation, high resolution imagery should be fused with low resolution imagery, e.g. fusion of Landsat TM with MODIS. Secondary data access, especially geospatial data such as us water points, new roads, new fences was a limitation. On the other hand, the term "range condition" is quite subjective, and vary from one context to another, thus, to provide effective evaluation of drivers of change, a more comprehensive data collection by way of interviews of different stakeholders is essential to get varied interests that influence rangeland utilization.

LIST OF REFERENCES

Ali, A., de Bie, C. a. J. M., Skidmore, a. K., Scarrott, R. G., & Lymberakis, P. (2014). Mapping the heterogeneity of natural and semi-natural landscapes. *International Journal of Applied Earth Observation and Geoinformation*, *26*, 176–183. doi:10.1016/j.jag.2013.06.007

Ali, A., de Bie, C. A. J. M., Skidmore, A. K., Scarrott, R. G., Hamad, A., Venus, V., & Lymberakis, P. (2013). Mapping land cover gradients through analysis of hyper-temporal NDVI imagery. *International Journal of Applied Earth Observation and Geoinformation*, *23*, 301–312. doi:10.1016/j.jag.2012.10.001

Anyamba, A., Small, J., Tucker, C., & Pak, E. (2014). Thirty-two Years of Sahelian Zone Growing Season Non-Stationary NDVI3g Patterns and Trends. *Remote Sensing*, *6*(4), 3101–3122. doi:10.3390/rs6043101

Bai, Y., Han, X., Wu, J., Chen, Z., & Li, L. (2004). Ecosystem stability and compensatory effects in the Inner Mongolia grassland. *Nature*, *431*(7005), 181–4. doi:10.1038/nature02850

Cleveland, R. B., Cleveland, W. S., McRae, J. E., & Terpenning, I. (1990). STL: A seasonal-trend decomposition procedure based on loess. *Journal of Official Statistics*, *6*(1), 3–73.

De Leeuw, J. M., Said, M. Y., Kifugo, S., Ogutu, J. O., Osano, P., & de Leeuw, J. (2014). Spatial variation in the willingness to accept payments for conservation of a migratory wildlife corridor in the Athi-Kaputiei Plains, Kenya. *Ecosystem Services*, *8*, 16–24. doi:10.1016/j.ecoser.2014.01.003

Diouf, a., & Lambin, E. F. (2001). Monitoring land-cover changes in semi-arid regions: remote sensing data and field observations in the Ferlo, Senegal. *Journal of Arid Environments*, *48*(2), 129–148. doi:10.1006/jare.2000.0744

Du Toit, J., Kock, R., & Deutsch, J. (2012). *Wild Rangelands□ : Conserving Wildlife While Maintaining Livestock in Semi-Arid Ecosystems*. Hoboken: Wiley.

Dunn, O. J. (1964). Multiple comparisons using rank sums. *Technometrics*, *6*(3), 241–252.

FAO. (1999). *Tropical Livestock Units. Livestock and Environment Toolbox*. Retrieved February 02, 2015, from http://www.fao.org/ag/againfo/programmes/en/lead/toolbox/Mixed1/TLU.htm

FAO. (2006). *Food and Agriculture Organization of United Nations (FAO) - Kenya Country Pasture and Forage Resource Profiles* (p. 16). Rome, Italy. Retrieved from http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF files/Kenya.pdf

Fensholt, R., & Proud, S. R. (2012). Evaluation of Earth Observation based global long term vegetation trends — Comparing GIMMS and MODIS global NDVI time series. *Remote Sensing of Environment*, *119*, 131–147. doi:10.1016/j.rse.2011.12.015

Forbis, T. A., Provencher, L., Turner, L., Medlyn, G., Thompson, J., & Jones, G. (2007). A Method For Landscape-Scale Vegetation Assessment: Application to Great Basin Rangeland Ecosystems. *Rangeland Ecology & Management*, *60*(3), 209–217. doi:10.2111/1551-5028(2007)60[209:AMFLVA]2.0.CO;2

Global Rangelands Knowledge System. (2014). *Rangelands Partnership (United States of America), Western Land-Grant Universities and Collaborators.* Retrieved May 25, 2014, from http://globalrangelands.org/

GoK. (1964). *Geology of the Mara River-Siana Area, Ministry of Natural Resources, Geological Survey of Kenya, Report No. 66.* Nairobi.

Gosz, J. R., & Moore, Douglas I, Shore, Gregory A., Grover, H. D. (1995). Lightning Estimates of Precipitation Location and Quantity on the Sevilleta Lter , New Mexico. *Ecological Applications*, *5*(4), 1141–1150. doi:http://dx.doi.org/10.2307/2269361

Hagen, S. C., Heilman, P., Marsett, R., Torbick, N., Salas, W., Ravensway, J. van, & Qi, J. (2012). Mapping Total Vegetation Cover Across Western Rangelands With Moderate-Resolution Imaging Spectroradiometer Data. Retrieved from http://www.srmjournals.org/doi/abs/10.2111/REM-D-11-00188.1

Harris, R. B. (2010). Rangeland degradation on the Qinghai-Tibetan plateau: A review of the evidence of its magnitude and causes. *Journal of Arid Environments*, *74*(1), 1–12. doi:10.1016/j.jaridenv.2009.06.014

Herrick, J. E., Bestelmeyer, B. T., Archer, S., Tugel, a. J., & Brown, J. R. (2006). An integrated framework for science-based arid land management. *Journal of Arid Environments*, *65*(2), 319–335. doi:10.1016/j.jaridenv.2005.09.003

Herrick, J. E., Zee, J. W. Van, Havstad, K. M., Burkett, L. M., Whitford, W. G., Pyke, D. A., … Shaver, P. L. (2005). Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems (pp. 9–15). USDA-ARS Jornada Experimental Range Las Cruces, New Mexico.

Huxman, T. E., Snyder, K. a, Tissue, D., Leffler, a J., Ogle, K., Pockman, W. T., … Schwinning, S. (2004). Precipitation pulses and carbon fluxes in semiarid and arid ecosystems. *Oecologia*, *141*(2), 254–68. doi:10.1007/s00442-004-1682-4

ILRI. (1975). *Evaluation and Mapping of Tropical African Rangelands.* Retrieved August 24, 2014, from http://www.fao.org/wairdocs/ilri/x5543b/x5543b0o.htm

Jong, R. De. (2000). Detection of Breakpoints in Global NDVI time series, 0–3.

Karl, J. W., Herrick, J. E., & Karl, B. J. W. (2010). Monitoring and Assessment Based on Ecological Sites, *32*(6), 60–64.

Khan, M. R., de Bie, C. a. J. M., van Keulen, H., Smaling, E. M. a., & Real, R. (2010). Disaggregating and mapping crop statistics using hypertemporal remote sensing. *International Journal of Applied Earth Observation and Geoinformation*, *12*(1), 36–46. doi:10.1016/j.jag.2009.09.010

Leica Geosystems Geospatial Imaging, L. (2005). *ERDAS Field Guide ™* (p. 770).

Li, J., Da, L., Wang, Y., & Song, Y. (2006). Vegetation classification of East China with multi-temporal NOAA-AVHRR data. *Frontiers of Biology in China*, *1*(3), 303–309. doi:10.1007/s11515-006-0038-3

Li, S., Verburg, P. H., Lv, S., Wu, J., & Li, X. (2011). Spatial analysis of the driving factors of grassland degradation under conditions of climate change and intensive use in Inner Mongolia, China. *Regional Environmental Change*, *12*(3), 461–474. doi:10.1007/s10113-011-0264-3

Lorent, H., Sonnenschein, R., Tsiourlis, G. M., Hostert, P., & Lambin, E. (2009). Livestock subsidies and rangeland degradation in central Crete. *Ecology and Society*, *14*(2). doi:Artn 41

MacEachren, A. M. (1992). Visualizing uncertain information. *Cartographic Perspective*, *13*(13), 10–19. doi:10.1.1.62.285

Mau Mara Serengeti Sustainable Water Initiative (MaMaSe). (2014). *UNESCO-IHE*. Retrieved June 03, 2014, from http://mamase.unesco-ihe.org/welcome

Ndegwa Mundia, C., & Murayama, Y. (2009). Analysis of Land Use/Cover Changes and Animal Population Dynamics in a Wildlife Sanctuary in East Africa. *Remote Sensing*, *1*(4), 952–970. doi:10.3390/rs1040952

NOAA Satellite Information System (NOAASIS). (2013). Retrieved June 03, 2014, from http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html

Olexa, E. M., & Lawrence, R. L. (2014). Performance and effects of land cover type on synthetic surface reflectance data and NDVI estimates for assessment and monitoring of semi-arid rangeland. *International Journal of Applied Earth Observation and Geoinformation*, *30*, 30–41. doi:10.1016/j.jag.2014.01.008

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., … Kassem, K. R. (2001). Terrestrial Ecoregions of the World: A New Map of Life on Earth. *BioScience*, *51*(11), 933. doi:10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

Ottichilo, W. K., Leeuw, J. De, Skidmore, A. K., Herbert, H., Prins, T., & Said, M. Y. (2000). Population trends of large non-migratory wild herbivores and livestock in the Masai Mara, 202–216.

Owe, M., de Jeu, R., & Walker, J. (2001). A methodology for surface soil moisture and vegetation optical depth retrieval using the microwave polarization difference index. *IEEE Transactions on Geoscience and Remote Sensing*, *39*(8), 1643–1654. doi:10.1109/36.942542

Parmentier, B. (2014). Characterization of Land Transitions Patterns from Multivariate Time Series Using Seasonal Trend Analysis and Principal Component Analysis. *Remote Sensing*, *6*(12), 12639–12665. doi:10.3390/rs61212639

Pellant, M., P. Shaver, D.A. Pyke, and J. E. H. (2005). *Interpretating Indicators of Rangeland Health* (Version 4 ., p. 122). U.S. Department of Interior, Bureau of Land management, National Science and Technology Center, Denver, CO. BLM/WO/ST-00/001+1734/REV05.

Peters, D. P. C., & Havstad, K. M. (2006). Nonlinear dynamics in arid and semi-arid systems: Interactions among drivers and processes across scales. *Journal of Arid Environments*, *65*(2), 196–206. doi:10.1016/j.jaridenv.2005.05.010

Pettorelli, N., Chauvenet, A. L. M., Duffy, J. P., Cornforth, W. A., Meillere, A., & Baillie, J. E. M. (2012). Tracking the effect of climate change on ecosystem functioning using protected areas : Africa as a case study. *Ecological Indicators*, *20*, 269–276. doi:10.1016/j.ecolind.2012.02.014

Pettorelli, N., Gaillard, J., Mysterud, A., Duncan, P., Stenseth, N. C., Delorme, D., … Toı, C. (2006). Using a proxy of plant productivity (NDVI) to find key periods for animal performance : the case of roe deer, *3*(August 2005).

Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J.-M., Tucker, C. J., & Stenseth, N. C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology & Evolution*, *20*(9), 503–10. doi:10.1016/j.tree.2005.05.011

Pricope, N. G., Husak, G., Lopez-Carr, D., Funk, C., & Michaelsen, J. (2013). The climate-population nexus in the East African Horn: Emerging degradation trends in rangeland and pastoral livelihood zones. *Global Environmental Change*, *23*(6), 1525–1541. doi:10.1016/j.gloenvcha.2013.10.002

Reed, D. N., Anderson, T. M., Dempewolf, J., Metzger, K., & Serneels, S. (2009). The spatial distribution of vegetation types in the Serengeti ecosystem: The influence of rainfall and topographic relief on vegetation patch characteristics. *Journal of Biogeography*, *36*, 770–782. doi:10.1111/j.1365-2699.2008.02017.x

Reeves, M. C., & Baggett, L. S. (2014). A remote sensing protocol for identifying rangelands with degraded productive capacity. *Ecological Indicators*, *43*, 172–182. doi:10.1016/j.ecolind.2014.02.009

Rogan, J., & Chen, D. (2004). Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning*, *61*(4), 301–325. doi:10.1016/S0305-9006(03)00066-7

Serneels, S., & Lambin, E. F. (2001). Proximate causes of land-use change in Narok District, Kenya: a spatial statistical model. *Agriculture, Ecosystems & Environment*, *85*(1-3), 65–81. doi:10.1016/S0167-8809(01)00188-8

Serneels, S., & Lambin, E. F. (2002). Impact of land-use changes on the wildebeest migration in the northern part of the Serengeti-Mara ecosystem. *Journal of Biogeography*, *28*(3), 391–407. doi:10.1046/j.1365-2699.2001.00557.x

Stavi, I., Lavee, H., Ungar, E., & Sarah, P. (2012). Grazing-Induced Modification of a Semi-Arid Rangeland from a Two-Phase to a Three-Phase Mosaic Geo-Ecosystem. *Arid Land Research and Management*, *26*(February 2015), 79–83. doi:10.1080/15324982.2011.631691

Sulkava, M., Luyssaert, S., Rautio, P., Janssens, I. a., & Hollmén, J. (2007). Modeling the effects of varying data quality on trend detection in environmental monitoring. *Ecological Informatics*, *2*(2), 167–176. doi:10.1016/j.ecoinf.2007.03.008

Tefera, S., Snyman, H. a, & Smit, G. N. (2007a). Rangeland dynamics in southern Ethiopia: (1) botanical composition of grasses and soil characteristics in relation to land-use and distance from water in semi-arid Borana rangelands. *Journal of Environmental Management*, *85*(2), 429–42. doi:10.1016/j.jenvman.2006.10.007

Tefera, S., Snyman, H. a, & Smit, G. N. (2007b). Rangeland dynamics in southern Ethiopia: (3). Assessment of rangeland condition in relation to land-use and distance from water in semi-arid Borana rangelands. *Journal of Environmental Management*, *85*(2), 453–60. doi:10.1016/j.jenvman.2006.10.006

Thi, N., & Ha, T. (2013). *Earth observation for rice crop monitoring and yield estimation: Application of satellite data and physically based models*. University of Twente.

Toxopeus, A. G. (1999). *ISM An Interactive Spatial and Temporal Modelling System as a Tool in Ecosystem Management.* (A. G. Toxopeus, Ed.) (Second Edi., p. 250). Enschede: International Institute for Aerospace Survey and Earth Sciences ITC. Retrieved from www.itc.nl

Vallentine, J. F. (2000). *Grazing Management* (p. 659). Elsevier. Retrieved from https://books.google.com/books?id=9bMd1WRnZtwC&pgis=1

Verbesselt, J., Hyndman, R., Newnham, G., & Culvenor, D. (2009). Detecting trend and seasonal changes in satellite image time series.

Ward, D. P., & Kutt, A. S. (2009). Rangeland biodiversity assessment using fine scale on-ground survey, time series of remotely sensed ground cover and climate data: an Australian savanna case study. *Landscape Ecology*, *24*(4), 495–507. doi:10.1007/s10980-009-9324-1

Wylie, B. K., Boyte, S. P., & Major, D. J. (2012). Ecosystem Performance Monitoring of Rangelands by Integrating Modeling and Remote Sensing. *Rangeland Ecology & Management*, *65*(3), 241–252. doi:10.2111/REM-D-11-00058.1

APPENDICES

A. Exchange ratios for Livestock in Tropical Livestock Units based on Metabolic Body Weight (FAO).

Body Weight (kg)	Metabolic Body Weight (kg 0.75)	T L U
5	3	0.05
10	6	0.09
15	8	0.12
20	9	0.15
25	11	0.18
30	13	0.2
35	14	0.23
40	16	0.25
45	17	0.28
50	19	0.3
60	22	0.34
75	25	0.41
100	32	0.5
125	37	0.59
150	43	0.68
200	53	0.85
250	63	1
300	72	1.15
350	81	1.29
400	89	1.42
450	98	1.55
500	106	1.68
600	121	1.93
700	136	2.16

B. Field data collection sheet (interview questions section C)

DATA COLLECTION SHEET

Date:	Sample CODE:	Observers:			
Photo No.:		GPS: S		Altitude:	
		E		Plot size:	

SLOPE		STEEPILY DISSECTED		ALMOST FLAT		HILLY			
STEEPY		FLAT		UNDULATING		RIVERBED			
MOUNTAINOUS		VERY FLAT		ROLLING		OTHER (specify)			

ACTUAL LAND COVER		ACTUAL LAND USE	

A. LAND COVER/USE DATA – (semi-)natural or planted

SAMPLE PLOT				POLYGON		
STRATA	HEIGHT	COVER %	DORMINANT SPECIES (for details p.to.)	*General cover/use type (if complex, estimate % cover of each type)*		
				TYPE	DESCRIPTION	%AGE
Trees						
Shrubs						
Herbs						
Grass						
Litter cover						
Bare soil						
Stones/rocky boulders						

OBSERVATIONS:

B. PLANT SPECIES LIST						SCALE FOR COVER ESTIMATION
PLANT CODE	GRASS/HERBS SPECIES	COVER %AGE (see scale)	PLANT CODE	SPECIES	COVER %AGE (see scale)	R = rare P= few a = abundant m= many i = invasive* } < 5%
						1 = 5-15% 2 = 15-25% 3 = 25-35% 4 = 35-45% 5 = 45- 55%
						6 = 55-65% 7 = 65-75% 8 = 75-85% 9 = 85-95% 10 = 95 -100%
						• *Datura stramonium* • *Parthenium hysterophorus* • *Lantana camara* • *Tithonia diversifolia*
						REMARKS:

C. OBSERVATIONS/INTERVIEWS ON VEGETATION, CROPS, ANIMALS AND MANAGEMENT ASPECTS (SAMPLE POLYGON)											
1. <u>Range condition:</u> Annuals grasses (list them if Y)	Y	N		2. Burning	Y	N	%age burn:	<25%	25-50%	50-75%	>75%
							frequency in a year				
Perennial grass/weeds (list them if Y)	Y	N		3. <u>Termite molds</u>							
4. <u>Water:</u> Source:	Quality (*1poor to 5 high*): 1 2 3 4 5			5. Rangeland modifications	Y	N	Grazing induced	Stocking rate			
Distance (*in km*)	Accessible Y N		Operational: Y N								

Seasonal		Permanent		Use: Domestic					
All use						Others (specify)			
Remarks:									

6. Droppings/ footmarks/ track	Livestock (How Many)	Wild (How Many)		Distance	N/E/W/S	7. <u>Mechanized Agriculture</u> Size of land (in ha):____________________ Crops grown: ____ Purpose:
8. Fencing	Y	N	Distance	Purpose		9. <u>Smallholder Agriculture</u> Size of land (in ha): ______________________ Main Crops grown:____ Purpose

10. Fuel wood collection	Y	N	Frequency	Daily	Weekly	Monthly	11. Livestock /wildlife: Herd Count______________/_____________ Distance ____________________ Direction: N/E/W/S: ____________________ Movement: Free_________ Restricted_________ Frequency: Dry Season____________ Wet season____________________ Wildlife alone: YES/NO Domestic animals alone: YES/NO
			Amount (bundles)				

12. Car tracks	Y	N	Frequency of use,	regularly	SIZE	Remarks
				seasonal		

D. SOIL DATA

EROSION:	AREA AFFECTED
TYPE: None☐ Sheet☐ Rill☐ Gully☐ Eolic☐ Pedestals☐	< 25% ☐ 20-50%☐

RATE: Very low☐ Low☐ Moderate☐ Strong☐ Severe☐ | 50-75%☐ >75%☐

PROPERTIES (*AT 30CMS*) TEXTURE COLOUR pH

REMARKS

E. BIOMASS – DRY WEIGHT QUADRAT CLIPPING

PASTURE SPECIE	RANK	CANOPY HEIGHT	PASTURE WEIGHT		RANK TALLY			WEIGHTED RANKS	% COMPOSITION
			FRESH WEIGHT (g)	DRY WEIGHT (g)	1	2	3		
GRAZING INTENSITY									

Very low grazing	<20%		GRAZING INDICATORS:
Low grazing	20-40%		
Moderate grazing	40-60%		
High grazing	60-80%		COMMENTS:
Severe grazing	>80%		

Lion Data -Observation					
1. Number of lions	Male	Female	Cubs	Distance (Approx.)	N/E/W/S
2. Condition of Lions	Healthy			Unhealthy	
3.. Footprints	How Many		Distance (Approx.)		N/E/W/S
4. Vocalisations e.g Roaring	Distance (Approx.)			N/E/W/S	
5. Behaviour of other animals e.g Sudden flight	Which Ones?		Distance (Approx.)	N/E/W/S	How Many?
6. Lion Carcasses	How Many		Distance (Approx.)		N/E/W/S
7. Lion Droppings	How Many		Distance (Approx.)		N/E/W/S
8. REMARKS					
Built-up Structures e.g Schools/Houses/villages/Livestock Pens	**How Many**		**Distance (Approx.)**		**N/E/W/S**
1					
2					
5. REMARKS					

C. Summary of animal counts used for the study

Conservancies	Buffalo	Cattle	Shoats	Donkey	Eland	Elephant	Grant	Impala	Kongoni	Thomson	Waterbuck	Warthog	Widebeest	Zebra
Lemek	582	49632	58289	1463	259	162	3099	7703	194	23634	8	194	24221	9110
Mara North	3760	20740	19842	67	379	176	1024	9399	335	17483	77	1133	49056	8039
Maasai mara	28216	14542	6816	70	1176	2048	2391	24443	3422	35276	1420	3810	300586	54189
Motorogi	530	3970	3474	23	98	15	231	4210	195	2156	23	145	4350	1466
Naboisho	1240	16014	11814	161	399	146	855	12062	545	5086	22	351	11903	4307
OlKinyei	402	37886	52850	1627	530	11	3941	11437	932	15332	42	284	14653	11449
Olare Orok	542	5150	4409	59	124	12	547	3535	175	4964	21	236	13577	1596
Siana	1819	57741	47857	533	302	361	1417	17555	1382	7862	73	367	12228	6549
Telek	8	9575	12832	776	4	49	133	1193	50	2288	11	79	4886	552

D. Summary of Tropical Livestock Units

Conservancies	Buffalo	Cattle	Shoats	Donkey	Eland	Elephant	Grant	Impala	Kongoni	Thomsons	Waterbuck	Warthog	Wildebeest	Zebra	Total TLU
Lemek	978	40698	5829	819	352	1118	558	1387	97	1418	5	35	16470	7652	71588
Mara North	6317	17007	1984	38	515	1214	184	1692	168	1049	52	204	33358	6753	68551
Maasai Mara	47403	11924	682	39	1599	14131	430	4400	1711	2117	966	686	204398	45519	335323
Motorogi	890	3255	347	13	133	104	42	758	98	129	16	26	2958	1231	9653
Naboisho	2083	13131	1181	90	543	1007	154	2171	273	305	15	63	8094	3618	31548
OlKinyei	675	31067	5285	911	721	76	709	2059	466	920	29	51	9964	9617	57265
Olare Orok	911	4223	441	33	169	83	98	636	88	298	14	42	9232	1341	17168
Siana	3056	47348	4786	298	411	2491	255	3160	691	472	50	66	8315	5501	72113
Telek	13	7852	1283	435	5	338	24	215	25	137	7	14	3322	464	12852

E. Table of main free ranging herbivorous animal species found in the Mara ecosystem with their daily matter intake of grass in relation to their life body weight during dry season, adapted from the study in the Amboseli Biosphere by Toxopeus, (1999).

Species	*Life body weight (kg/animal)*	*% Grass in diet (%/animal)*	*DM Grass requirement (KgDM/day)*	*% Life Body Weight*
Cattle	205	100	3.1	1.5
Shoats	25	50	0.6	2.4
Donkey	140	100	3.5	2.5
Elephant	1725	20	8.3	0.5
Buffalo	420	100	8.5	2.0
Wildebeest	170	100	4.5	2.6
Zebra	210	100	5.2	2.5
Thomson	15	65	0.5	3.3
Grants	45	75	1.0	2.2
Kongoni	125	100	3.0	2.4
Impala	45	65	0.9	2.0
Eland	340	65	2.9	0.9
Oryx	140	100	3.5	2.5
Waterbuck	170	100	4.3	2.5
Warthog	45	50	0.7	1.6
Ostrich	115	100	2.8	2.4

F. MODIS NDVI values and Field Vegetation Cover Data used in the study

DATA ID NO.			MODIS NDVI DATA							VEGETATION COVER FIELD DATA							
Sample Unit	Latitude	Longitude	Raster Class	Median Class	Std Dev Class	Trend Class	Median Values	Std Dev Stack	Trend Stack Values	Trees Cover	High Shrub	Low Shrub	Herbs	Grass	Litter	Bare Soil	Stony
s-5	-1.5419	35.02022	25	11	2	4	129	18	0.040808	8	9.6	0	0	26.94	0	73.06	0
s-1	-1.21371	35.42031	18	10	3	4	121	23	-0.01138	0	0.9	3.31	0	30.13	0	66.56	0
s-2	-1.22537	35.52885	18	10	4	3	117	27	-0.03295	0	10.8	0	0	35.84	0	64.16	0
s-4	-1.21788	35.52038	18	10	5	3	118	30	-0.04564	0.8	4	1.37	0	27.34	0	71.29	0
s-16	-1.47478	35.36636	25	12	4	3	135	27	-0.04824	0	0	0	15	35	0	50	0
s-6	-1.43003	35.43518	25	11	3	3	123	25	-0.04261	0	0	0.89	0	40.1	0	59.01	0
s-8	-1.43188	35.4375	25	11	4	3	125	27	-0.04319	0	0	0.79	0	35.64	0	63.56	0
s-10	-1.19686	35.48584	25	11	5	3	129	31	-0.03359	0	17.15	0	0	70.56	0	29.44	0
s-11	-1.20322	35.48924	25	11	5	4	128	31	-0.01393	0	5	0	0	68.42	0	31.58	0
s-18	-1.18143	35.47245	25	12	5	3	131	30	-0.04613	1.7	13	0	0	80.82	0.47	18.71	0
s-19	-1.19881	35.44279	25	12	5	4	133	31	0.032036	8	10.4	1.65	0	47.11	0	51.24	0
s-7	-1.26173	35.50121	25	11	3	4	126	25	-0.02193	0	25	7.61	0	27.17	0	65.22	0
s-9	-1.24523	35.44118	25	11	4	4	127	28	0.009939	0	3	0	0	53.61	0	46.39	0
w-4	-1.26613	35.46271	25	11	4	4	129	28	-0.01452	0	3	0	0	58.76	0	41.24	0
s-17	-1.19332	35.22935	25	12	4	4	137	27	-0.00547	0.5	0	0	0	70	0	30	0
s-3	-1.14858	35.51028	25	11	4	3	124	28	-0.03711	0	0	2.17	0	97.83	0	0	0
w-6	-1.23312	35.25944	25	12	3	4	138	24	0.003439	0	0.5	0	0	85	0	15	0
s-13	-1.5388	35.02237	25	12	2	4	133	19	0.009701	16	17.2	0	3.6	17.4	79	0	0
s-21	-1.49287	35.38976	35	13	3	3	147	24	-0.05123	1	21.2	3.75	0	20.79	0	63.26	12.2
w-3	-1.66188	35.43172	39	14	4	3	157	27	-0.03345	2	15	4.76	0	57.14	0	38.1	0
w-5	-1.45688	35.38206	35	12	4	3	139	27	-0.04565	0	5	0	0	63.16	0	36.84	0
s-26	-1.41789	35.38566	35	13	5	4	149	30	-0.00432	1	5	0	0	58.82	0	41.18	0

DATA ID NO.			MODIS NDVI DATA							VEGETATION COVER FIELD DATA							
Sample Unit	Latitude	Longitude	Raster Class	Median Class	Std Dev Class	Trend Class	Median Values	Std Dev Stack	Trend Stack Values	Trees Cover	High Shrub	Low Shrub	Herbs	Grass	Litter	Bare Soil	Stony
s-14	-1.14869	35.25202	35	12	3	3	135	24	-0.03742	0	0.5	0	0	35	0	65	0
s-36	-1.19151	35.22122	35	13	4	4	146	28	-0.01079	1	2	0	8.33	25	0	66.67	0
s-22	-1.10073	35.20283	35	13	3	4	146	23	-0.00431	0.5	5	0	0	31.58	0	68.42	0
s-23	-1.39053	35.1902	35	13	4	3	145	27	-0.06228	0	0	0.45	0	40.72	0	58.82	0
s-25	-1.53819	35.50162	39	13	5	3	156	31	-0.0391	0.5	2	0	0	55	0	45	0
s-27	-1.60928	35.38409	35	14	2	4	161	20	-0.00424	0.5	24.75	0	0	20.69	6	69.97	3.33
s-28	-1.5596	35.45913	39	14	3	3	158	23	-0.04391	8.25	16.75	1.52	0	42.3	0	56.19	0
s-31	-1.16495	35.15278	39	14	4	4	157	28	-0.00566	0.5	0.5	0	0	64.36	0	34.65	0.99
s-29	-1.12163	35.3176	39	14	3	4	157	25	-0.00485	0.5	20	0	6.25	31.25	0	62.5	0
s-35	-1.11656	35.35324	39	15	2	4	162	21	0.002047	0	50	0	0	20.83	0	75	4.17
s-15	-1.45501	35.24857	48	12	3	4	159	25	-0.01338	0	0	0	0	49	0	51	0
s-32	-1.46018	35.08139	48	14	5	4	160	32	0.012299	0	0	0.5	0	59.7	34.83	4.98	0
s-33	-1.61613	35.20168	48	14	6	4	159	34	0.003166	0	0	3	0	57	35	5	0
s-38	-1.3034	34.97937	48	15	4	3	168	29	-0.02957	0	0.5	0	0	70.37	29.63	0	0
s-39-1	-1.33812	34.95015	48	15	4	4	169	29	-0.01285	0	0	0	0	67.86	28.57	3.57	0
s-39-2	-1.37009	34.89722	48	16	5	3	173	31	-0.03043	0	1	0	0	70.37	29.63	0	0
s-40	-1.30109	34.97836	48	15	5	3	168	30	-0.04145	0	0	0.52	0	94.24	5.24	0	0
s-41	-1.31997	34.9576	48	15	5	4	167	31	-0.01476	0	1	0	0	68.35	28.78	2.88	0
s-42	-1.61411	35.17738	48	15	6	4	162	35	0.006285	0	2	0	0	65.31	30.61	4.08	0
s-46	-1.3034	34.97937	48	15	4	3	168	29	-0.02957	0.5	0.5	0	2.13	67.38	28.37	2.13	0
s-47	-1.4359	34.88211	48	16	5	4	176	31	0.009456	0	2	0	0	96.94	0	3.06	0

DATA ID NO.			MODIS NDVI DATA							VEGETATION COVER FIELD DATA							
Sample Unit	Latitude	Longitude	Raster Class	Median Class	Std Dev Class	Trend Class	Median Values	Std Dev Stack	Trend Stack Values	Trees Cover	High Shrub	Low Shrub	Herbs	Grass	Litter	Bare Soil	Stony
s-51	-1.46685	34.96623	48	15	5	4	173	32	0.005451	0	0	0	0	67.39	28.99	3.62	0
s-52	-1.44961	34.96282	48	14	4	4	159	29	0.009489	0	0	0	0	73.4	0.6	26	0
w-2	-1.51985	35.16995	48	14	5	4	157	30	-0.00521	0	0	5	0	72	3	20	0
s-44	-1.1505	35.29169	52	16	3	4	176	25	0.033519	1	29.95	0	11.47	75.99	0	12.54	0
s-45	-1.1077	35.23672	39	15	4	4	165	29	0.005741	0.1	48.6	0	4.53	51.42	0	44.05	0
s-43	-1.0955	35.21561	52	16	2	4	175	18	-0.00849	0	32	0	2.86	22.86	0	74.29	0
s-50	-1.28341	35.03542	57	18	2	4	193	21	-0.02242	48.3	27	19.5	0	48	7.5	15	0
s-37	-1.72112	35.43244	52	15	3	4	170	22	0.007991	13.75	43.75	0	0	8.46	0.82	89.91	0.82
s-48	-1.70279	35.4487	57	17	3	4	192	25	0.000704	1	95	0	0	0.62	37.27	49.69	12.42
s-49	-1.70104	35.43771	52	17	4	4	185	26	-0.00794	1	80	0	0	0.58	58.48	35.09	5.85