PLANT SPECIES COMPOSITION MAPPING, BASED ON HYPER-TEMPORAL NDVI VARIABLES, IN THE MAASAI MARA ECOSYSTEM, KENYA

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February, 2015

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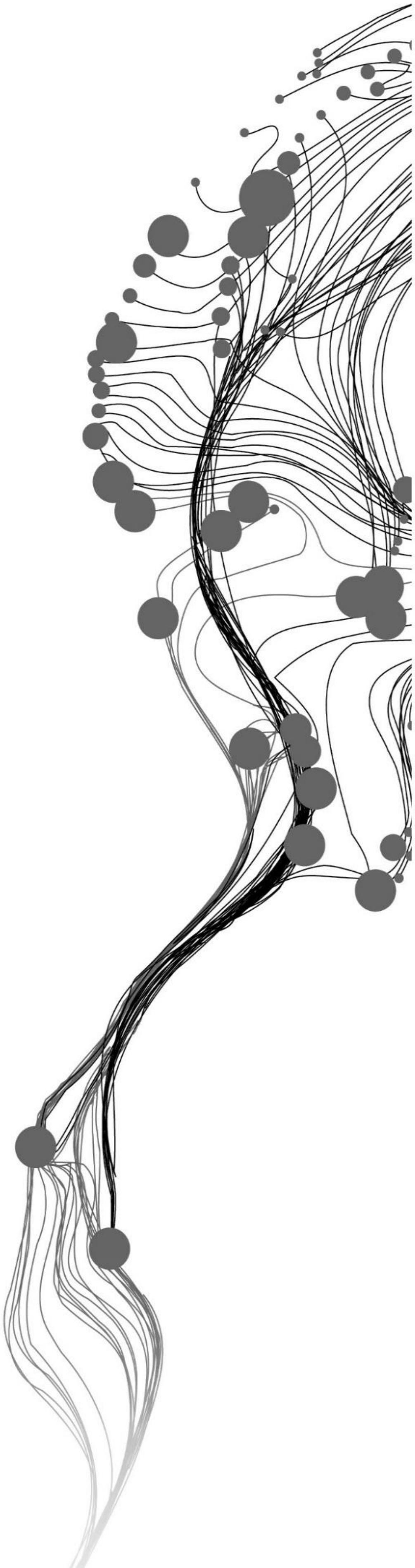

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Enschede, The Netherlands, MARCH, 2015

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requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Resources Management

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ABSTRACT

Classifying and mapping vegetation is an important technical task for natural resource managers, because vegetation provides a base for all living things, and plays an essential role in affecting global climate change, by influencing the amount of carbon sequestration. The main objective of this study was to map plant species composition, based on longterm hyper-temporal NDVI variables, in the Maasai Mara Ecosystem. The NDVI variables, which include Median, Trend, Standard deviation and 71 classes of MODIS, had the strength in that, they were able to filter the rainfall variability, that occurs in the Maasai Mara Ecosystem, from the east and west. Previous mapping efforts were not able to map vegetation clearly. A sample scheme was designed using the NDVI variables, in a stratified manner, which conforms to any scientific study. The floristics were clustered manually, based on percentage cover, using the Braun Blanquet approach, considering environmental variables, and the floristic types emerged. However, only soil texture had a clear relationship with the landcover types. Other environmental variables, soil pH and slope did not vary a lot in this ecosystem. Synoptic tables, which summarizes the classification table, were prepared. These floristic types, together with the NDVI variables produced a legend and a vegetation map. The legend was further enriched by adding the Shannon diversity index and Palatability, which is invaluable information to ecologists, especially for monitoring the ecosystem.

The outcome shows that it is possible to use combine floristic types, with NDVI variables. The NDVI variables, discriminated the clustered floristic types. However, in some cases, the median and SD were not able to distinguish these differences effectively. In most cases, the 71 classes had to be relied upon. Nevertheless, the output of the clustering corroborated with previous research in the Maasai Mara Ecosystem, based on different approaches. The trend, Median and Standard deviation and google maps, showed a pattern with the vegetation map output. The relationship between the legend and the vegetation map with the longterm NDVI variables was not tested in this study, and therefore, it is important for future studies to focus on that. Another important aspect, is the rangeland condition assessment, to assess which areas are degrading, and the information can also be added to the legend. This is crucial for the managers of Maasai Mara National Reserve, the surrounding group ranches, and the communal land, because using the freely available longterm NDVI, and they can design policies that will help manage this ecosystem sustainably.

Key words: Remote Sensing, NDVI statistics, NDVI variables, 71 classes, SD, Median, Trend, Floristics, Clustering, Vegetation types, Legend, Vegetation Map, Ecosystem

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ACRONYMS

MMNR	Maasai Mara National Reserve
SD	Standard Deviation
NDVI	Normalized Difference Vegetative Index
MaMaSe	Maasai Mara-Serengeti Initiative

1. INTRODUCTION

1.1. BACKGROUND

Tropical savannas are associated with the tropical wet and dry climate type. They form in regions where the climax community is either seasonal forest or woodland, but edaphic conditions or disturbances prevent the establishment of those species of trees associated with the climax community ("Tropical Savannas | Biomes of the World," n.d.). The East African acacia savannas and grassland complexes, are among the most distinctive in the world, and they support a large diversity of wildlife ("WWF - East African Acacia Savannas," n.d.). Land cover includes grazing land interspersed with cropland mosaic and woodland, all representing habitat for wild and domesticated herbivores. The populations are highly mobile, and frequent fights for resources are common (Homewood, 2004). They cover one fifth of the land surface, and nearly half of the African continent. Tropical rangelands were considered man-made ecosystems, because structure and dynamics were formed by cultures, especially livestock grazing, besides soils, rainfall and fires. However, in the last few decades, rangelands have been undergoing through serious degradation through soil, water, vegetation and biodiversity decline (Homewood, 2004, Hejcmanová *et al.* , 2010).

1.1.1. PLANT SPECIES COMPOSITION STUDIES

Classifying and mapping vegetation is an important technical task for natural resource managers, because vegetation provides a base for all living things, and plays an essential role in affecting global climate change, by influencing the amount of carbon sequestration. On the other hand, it provides important information, for understanding the natural and man-made environments through quantifying vegetation cover at different scales (Xie *et al.*, 2008). In rangelands, changes in grassland plant species composition affect higher trophic levels and herbivores in particular, through forage nutritive quality. Because plants vary in their tissue nutrient concentrations, differences in plant species composition are associated with variation in the availability of nutrients to herbivores in forage. Spatial variation in plant species composition alters the availability of nitrogen, phosphorus and sodium in forage. These nutrients are of particular interest because they are essential for sustaining pregnancy and lactation in female ungulates. Another important reason to study plant species composition in natural grazing ecosystems is that, plant assemblages differ in their ability to resist invasion of exotic species (Adler and Levine, 2007). On the other hand, temporal changes in grassland species composition in other grassland ecosystems have been linked to environmental factors, such as rainfall, and rainfall variability and disturbance factors, such as fire. Thus, environmental factors believed to contribute to temporal plant species change in grasslands generally fall into two broad categories: those related to resource inputs and disturbance (Anderson., 2008).
The recognition that communities are dynamic in terms of species composition and abundance over time is central to the view of most contemporary ecologists. But knowledge of the temporal scale on which communities change, and the factors that drive community dynamics, remain elusive for all but the best studied systems. Despite this fact, the success of conservation efforts depends on the ability of ecologists to understand and predict future changes in the composition and abundance of communities. Prominent examples include understanding non-native species invasion managing rare or endangered species, and mitigating threats of climate change. The Mara Ecosystem is home to massive numbers of ungulate herbivores, canine predators and a profusion of wildlife and vegetation diversity, and is one of the great

conservation successes on earth. At the base of this complex ecosystem, is water, grassland and woodland vegetation, on which natural ecosystem processes and foodweb dynamics depend on. Therefore, long-term studies of vegetation are requisite, to understand the natural dynamics of the ecosystems and to predict and mitigate future threats, such as those posed by exotic species introductions and global climate change (Anderson, 2008).

1.1.2. LOSS OF BIODIVERSITY

The Millennium Ecosystem Assessment identifies anthropogenic actions as the main cause of loss of biodiversity on earth. These actions are leading to a homogenous distribution of species, by making one set of species at one location, and another set in a different location, diminishing, on average. This trend is caused by species extinction, and high rates of species invasion, through introduction of species into new ranges. Currently, documented species invasion is greater that species extinction (Watson. et al., 2005). Invasion is threatening 12% of bird species, 23% of mammals, 32% of amphibians, and 50% of cycads. Biological diversity is of concern, because it contributes directly to the provision, regulation and cultural ecosystem services, and indirectly through supporting ecosystem services. These factors influence human wellbeing by providing basic materials for life, security, health, good social relations and freedom of choice and action (Watson. *et al.*, 2005).

Kenya's wide range of ecosystems, mainly hosted by protected areas, i.e. saline and freshwater lakes, moist forests, coral reefs and mangroves, semi-desert and dry savannah, are homes to about 35,000 species of flora and fauna. These support human wellbeing and promotes socio-economic growth (KWS, 2013).

1.1.3. JUSTIFICATION

According to Serneels *et al.* (2001), the Mara ecosystem has been subject to vegetation changes since the early 20th century. Explorers and hunters encountered an ecosystem characterized by broad, open expanses of grasslands. Over time, the ecosystem underwent through major stages of transformation due to interactions between four distinct changes i.e. vegetation, climate, tsetse and tick infestation, and pastoral occupation and management. In the 1890s, there was a great rinderpest epidemic and human and wildlife numbers were reduced considerably. This affected the grazing and patterns of displacement of the Maasai.

In the 1950s, grazing and settlements were concentrated away from the Mara plains. Due to low fire occurrences, and recurrent droughts, dense woodlands and thickets established. This formed a habitat for tsetse flies, and prevented human settlement. In the 1960s, the woodlands were converted to grasslands and human population, mainly Maasai increased. Fire was used frequently to clear tsetse infested bushes, and to improve grazing pastures. Wildlife numbers increased tremendously, moving outside of the protected areas. The land was held in trust for the Maasai community by the government. Since the 1970s, these trust lands have been converted to group ranches under local administration (Mundia and Murayama, 2009).

However, non-Maasai immigrants from other parts of Kenya, continue to relocate to the Mara region. Human population in the Mara region increased nearly 25-fold between 1957 and 2002, while pastoral settlements (bomas) increased almost 23-fold over the same period. Traditional pastoralism remains the economic mainstay of the Maasai, who share their pastoral lands with livestock and wildlife. There are no barriers to wildlife movements between the pastoral ranches and the adjacent Maasai Mara National Reserve, the northern-most section of the vast Serengeti–Mara ecosystem. (Ogutu, *et al.*, 2010).

As a result, wildlife calving grounds have been ploughed for commercial wheat cultivation, and grazing areas for wildlife and livestock have become fragmented and lost, in parts of the pastoral ranches in the Mara region. Furthermore, the ongoing intensification of land use, overgrazing, sedenterization of the Maasai, privatization of land tenure, diversification of livelihood options and fencing in the pastoral areas, are further reducing grazing areas available for herbivores, intensifying competition between wildlife and livestock for forage resources, and exacerbating habitat fragmentation and degradation. These changes, along with repeated droughts, flood, declining woodland cover, expansion of commercial wheat farming and poaching of wildlife, jointly contributed to 70% decline in wildlife numbers in the Mara region, between 1977 and 1997. The resulting disturbance has also promoted proliferation of invasive species in this area too (Ogutu *et al.*, 2010).

Continued degradation may lead to a decline in quality and quantity of forage, that might result into negative consequences for grazers and browsers, especially affecting inter specific competition between large herbivores. Large herbivores require large areas to forage. The movement and foraging may be important in generating soil disturbances, or seed dispersal, that may also impact other plant communities. Both increase and decrease in abundance of large herbivores can change plant communities and lead to plant invasions. Overgrazing also affects the species composition and abundance (Ogutu *et al.*, 2010).

1.2. RESEARCH OBJECTIVE

The purpose of this research is to study the differences in plant species composition based on hyper-temporal NDVI variables, in the Maasai Mara ecosystem.

1.2.1. Specific Objective

1. To prepare floristics types, legend and a vegetation map, using longterm NDVI variables, environmental variables, and site based collected dataset, that differentiates landcover types in Maasai Mara Ecosystem

1.2.2. Research Question

1. Can longterm NDVI variables, environmental variables and floristic types, produce a legend and a vegetation map? The variables include Longterm NDVI statistics (SD, Median and Trend), 71 classes NDVI, soil texture, soil pH, topography and vegetation cover characteristics, palatability and the Shannon Weiner diversity index

2. LITERATURE REVIEW

2.1. REMOTE SENSING AND GIS IN RANGELAND VEGETATION MONITORING

An important issue in terrestrial vegetation study is to identify the distribution patterns of floristic composition of a given site, and to determine the factors controlling the distribution and diversity of species. Ecologists have long realized, that using field or plot data to assess the spatial-temporal changes in species composition is difficult, particularly when the scale is at regional or global levels (Huang and Asner, 2009). Traditional methods for mapping floristics from ground based surveys involve intensive, data lagged, costly, repetitive and time-consuming exercise (Schmidt and Skidmore, 2001).

To address this problem, Geographic Information Systems (GIS) and Remote Sensing (RS), can be used as tools to monitor rangelands. These are well established tools for mapping vegetation across large areas over time. Remote sensing is increasingly being used for these studies for detection and mapping plant species, especially those with distinct phenological and morphological features (Evangelista, *et. al* , 2009, Huang and Asner, 2009, Ustin *et. al* 2003, Hamada et.al, 2007, Müllerová *et al.*, 2013, Everitt *et. al* 2007, Bradly and Mustard, 2006 and Pettorelli *et. al*, 2005). Spatial patterns are observed visually (Huang and Asner, 2009).Other studies have used Hyperspectral remote sensing and advanced statistics.

Remote sensing has facilitated these studies, due to the availability of sensors, with moderate to fine spatial resolution, which allows ecologists to investigate ecosystem dynamics and monitor changes in species diversity, based on spectral reflectance of vegetation (He *et al.*, 2009). Mapping species richness and distributions is an important aspect of conservation and land use planning. For example, maps can help identify areas of special biodiversity importance where conservation resources should be focused. Such areas include 'hot spots' of high species richness, as well as places where species assemblages of particular interest occur. As the current rate of species extinction causes increasing concern, land managers and biologists have sought to identify habitats important to the preservation of species diversity (Oindo *et. al.* , 2003).

Hyperspectral imaging, is heavily used in studying plant species (Lucas, *et al.* , 2004, Asner and Vitousek, 2005, Tsai *et. al*, 2007, Glenn *et. al*, 2005, Mutanga *et al.*, 2004, Andrew and Ustin, 2009, He *et al.*, 2011, Rocchini, 2013, Bradley, 2013). The main advantage of Hyperspectral imaging is that, spectral profiles can be developed for vegetation, by analyzing the spectral regions that are sensitive to the variation of the species (Huang and Asner, 2009). However, there are disadvantages too for using this approach. First, it is hard to discriminate the signatures of most herbaceous plants. Secondly, they need complicated algorithms, skills labour for interpretation, which are costly. Most people cannot afford them due to cost and data volume, small footprint, and uncertainty due to similarities in signatures, hence they are not feasible (Huang and Asner, 2009).

Medium resolution remote sensing, have also been used successfully in few plant studies, using Landsat TM and ETM+ images (Evangelista *et. al*, 2009). However, some characteristics e.g. species invasion, requires data collected from sensors that push one type of resolution, to be able to discriminate profiles. It is only useful is the stands are large (Huang and Asner, 2009).

LiDAR and Image fusion has also been used for invasions, when combined with high spatial resolution imagery. Walsh *et. al*, (2008), successfully combined Hyperion and Quickbird image to map common guava in Galapagos. However, LiDAR alone cannot detect individual species, since it is not easy to discriminate canopies.

2.1.1. Longterm Remote Sensors for Vegetation Monitoring

Elaborate and successful study of vegetation can be done by use of high time series data (hypertemporal), available for free. A key advantage of time series analysis, is the historical availability of data (i.e. decadal), large spatial footprint, daily acquisition and cloud free, therefore, highly suitable for monitoring purposes, e.g. Moderate-resolution Imaging Spectroradiometer (MODIS), (NASA n.d, 2014).

The most common used indices is the Normalized Difference Vegetative Index (NDVI), to study the relationships between productivity, biodiversity and habitat heterogeneity (He *et al.*, 2009). The relationship between NDVI and vegetation productivity is well established. Long-term NDVI datasets are available at different spatial-temporal resolutions. The MODIS terra has better quality of 250-1000m spatial resolution, and a temporal resolution of 16 days, since 2000. It contains the most reliable and readily available data for the whole world. These datasets are MODI13A2, MODI13A1, MODI13Q1, at 1km, 500 m and 250 m respectively.

Other longterm NDVI sensors are available. The National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR), with a spatial resolution of 8-16km and is available daily. NDVI data for NOAA-AVHRR has been available consistently since 1982, and from 1989 to present at 1km resolution for the United States. Although it has a good temporal resolution, the coarseness limits its use at local scale. Satellite Pour l'Observation de la Terre Végétation (SPOT-VGT) has a resolution of upto a few meters and available daily (Pettorelli, N. et al., 2005).

NDVI is a ratio between red and near-infrared reflectance ratio captured by satellite sensors [NDVI= (NIR-RED)/ (NIR+RED)]. The NIR and RED are amounts of near-infrared and red light, reflected by vegetation and captured by the satellites, and used for photosynthesis. Visible light range is between 0.4-0.7µm. In the leaves, the chlorophyll is excited by this visible light between 0.62-0.69µm, within the red edge. This light is absorbed and triggers electrons transmission in chloroplasts, which store energy in the cells. On the other hand, light ranging from 0.7-1.1 µm, found in the Near Infrared (NIR) region, is reflected by the leaves (De Bie and Skidmore, 2010). NDVI correlates directly with vegetation productivity, and provides information about the spatial-temporal distribution of vegetation communities (Pettorelli, N. et al., 2005). Previous successful studies prove this (Huang and Asner, 2009, Justice *et. al*, 1985, Bradley and Mustard, 2005).

He *et al.*,(2009), linked variability in species composition and MODIS NDVI based on beta diversity measurements, and found a significant positive correlation between species composition dissimilarity matrices and NDVI distance matrices. Bradley and Mustard (2005), successfully studied the phenology of a grass species, cheatgrass, *Bromus tectorum*, to locate infested areas. Huang and Asner (2009), investigated *Eragrostis Lehmanniana* grass, using MODIS NDVI and brightness (red and near infrared bands), field observations and statistical models, to characterize its phenological differences in invaded areas across landscapes.

The main limitation with hypertemporal imagery is that, it gets saturated when vegetation exceeds a certain threshold , and captures all components which are untargeted, like surface soils and senescence vegetation, thus limits species monitoring (Fang *et al.*, 2012).Clouds and snow contaminate the images, requiring use of an algorithm, to filter the noise. Moreover, when using hyper-temporal images, ground survey of the units to determine floristic compositions is essential (Huang and Asner, 2009).

2.2. Research Problem

The Mara ecosystem is shared by Kenya and Tanzania. It has been a source of many aspects of socio-economic development and environmental sustainability. It is both a key component of future growth and a limitation. People, cattle, and wildlife, have depended on it for long. However, decades of encroachment, deforestation and poor agricultural practices have diminished recycling, promoted rapid runoff of rainwater, and polluted rivers with eroded topsoil. Downstream users have experienced changes, as dwindling rivers in dry seasons, more extreme floods in wet seasons, death of cattle and wildlife, and sickness among people, continues to haunt them.

Changing land practices in rangelands of lower part of the ecosystem, is affecting water security, as overgrazing and inappropriate agriculture, have led to increased runoff of valuable rainwater, degrading water quality. The region's extraordinary biodiversity is suffering as well. Historically, wildlife coped with water scarcity by migrating, animals covered hundreds of kilometres in search of water in rivers and green pasture. However, unsustainable encroachment of agriculture into migration pathways and fencing of once open savannah, has closed dispersal routes, and blocked animals from the water they require.

Combined, these factors have set the Mara on a path of decline that is advancing faster every year as population, associated pollution and demands for land, water, and livelihoods increase. There will be catastrophic consequences for the Maasai-Serengeti ecosystem, the wildebeest migration, and the lucrative tourism industry. Likewise, if inefficient and poorly regulated uses of water for agriculture and other forms of development continue, there will be severe consequences for people in the form of degraded livelihoods, food insecurity, proliferation of disease, and likely forced migration (UNESCO-IHE, 2014).

The spatial distribution of this ecosystem's vegetation types, is key to understanding animal behaviour (Reed *et al.*, 2009). Most studies conducted in the Mara, have been on vegetation biomass estimation (Schmidt and Skidmore, 2001, Mutanga and Rugege, 2006), habitat types (Oindo *et. al*, 2003), species richness (Boniface *et. al*, 2000), and spatial distribution of vegetation types (Reed et al., 2009). However, no vegetation study has been done, using longterm remote sensing data. This is crucial to enhance monitoring efforts by all stakeholders. Moreover, this ecosystem experiences high localized variability in rainfall patterns, and no study has been done, to monitor spatial temporal vegetation trends, taking into account this factor. This study proposes use of using hypertemporal remote sensing (MODIS) for 14 years, (2000-2014), to study species composition based on hypertemporal NDVI variables, in the Maasai Mara Ecosystem.

3. RESEARCH DESIGN AND METHOD

3.1. Study Area

3.1.1. Geographic context

The Maasai Mara Ecosystem lies in the southwestern Kenya and comprises of approximately 7000 square kilometres. Less than 10% represents the Maasai Mara National Reserve (MMNR). It is surrounded by privately owned group ranches, while the rest is an unprotected area, inhabited by the Maasai agro-pastoral community. The main land use is pastoralism and agriculture (Mundia and Murayama, 2009). It is bounded by the international boundary of Kenya and Tanzania in the south, Transmara plateau to west, and separated from MMNR by Siria escarpment to the west. Mau uplands border the ecosystem in the north. The triangular shaped plateau can be divided into three range units, based on biogeographic and climate difference. The Mara eco-unit consisting mainly of the grasslands in the western part, and comprises of the MMNR, Loita plains to the north-eastern part, covered by dwarf shrubs and whistling thorn grasslands, and Siana to the east, in an area dominated by hills and plains, and dominated by the croton supports a mixture of gallery forests and woodlands with scattered bushes, *Themeda* grasslands, dwarf shrubs of *Acacia drepanolobium* and plains supporting *Croton dichogamus* bushland and other woody species (Serneels *et al.*, 2001).

3.1.2. Climate

The rainfall is mainly influenced by the Inter Tropical Convergence zone ITCZ) but local variations in topography, orographic and diurnal effects plays a major role in the rainfall patterns of the study area. The main rain shadow of the area comprises the Loita and Siana plains. The mean annual rainfall is 400mm. There is a rainfall gradient from the dry south-eastern plains (500 mm/yr), to the wet northern western part with approximately (1200mm/yr). In Loita and Siria escarpments, rainfall increases with altitude. The rainfall pattern is bimodal. Long rains occur in March to May and short rains from late October-December. June to mid-October marks the dry season, and sometimes a mild wet period in January-February. Sometimes, the short rains do not occur at all (Serneels et al., 2001).

3.1.3. Topography

The dominant topographical features are Siria escarpment to the west, at an altitude of 2000-3000 m a.s.l, which is as result of fault in the basement system. The relief of south-western, Loita, Mara and Siria plains are dominated by flat plains at an average altitude of 1900m a.s.l. The plains undulate as you move towards the north, with inselbergs of 2000m a.s.l rising in the plains. The Loita plains and hills are the dominant to the north and north east at an average altitude of 2700m a.s.l. The Siana hills and plains dominate the south east (Serneels et al., 2001).

3.1.4. Geology and Soils

The soils are generally shallow, sandy and rocky. Volcanic deposits dominate Loita plains. Brown clay soils, seasonally waterlogged, but better drained than true clays; dominate the south especially in the MMNR. The central plains consist of weak alkaline volcanic phonolitic tuff, derived from tertiary-recent volcanic activity in the Mau ridge to the north east. Brown calcareous loams occur mainly in the Loita plains. Dark red friable clays occur in the south eastern parts. Riverbeds have deposits of sand, gravel and silt (Serneels et al., 2001).

3.1.5. Drainage

All the watercourses join the Mara river, which drains into Lake Victoria to the west. The Mara originates from the Mau and Kipsigis ranges, which feed it before it flows south westwards, to the base of Siria escarpment, then south through the reserve, before discharging into the lake. Talek is the longest tributary of the Mara river. It drains the Siana hills and western Loita plains throught two tributaries (Kaimurunya and Ol Sabukaiai). The tributaries are seasonal, but Mara and Talek are perennial. Loita plains are drained by Uaso Ngiro river which ends in swamps around Lake Natron. Sandy river flows at the Kenya-Tanzanian border and joins the Mara at the bridge. Water availability is a major determining factor of the seasonal distribution of wildlife and livestock in this ecosystem (Serneels et al., 2001).

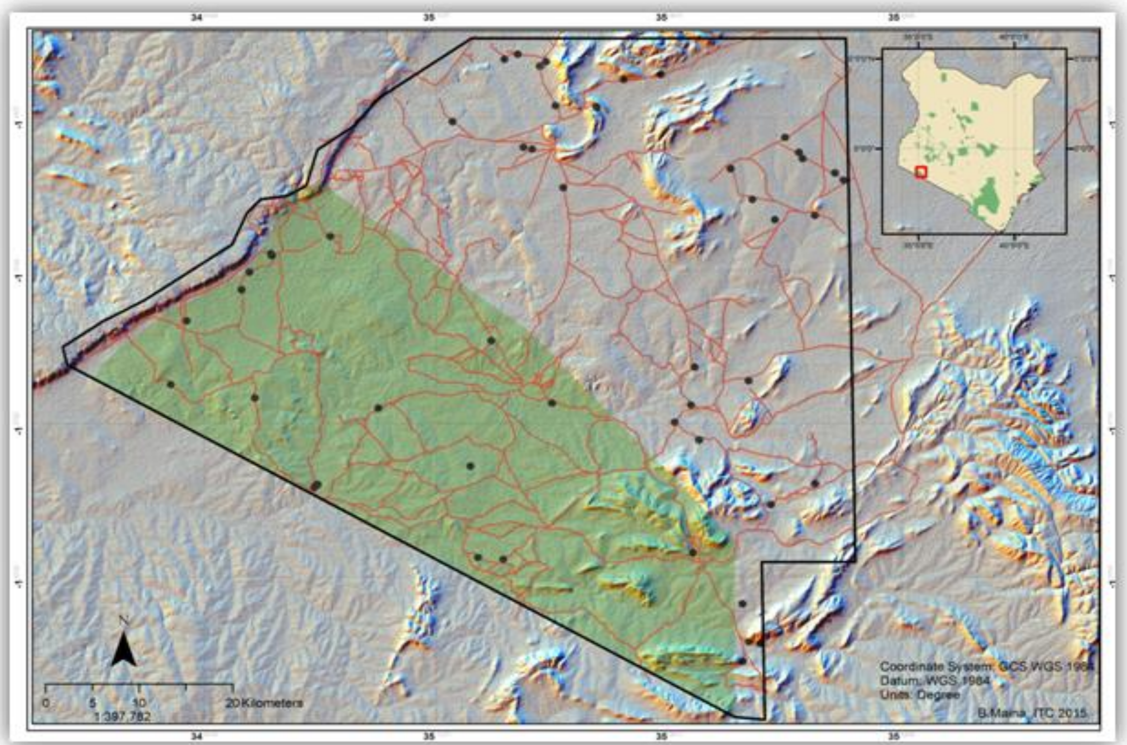


Fig. 1 Map of the study area and location (inset) showing the roads (red), sampled points (black) and the MMNR in light green colour

3.2. DATASET AND METHOD

The research design or method is divided into 4 stages i.e. data needs, data preparation, data collection and data analysis.

a) Datasets: These are Google Earth imagery (1m), Longterm NDVI variables (standard deviation, median and trend maps), 71 classes NDVI image, digitized roads, bomas and agricultural fields

b) Field equipment: Infrastructure maps, soil pH kit, IPAQ for loading maps, Garmin GPS for sample points collection, notebooks and pens, battery pack, field soil chart, plant press

c) Software and tools: ArcGIS 10.2 for digitizing and map production, Erdas Imagine for image processing, MODIS NVDVI stacking and generation of stack statistics, Mendeley for referencing and Ms Office

Data	Type Of Data	Spatial Resolution (m)	Temporal Resolution	Format	Availability	Software
Google earth	*Spatial*	*1X1*	*Monthly*	*.img*	*High*	*ArcGIS 10.2*
MODIS-TERRA	*Spatial*	*250x250*	*Weekly*	*.img*	*High*	*Erdas 2013*
Roads	*Spatial*	*1x1*	*Yearly*	*Shapefile*	*High*	*ArcGIS 10.2*
Agric. fields	*Spatial*	*1x1*	*Yearly*	*Shapefile*	*High*	*ArcGIS10.2*
Palatability	*Non-spatial*	-	*Yearly*	*Text*	*High*	*Ms Office*

Table 1: Summary table showing nature of data required for the study, and their formats

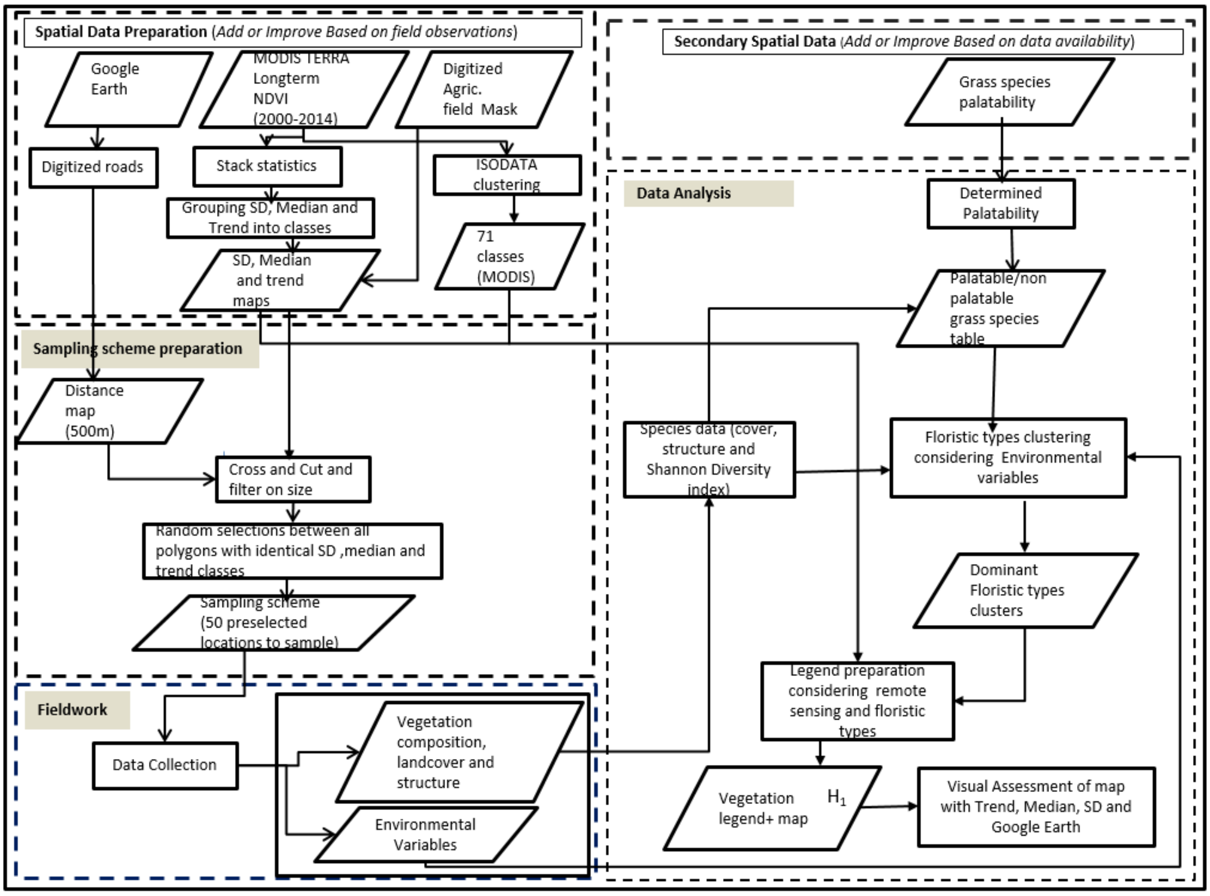


Fig 2: Flowchart of the study

3.2.1. DATA PREPARATION AND SAMPLE SITE SELECTION

Image pre-processing: Before embarking on the fieldwork, all the required data was processed by MaMaSe project team. This included downloading, stacking and classifying MODIS images in Erdas Imagine 2013 software ("Intergraph Corporation," n.d.), for the period beginning January 2000-September 2014. This multidimensional NDVI profile in time, contains a wealth of information, but the question is how to extract it. When classified, it produces a 2-dimensional map, having classes described by temporal NDVI-profiles, that bring out exactly where (spatial) and when (temporal) the major part of the variability in the NDVI for the area and time-span studied (De Bie *et al.*, 2008). A total of 317 images were downloaded from REVERB ECHO ("Reverb ECHO," n.d.).

The stack of images image was declouded by pixel and the outliers were removed. De Bie *et al.* (2008) states that "Declouding is done by image and by pixels, which have "good" radiometric quality for bands 2 and 3 i.e. quality for bands 2 (red; 0.61-0.68 µm) and 3 (near IR; 0.78-0.89 µm), and not having 'shadow', 'cloud' or 'uncertain', but 'clear' as general quality. A modified Adaptive Savitzky Golay Filter (MASAVGOL) upper envelope filter, was used (De Bie *et al*, 2008). An example of profile, showing how the filter works, is as shown in the figure below.

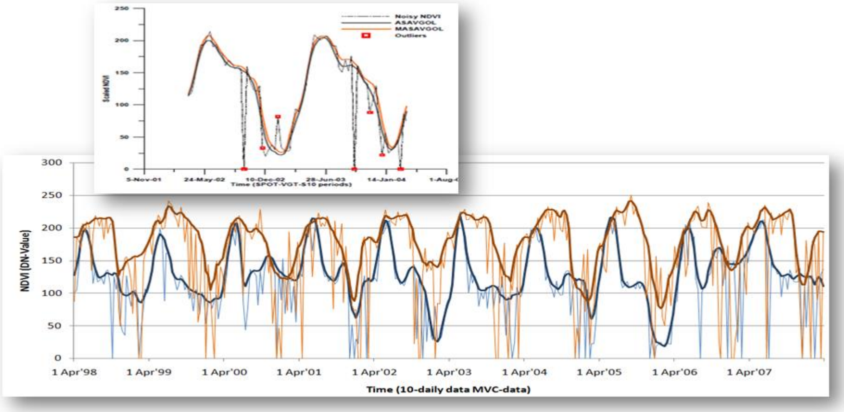


Fig.3 Upper envelope noise reduction in MODIS image using MASAVGOL and ASAVGOL

The stack was classified by MaMaSe project, using unsupervised classification using Iterative Self Organizing Data Analysis Technique (ISODATA) clustering algorithm (De Bie *et al.* 2012). He states that, "Unsupervised means that no expert guidance was applied or additional data used to classify". The maximum numbers of iterations, were, set to 50, and the convergence threshold to 1.0. One run performed an entire classification, and was self-organizing, regarding how it located clusters, that are inherent in the data. This algorithm uses minimum spectral distance formula to form clusters. A total of 10-100 map clusters were used, and a batch file was prepared to make them to run efficiently. The divergence separability statistics derived for each output, were retrieved in Microsoft excel, and plotted on a graph to visualize and determine the minimum classes needed. Average divergence, denotes the mean similarity between the temporal signatures amongst all possible pairwise combinations of output clusters, while minimum divergence values show similarity between the temporal signatures of the two most similar signatures. Ali *et al*., (2014) states that, "The idea, is to have the predefined classes and either keep the classes low to gain maximum data reduction or to optimize separability within classes, without information loss". 71 classes were selected based on the peak in both the minimum and average separability.

However, in the Mara ecosystem, there is a lot of local rainfall variability, due to local variations in topography, orographic and diurnal effects, and this has been a major problem, in making vegetation maps for years. The resulting effect is that, time of the year is important to what is seen, because, the greenness of the vegetation seen could be a reaction to rainfall, rather than real vegetation greenness. To counter this, these effects were eliminated by further generating MODIS products by the MaMaSe team that have factored in this variability.

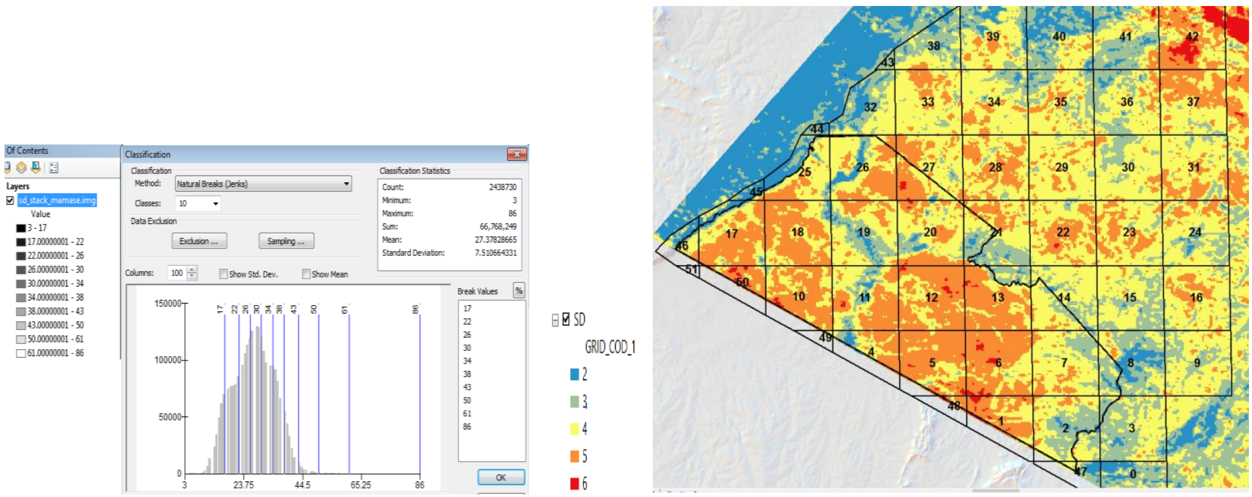
Digitizing and masking features: Roads, agricultural fields, bomas and drainage patterns were digitized from Google Earth. MODIS generated images i.e. Standard Deviation (SD), trend and median maps, were crossed with digitized agricultural fields mask, as well as a road distance of 500m, to produce a sample scheme. A study area boundary was also digitized, based on existing topographic maps and Google Earth imagery. This boundary was used to clip images too. Field collection data sheets were prepared. Maps of the polygons overlayed on Google Earth image were printed for use in the field, to help visualize the spatial vegetation heterogeneity for each site visited, and to guide whether to survey the area as a complex, or a single component/unit.

Sample scheme: The SD, median and trend were crossed, and random selection between all adjacent pixels with the same values for each layer, was done. These 3 layers together capture long-term spatial-temporal variability without much influence by local and short-duration rainfall impacts, on vegetation. Potentially, these were 5*9*2, resulting to approximately 80 sample clusters. The number of polygons were was 1100. Clusters representing woody vegetation were not to be sampled, thus they were removed. A total of 50 preselected locations, with identical SD, trend and median classes to sample were randomly identified. Selection was limited to only polygons that were at least 20 ha. This provided a strata or field classes. To select a fieldwork site, agricultural fields and roads played a role. Digitized agricultural fields were used as a mask, to avoid picking polygons within them. A distance map from digitized roads, was used to make a distance map. A distance of 500m from road had been selected, and the polygons which intersected with this distance, were considered. Classes of NDVI-SD (codes 2-6), Median-NDVI (codes 10-18), and NDVI-trend [yes/no; codes 3 and 4], were used. The figures below illustrate the range of the different classes. Figures 5, 6 and 7 show the products of longterm NDVI statistics, and the histograms of various classes that were selected for the sake of this fieldwork.

SD values of NDVI time series (Digital Number-Values)

The SD (based on the median), is a measure of dispersion, shows variation that is within the values, from the mean, and therefore it is the square root of the variance of the means. For the MODIS image stack, ERDAS imagine software was used to calculate the SD using the stack statistics. A model builder was used to input the stack image, and an SD stack statistics algorithm was selected. The output was a map with classes. The map was classified in ArcGIS 10.2, using the Natural breaks (Jenks method), and 10 classes were selected. According to (Smith, *et. al.* , 2007), "Natural breaks is a method of manual classification that seeks to partition data into classes, based on natural groups in the data distribution. The breaks occur at the histogram, and maximizes the between class differences. The number of breaks is normally an odd value, since even numbers do not have central values. However, the numbers of classes are limited to 9, to avoid the gradations to be too fine to distinguish differences." Therefore a maximum of 10 classes were selected for this purpose

In this case, class 1 and 2 related to woody vegetation, 3 degraded pastures and rangeland, class 4 and 5 good to very good rangeland/ pastures, and classes 6, 7 and 8 mostly to agricultural land. However, classes 3, 4 and 5 were the most relevant for this study, since the focus was on rangelands. The figures below show the captions from ArcGIS for the classification.



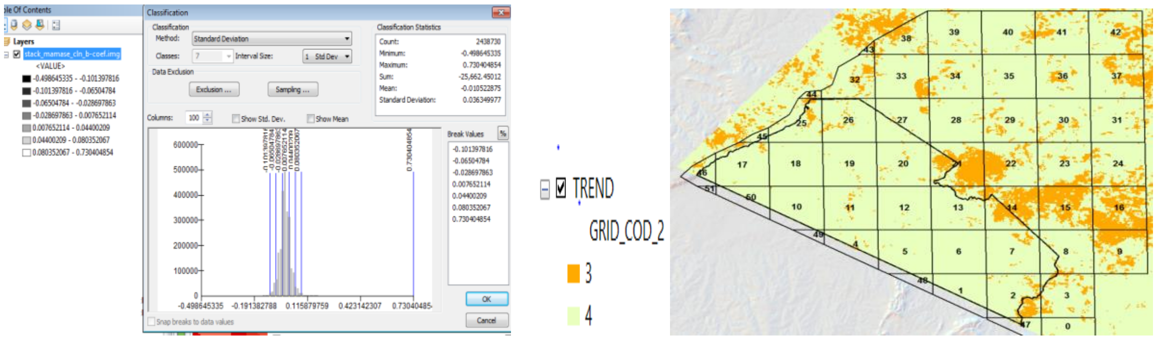
Most relevant SD classes: 3, 4, 5 and their assumed cover

- class 1+2 relates to woody vegetation
- class 3 to degraded rangeland / pasture
- class 4 and 5 good to very good rangeland / pasture
- class 6+7+8 mostly to agric. fields

Fig 4. SD values of NDVI time series (Digital Number-Values)

Trend Values of NDVI time series (Applied to Digital Number Values)

The trend map was generated using simple linear regression on a pixel by pixel basis by MaMaSe project. The trend shows areas that have been stable or have been declining in the last 14 years. It is useful to monitor the condition of the rangelands and where possible improve the management, to reverse the trend. It is especially helpful because despite high rainfall, most of the vegetation has been declining.



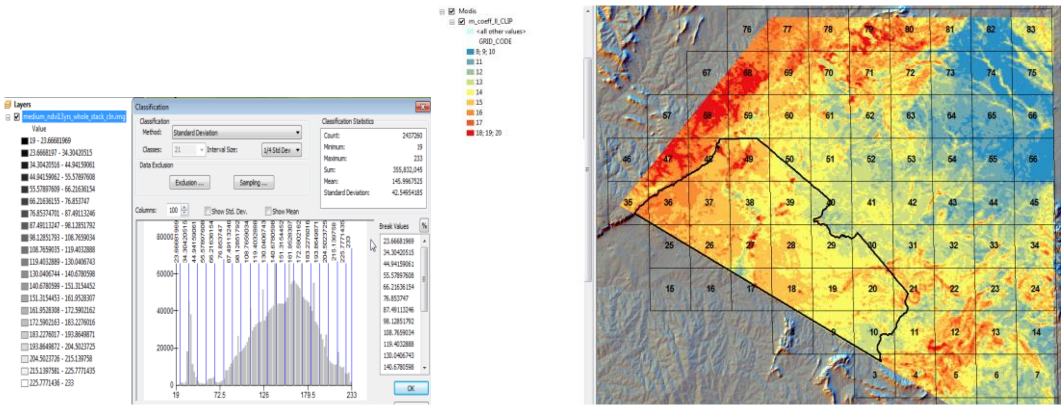
Most relevant class: 4 (or higher), but if degradation is very relevant, also class 3 (or lower)

- classes 1+2 (and 3) relate to degrading rangeland / pasture and/or (conversion to) agric. land
- classes 4 or higher refers to relatively stable rangeland / pasture / agric. land

Fig 5. Trend Values of NDVI time series (Applied to Digital Number Values)

Median values of NDVI time series (Digital Number Values)

In statistics, the median, as a measure of central tendency, is normally preferred to the mean, when the data has the likelihood of being skewed and thus the means are likely to be skewed to one side. In this case, the median is preferred, because it includes all values in the dataset, and excludes the effects of outliers. The Maasai Mara ecosystem experiences alot of rainfall variability and use of the median NDVI values and classes excludes this variation. Using the stack statistics in Erdas imagine software, an algorithm for median statistics was used together with the stack image using a model builder to produce the median map. In ArcGIS 10.2, standard deviation option was used for classification, and a total of 21classes interval was selected. According to (Smith *et al.*, 2007), "standard deviation, calculates the mean and SD from the mean, and the values are calculated from the deviation from the mean. However, unlike the calculation SD of the SD map previously discussed, the median does not have central classes, only classes from either side of the mean". From the 21 classes, only those that were relevant for this study were selected. Classes below 11



were left out because they relate to agricultural land, and values higher than 18 related to mixes of trees, woody vegetation or perennial crops. The figures below show the captions from ArcGIS 10.2 for the classification.

Most relevant median classes: range from class 12 to 17

- class 11 (or lower) relates to agric. land
- class 18 (or higher) relates to mixes of trees / woody vegetation / perennial crops

Fig 6. Median values of NDVI time series (Digital Number Values)

3.3. FIELDWORK SAMPLING AND RECORDING OF ENVIRONMENTAL VARIABLES

Field data was collected using a stratified random clustered sampling scheme. Data collection took place from October through early November 2014. All maps (in ECW format) and shapefiles were uploaded in an IPAQ, and were useful in locating the selected polygons on site. This means that there was 4-dimensional approach, from MODIS, and each data was useful in its own unique way. The SD was used in the field to look for differences in the polygons that a naked eye could not see. Based on the sample scheme that was prepared, physiognomy (form and morphological structure of vegetation) within each polygon was recorded. Species composition and cover percentage for trees and high shrubs, grasses and herbs, for each landcover type that contributed to the complex of cover types within each polygon was recorded. However, only one polygon per stratum was used.

Vegetation Survey: The mosaic parts and the complexes were sampled. Within the complexes, two samples were collected. Data was recorded on data sheets

1. Global Positioning Systems coordinates:, and GPS co-ordinates were marked using Garmin 62cx™ GPS (Garmin,n.d.), for each sampled site.
2. Digital Photography: Photographs of all the sites were taken using a digital camera and geotagged. A unique code for each sample plot was used.
3. Cover percentage and height of the vegetation layers: Vegetation observations involved estimation of tree cover, shrubs, herbs and grass layers. This cover was observed vertically. Each species was identified on the spot by an experienced botanist. Species that could not be identified in the field were pressed and identified in the National Museums of Kenya herbarium. Heights for all species was recorded, and growing season (annual or perennial) for grasses

a) Tree layer: Trees were classified as rising above 5 meters
b) High shrub layer: high shrubs less than 5m-1.5m
c) Lower shrubs: 1m-below
d) Grasses and herbs: 50 cm and below

4. Ground cover observations: included percentage cover of bare, litter, stones, and termite mounds. Presence/absence records for invasive species present in the sample plots e.g. *Solanum* were also recorded.
5. Soil pH: on the spot (at a core depth of 10cm then 30cm)
6. Soil colour and texture
7. Topography: was recorded subjectively as flat, almost flat, rolling, undulating, steep, and footslope.
8. Altitude

3.3.1. DATA CLEANING

After the fieldwork, point data collected was downloaded and merged with datasheet information, into a database. Data was checked for errors, and all the necessary data cleaning was done. Weighted averaging was done for all the samples, to ensure that they added up to a 100%. This was to harmonize all the information for each pixel, in the complex sample sites, and for the single unit/component, since satellite information was considered for clustering, at the MODIS pixel level of 250m. A pixel is a reflection of what is there, and therefore represents the mapping unit. Therefore, sample data from the complexes were aggregated into one sample. Coding was done for topography, ranging from 1 (flat) to 6 (footslope). Soil texture was also coded as 1 for black clay, 2 loamy clay and 3 for sandy loam. Soils colour was also coded as BC for black clays, LC for loamy clay and SL for sandy loam respectively. This coding made the analysis of data more convenient.

3.4. VEGETATION CLUSTERING USING BRAUN BLANQUET APPROACH

Manual vegetation clustering was carried out using the Braun Blanquet approach, where in a matrix, samples with similar species composition, and species with a similar distribution over the samples are grouped into types (Dombois & Ellenberg,1974). According to Dombois and Ellenberg (1974), the Braun Blanquet floristic association system, "consists of preparing species lists in samples, and processing them into synthesis tables. Species common to several samples are identified and emphasized. According to Legendre and Legendre, (1998), "*Clustering is an operation of multidimensional analysis, which consists in partitioning the collection of descriptors in the study*". This results to single, hierarchical clusters depending on the model selected. Floristic types are composed of species which have a similar relationship to environmental variables. The species unique to each releves are not ignored, but they are not given the same values as the species that recur together in a number of releves. These common species are the key identification units". Later, floristic information was considered at pixel level. Pixel level means, the sample sites that had components were merged to represent the MODIS pixel of 250m.

3.4.1. THE CLUSTERING PROCESS

During clustering, species and environmental variables data was organized in a way that it was able to rearrange the species in the rows and columns, without interfering with any information. A constancy count was conducted, both for sample and the species, in columns and rows respectively. Any species with a constancy value of less than two was left out during clustering, because it was considered too low to give any judgement. A boundary of those species that were not considered for clustering due to low cover, in this case were separated using a bold grey line in this case. Indicator species for each group that form discrete classification groups were identified, together with their subgroups, which occur together. The objective was to find patterns and relate them to environmental variables and later to remote sensing NDVI values. Synoptic tables were later made for the types.

Dominant species with high cover were identified and grouped in ordinate partial table, by repeated tabular rearrangements, and personal judgement. During clustering, shifting of cells was done in such a way that information for each class was left intact, when re-arrangement was being done. Cut and insert copied cells, were the options used when shifting the rows and columns, to the desired positions. Through this, orderly comparison, the most qualitative differences within types emerged. During this process, it is crucial to have some background ecological knowledge on the species, because species that coexist together are clustered together and therefore, this association helps to group such species together. The result of the vegetation classification is the classification table and synoptic tables (See appendix 1).

3.5. FINAL CLASSIFICATION TABLE FOR ALL VEGETATION TYPES

Classification tables that were made for forest, trees and shrubs, grasses and herbs and bare, were harmonized into one complete classification table. All the information was harmonized first to ensure that all columns and rows matched in all synoptic before combining them. To do this, they were compiled in one datasheet, and their rows and columns cross checked, and any missing samples. Missing information or errors were cross-checked using photography and the original database. Since the same order of rows and columns had been maintained, it was easy to cross check one matrix against the other. Palatability information was added, as well as Shannon diversity index (See appendix).

3.5.1. SYNOPTIC TABLES FOR GRASSLAND COVER TYPES:

These are a summary of the results of the classification of the dataset. They give an overview of the classified vegetation units or samples. Synoptic tables gives the most important characteristics for land cover types, because they summarize the different landcover types in a way that can be interpreted easily (Dombois & Ellenberg, 1974). However, the number of columns for each type was reduced to a minimum, so as to make the table as generalized as possible. Therefore, it was crucial to keep the final landcover type matrix, and make a copy in a new worksheet, which was easy to recover in case of errors, like deleting columns before looking clearly and entering the right label, before deleting the rows to remain with three (used in this case). On the other hand, the original classification table must be retained, because it is a proof of the synoptic table, and it can be validated.

In the grassland synoptic table, types were differentiated by bold lines. Averages for the environmental variables collected, were calculated and entered, between two bold lines for each type (a column width of 15 was adopted as the standard). Values within each type for all parameters were given the range (lowest and highest values) and annotated. This makes it easy to see the ranges of values that were collected. Soil types were also indicated and where there were different soil types, they were all put together. Soil texture was categorized as either the prevailing soil texture or the occasional soil texture. Information about the growing season for the grasses was added (annual or perennial, or a mix of both), was added. They were averaged and annotated. Synoptic tables do not contain sample number information, since the interest is to see how many samples were in each type. The NDVI values were not included too, because they were not adding any value in the synoptic table. Therefore, number of samples replaced the sample numbers, and the count was entered. Shannon Diversity index and palatability vales were also averaged and annotated. Finally, unique labels which were east to remember, were used to describe the land cover types, by replacing species cover information in the rows. A legend describing clearly the distinguishing differences between the chosen symbols (In this case thick full line, thin full line, dashed lines with different weights), was prepared.

Number of samples	3	5	15	5	4	5	5	1	1	1
prevailing texture	BC	BC	BC	LC	LC	LC	BC	SL	LC	BC
occasional texture	LC	SL		BC	BC and SL	BC and SL	SL			
Palatability	(06)1.5(2)	(06)0.7(1.1)	(0.2)0.5(1)	(0.5)0.7(1)	(08)1.4(3)	(3)3(3)	(0.9)0.9(1)	1	3	2
Shannon index	(0.7)1(1.4)	(0.4)0.8(1.09)	(1)1.3(1.76)	(1.0) 1.4 (1.6)	(0.9)1(1.4)	(0.2)0.8(1.2)	(0.8)1.1(1.4)	1.1	0.9	0.7
Perrenial or annual grasses	Pe	Pe	Pe/A	Pe	Pe	Pe	Pe	Pe	Pe	A
Grass height	(2)2.5(3)	(3)3.5(4)	(3)30(50)	(2)25(3)	(3)3(3)	2.5(3)3	2(2.5(3)	3	3	30
Tree layer %	92	0	0 (2)	0	0	0	0	0	0	0
Shrub layer %	(5) 19 (15)		(0) 5 (15)	0-3	(2)3(5)	(10)15(20)	(2)3(5)	5	0	0
grass/herbs %	(45)55(75)	(40)65(95)	(55) 80 (95)	(45) 50 (55)	(30)55(85)	(25)50(65)	(33)40(70)	60	50	60
LITTER			(2)30(40)						0	35
Bare soil	(20)40(55)	(3)30(60)	(3)10(40)	(40) 50 (55)	(15)40(65)	(15)40(60)	(30)55(65)	35	45	5
Stones & boulders	0	0	0	0	0	0 (5)	0	0	0	0
Aristida adoensis	■■■■									
Microchloa kunthii	- - - -								- - - -	
Bothriochloa insculpta		■■■■	▬ ▬ ▬				- - - -			
Sporobolus pyramidalis		▬ ▬ ▬	▬ ▬ ▬				- - - -			
Themeda triandra			■■■■	■■■■						
Pennisetum hohenackeri			▪ ▪ ▪ ▪							
Cymbopogon caesius			▪ ▪ ▪ ▪							■■■■
Setaria plicatilis			- - - -							
Cynodon dactylon		- - - -	- - - -	▬ ▬ ▬	■■■■					
Pennisetum mezianum			- - - -	- - - -			- - - -	- - - -	- - - -	
Eragrostis tenuifolia	────	- - - -		────	■■■■	■■■■	▬ ▬ ▬	- - - -	- - - -	
Chloris gayana				- - - -			■■■■	- - - -		
Chloris pycnothrix			────					■■■■		
Enneapogon schimperanus									■■■■	
Harpachne schimperi	- - - -									
Code	G1	G2	G3a	G3b	G4a	G4b	G5	G6	G7	G8
Name	Aristida grassland	Bothriochloa insculpta grassland	Themeda triandra - Sporobolus pyramidalis grassland	Themeda triandra typicum grassland	Eragrostis tenuifolia - Cynodon dactylon grassland	Eragrostis tenuifolia typicum grassland	Chloris gayana grassland	Chloris pycnothrix grassland	Enneapogon schimperanus grassland	Cymbopogon caesius grassland

LEGEND	
■■■■	Dominant cover relative to other species ,and always present
▬ ▬ ▬	Co-dominant, present 50-75% ,in high cover
▪ ▪ ▪ ▪	Present 25-50%,in high cover but never co-dominant
────	Present 75-100% of the time but in low cover
- - - -	Present 50-75% of the time in low cover
BC	Black clay
LC	Loamy clay
SL	Sandy loam
Pe	Perrenial grass
A	Annual grasses
Pe/A	Mix of annuals and perrenials

Table 2. Synoptic table for grassland landcover types, in the Maasai Mara Ecosystem. The legend contains explanation for symbols that were used to simplify the different landcover types. Naming is based on the dominant and sometimes the dominant and the co-dominant type/s

3.5.2. SYNOPTIC TABLE FOR TREES AND SHRUB COVER TYPES

A similar method was used to prepare a synoptic table for the trees and high bush. The labels used to show different types were maintained like those of the grasslands, to maintain consistency, and to make it easy to produce the final differentiated synoptic table for all the land cover types.

Palatability	(1)1(1)	(1)1(1)	(1)1(1)	(1)1(1)	(1)1(1)	(1)1(1)
Shannon index	0.3	0.6	0.74	1	1	1.4
Perrenial or annual grasses		Pe	Pe	Pe	Pe	Pe
Grass height		0-3	(3)10)30	(2)5(10)	(3)5(10)	5
Tree layer %	(40) 45 (80)			2	0 - 5	
Shrub layer %	(5) 35 (40)	80	(20) 40 (50)	(60) 70 (80)	(30) 60 (95)	80
grass/herbs %	(0) < 5 (10)	0 - 10	(25) 35 (55)	(25) 35 (40)	(0) 10 (15)	25
LITTER		0 - 20	0	0-5	(0) 35 (50)	
Bare soil	(5) 35 (85)	20	(15) 50 (90)	(25) 35 (40)	(30) 50 (80)	60
Stones & boulders		0	0- 5	0	(0) 10 (25)	
TREES						
Euclea divinorum / Ficus thorningii						
Olea europaea ssp. africana						
SHRUBS						
Euclea divinorum						
Ormocarpum trichocarpum						
Tarchonanthus camphoratus						
Croton dichogamus						
Combretum molle						
Grewia similis						
Cadaba farinosa						
Sida ovata						
Acacia drepanolobium						
Acacia kirkii						
Acacia brevispica						
Solanum incanum						
GRASSES & HERBS						
Aristida adoensis						
Microchloa kunthii						
Bothriochloa insculpta						
Pennisetum hohenackeri						
Eragrostis tenuifolia						
Chloris gayana						
Enneapogon schimperanus						
Harpachne schimperi						
Eragrostis paniciformis						
Digitaria abyssinica						
Hypoestes forskahlii						
code	F1	S1	S2	S3a	S3b	S4
Name	Euclea divinorum-Ficus thorningii forest	Euclea divinorum - Ormocarpum trichocarpum shrubland	Tarchonanthus camphoratus shrubland	Croton dichogamus typicum	Croton dichogamus - Grewia similis Shrubland	Acacia drepanolobium-Sida ovata shrubland

LEGEND	
	Dominant cover relative to other species ,and always present
	Co-dominant, present 50-75% ,in high cover
	Present 25-50%,in high cover but never co-dominant
	Present 75-100% of the time but in low cover
	Present 50-75% of the time in low cover
BC	Black clay
LC	Loamy clay
SL	Sandy loam
Pe	Perrenial grass
A	Annual grasses
Pe/A	Mix of annuals and perrenials

Table 3. Synoptic table for trees and shrub landcover types, in the Maasai Mara Ecosystem.

3.6. PALATABILITY AND SHANNON DIVERSITY INDEX FOR GRASSLAND TYPES

After clustering was done, average palatability for each sample type was calculated, as well as the average Shannon diversity Index. A weighted average was first calculated for cover for those grass species that were more than 10% for each sample site. Then these values were multiplied by the palatability code, which in these case was 1 (highly palatable), 2 (intermediate) and 3 (least palatable). This gave an average palatability for each sample for all the 3 classes. The resulting values were then averaged for all the samples within a type, and the result was an average palatability for that type (see attachment in appendix). Shannon Index was calculated for each sample, and then averaged for the group.

3.6.1. SHANNON WEINER DIVERSITY INDEX (H')

This index was used to express the diversity of communities along the environmental gradient for each sample site. It is one of the most widely used indexes to calculate species diversity. The diversity examined at this scale was α diversity. The Shannon Wiener Index takes into account the relative abundance of species present, and evenness. It also takes into account the rare species. High H values is an indication of diverse and equally distributed community and vice versa (Gamoun., M., 2013).

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

Where,

H = the Shannon diversity index

P_i = fraction of the entire population made up of species i (proportion of a species is relative to TOTAL

number of species present, not encountered)
S = numbers of species encountered

After calculating the species diversity index for each species and each site, the values were added to the matrix legend

3.6.2. GRASS SPECIES PALATABILITY

Information on palatability for grasses was obtained from literature and from botanical records in the National Museums of Kenya. Palatability was classified as highly palatable, intermediate and least palatable (Teka *et al*, 2013). They were coded as 1, 2 and 3 respectively. For each sample site, only species cover that was more than 10% was considered significant. For each sample, the cover for all the species was weighted to 100% before the weighted palatability factor was calculated for each sample. This weighted cover was multiplied by the code for each palatability class, and divided by 100, to give the weighted palatability. These weights (1, 2 and 3), were averaged, to show palatability for that landcover each sample. (See appendix 6.2). This information was added on the final classification table.(Sasaki et al., 2009).

Species name	Palatability factor	Factor reference
Eragrostis tenuifolia	3	Least palatable
Digitaria abyssinica	1	Highly palatable
Eragrostis cilianensis	2	Intermediate
Microchloa kunthii	2	Intermediate
Aristida adoensis	2	Intermediate
Cynodon dactylon	1	Highly palatable
Pennisetum hohenackeri	2	Intermediate
Chloris gayana	1	Highly palatable
Setaria plicatilis	3	Least palatable
Eragrostis chapelieri	3	Least palatable
Digitaria velutina	1	Highly palatable
Enneapogon schimperanus	3	Least palatable
Eustachys paspaloides	1	Highly palatable
Pennisetum mezianum	2	Intermediate
Sporobolus pyramidalis	2	Intermediate
Themeda triandra	1	Highly palatable
Heteropogon contortus	2	Intermediate
Harpachne schimperi	2	Intermediate
Chrysochloa orientalis	1	Highly palatable
Chloris pycnothrix	1	Highly palatable
Tragus berteronianus	3	Least palatable
Bothriochloa insculpta	2	Intermediate
Cymbopogon caesius	2	Intermediate
Cymbopogon pospischilii	3	Least palatable
Eragrostis paniciformis	3	Least palatable
Eragrostis cilianensis	1	Highly palatable

Table 4. Palatability rating factors of the grass species in the Maasai Mara Ecosystem. The codes were used to generate the palatability weights, which were added to the classification table. These weights were then averaged for each type. This information enriched the synoptic tables as well the legend (see figure 9)

4. RESULTS

4.1. FLORISTIC TYPES CLUSTERING CONSIDERING ENVIRONMENTAL VARIABLES

Legendre and Legendre (1998), recommend manual clustering, since computer based programs, are used without a proper understanding of the properties and limitations of the available techniques. Manual clustering of floristic criteria was done in Ms Excel, because the database was not huge, and it also contained values and letters. The output of this clustering or classification are vegetation types which can be characterized by a unique combination of species (see appendix 1). The information in the classification table thereafter is summarized resulting in the synoptic tables, which are a summary of the classification tables (Dombois &Ellenberg,1974).

Trees and high bush were combined and clustered separately from the grasses and herbs, which were clustered together. First all samples with a tree cover exceeding 30%, were grouped into the main vegetation type "Trees". From the remaining data set, all samples with a shrub cover exceeding 30% were grouped into "shrub lands" and the remaining samples were divided into the main type "grasslands" if the grass cover exceeded 25% or "Bare" if the grass cover was less than 25%. Within these main types, samples were clustered by grouping samples with a similar species composition and species with a similar distribution over the samples are into vegetation types characterized by a unique combination of species.

Before clustering, a decision was made based on the available percentage cover for each different species. In the end, a decision was made, that only percentage values higher than 10 would be used. This is because this cover was considered more representative and dominant. Rare species were used to characterize these dominant types, in the synoptic tables. Therefore they were not rejected. To be able to distinguish the dominant covers easily, they were given different shades of colour. Values higher than 30 percent, were given a darker colour and those below 30 percent, a lighter colour. Species less than 10 percent were given a letter P (present), whereas those less than 2 percent were coded as r (rare). This made it easier to recognize the values visually. On the other hand, species that had more than 30% cover, were considered dominant and therefore were given more consideration, during clustering. Photos that were taken in the field were often used, when errors were detected in any case, like under-estimation or over-estimation of the floristics composition. This is common due to data entry errors. Where one or two species were dominant, and they were not matching to any cluster, they were grouped as a type. This was not common, and reference was made from literature, before any decision was made.

4.2. DOMINANT FLORISTIC TYPES

The field data collected included trees, shrubs, herbs and grass species. The results showed a strong relationship between the different species and soil texture. Soil pH and slope did not play a major role in discriminating the different land cover types. Soil pH was almost homogenous in all the sampled points despite the differences in slope and soil types, and therefore was not a good indicator of variation between the floristic types. Slope ranged from almost flat to flat to rolling in most of the areas sampled, with occasional hilly areas (see appendix 1).

4.2.1. GRASSLAND TYPES

After clustering (see table 5 and appendix 1), eight main grassland types emerged. These were *Aristida adoensis, Bothriochloa insculpta, Themeda triandra-Sporobolus pyramidalis, Themeda triandra typicum grassland, Eragrostis tenuifolia-Cynodon dactylon, Eragrostis tenuifolia typicum, Chloris gayana, Chloris pycnothrix, Enneapogon schimperanus, and Cymbopogon caesius grassland type.* There are also two bare types, one with rare species and the other type completely bares.

4.2.1.1. Aristida *adoensis grassland type*:

The Aristida adoensis grassland type occurred predominantly in the flat plains dominated by black clays, and occasionally in the loamy clays, with a soil pH of 5. It is common in bushland and open grasslands. It excluded all the other types. *Microchloa kunthii* is always present in the grassland type, in high covers of 50-75%. The bare soil in these patches range between 20%-55%, with an average of 40%. The Shannon diversity index is 1 on average, and average palatability of this grassland type is 1.5.

4.2.1.2. *Bothriochloa insculpta grassland type*:

This grassland type is common in black clays and occasionally in sandy loams. It prefers an average soil pH of 6, in the rolling slopes in open spaces, with little or no tree and shrub cover. The grass cover is very high ranging from 65%-95% in some areas, with an average of 65%. Bare soil in the type can be as low as 3% to as high as 60%. In this grassland, *Sporobolus pyramidalis,* is co-dominant, because is present 50-75% of the time, in high cover, while *Cynodon and Eragrostis tenuifolia,* are always present 50-75%, not co-dominant, but are present in high cover. The Shannon diversity index is 0.8, and palatability 0.7.

4.2.1.3. *Themeda triandra - Sporobolus pyramidalis grassland type*:

This is dominant grassland type in the Maasai Mara ecosystem. *Themeda* occurs mainly in the black clays, in open areas with low tree (2%) and shrub cover (5%). It can reach It is predominant in soils with a pH of 5. Litter up to 30% is common in this grassland type, sometimes with litter cover as high as 40%. *Sporobolus* and *Bothriochloa* are co-dominant present at 50-75%, with high cover. *Pennisetum hohenackeri* and *Cymbopogon caesius* are also always present with 20-50% cover. *Cynodon* is present as a subtype all the time in low covers. *Setaria plicatilis, Eragrostis tenuifolia* and *Pennisetum mezianum* are present 50-75% of the time in this grassland, but not co-dominant. It excludes *Chloris gayana Microchloa* and *Aristida*. *Harpachne, Digitaria Abyssinica*, *Heteropogon contortus* and *Chloris pycnothrix* are also found but in very little proportion in this grassland. It withstands overgrazing and this probably explains its high presence. The Shannon diversity index is 1.3 and palatability is 0.5.

4.2.1.4. *Themeda triandra - typicum grassland type*:

This is the species poor *Themeda* grassland. *Cynodon dactylon* is co-dominant; *Pennisetum mezianum* is present in 50-70% of the cases, in high cover but not co-dominant. The same case applies to *Chloris gayana. Eragrostis tenuifolia* is also present 50-70% of the time, but in low cover. *Pennisetum hohenackeri* and *Cymbopogon caesius* are not present at all probably due to change of soils from black clays to loamy clays. Bare soil is normally high, at 50%. The species diversity index is 1.4 in this grassland. Palatability of the grasses is 0.7.

4.2.1.5. *Eragrostis tenuifolia - Cynodon dactylon grassland type*:

This is also a common grassland type in this ecosystem. *Eragrostis tenuifolia* and Cynodon *dactylon* dominate. They occur predominantly in loamy clays, and occasionally in black clay and sandy loamy soils, in flat areas. This grassland excludes all other grass species. The Shannon diversity Index is 1, and palatability is 1.4. Soil pH range is 5, with some occurring in neutral soils (pH7). Bare soils of as high as 65%, are common in this grassland. Shrub cover is low, at 3%.

4.2.1.6. *Eragrostis tenuifolia - typicum grassland type*:

In this grassland, *Eragrostis tenuifolia* is the dominant grass species, but it is a species poor subtype. It occurs in loamy clays, and occasionally in black clays and sandy loams. The shrub cover is high (average of 15%), and bare patches are common, as high as 60%. Stones and boulders, 5%, are also common in this grassland. Palatability remains at 3, therefore, it is least preferred by animals. The Shannon Diversity Index is 0.8.

4.2.1.7. *Chloris gayana grassland type*:

Chloris gayana grassland type occurs in almost flat and flat areas, in black clay and occasionally in sandy loams, with a pH range of 5. Tree and shrub cover are almost absent in this grassland. However, bare soils up to 55 % sometimes as high as 65% are common. It coexists together with *Eragrostis tenuifolia* which is co-dominant occurring 50-75% in high cover. It completely excludes *Themeda*, and *Cynodon dactylon* but *Bothriochloa, Sporobolus, Pennisetum mezianum* are present, 50-70% of the time, but do not reach co-dominance. The palatability is 0.9 and Shannon diversity index is 1.1.

4.2.1.8. *Chloris pycnothrix grassland type*:

Chloris pycnothrix is dominant in sandy loams, where it occurs in totality. It excludes all dominant grass species, except *Eragrostis tenuifolia, Pennisetum mezianum* and *Cynodon dactylon, which* occur at 50-75% of the time but not dominant. The Shannon Diversity index is 1.1 and palatability is 1. Bare soil is normally at an average of 35%. Trees and shrubs are absent in this grassland type.

4.2.1.9. *Enneapogon schimperanus grassland type*:

Enneapogon schimperanus occurs in loamy clays. It is least palatable grassland (3), with bare patches of up to 45%. The Shannon Diversity index is 0.9. It completely lacks trees and shrubs, and only coexists with, *Microchloa kunthii, Pennisetum mezianum* and *Eragrostis tenuifolia,* which are present 50-75% percent of the time, but do not gain dominance.

4.2.1.10. *Cymbopogon caesius grassland type*:

This grassland is dominant, and seems to exclude all the other species. This grassland is relatively palatable (2). Litter can accumulate up to 35%. Bare soil is apparently very low at 5%. The Shannon Diversity Index is at 0.7. Trees and shrubs are completely absent in this grassland.

4.2.2. BARE

There are also two "bare" types, one sparsely vegetated (grass/herb cover 5-20%) and the other type completely bare (see figure 12).

4.2.1. Bare type 1:

This type of bare was characterized by an average bare of presence of 80%, with low cover of grass and herb species (15%), and shrubs of up to 5%. Grass species palatability is at 0.7 % and Shannon diversity index of 0.9. The commonest shrubs are *Justicia elliotii, Solanum incanum* and *Sida acuta*. *Microchloa kunthii* and *Cynodon dactylon,* are the commonest grass species found, but in very rare quantities.

4.2.2. Bare type 2

This type has an average bare of 90%, and no vegetation cover

4.3. TREE *AND SHRUBLAND TYPES*:

Shrublands and tree samples were clustered separately, and *Euclea trichocarpum-Ormocarpum* shrubland, *Tarchonanthus camphoratus, Croton dichogamus typicum, Acacia drepanolobium-Sida ovata,* and *Croton dichogamus-Grewia similis* shrublands emerged. The tree type was *Euclea divinorum-Ficus thonningii* species.
(See appendix 1).

4.3.1. *Euclea divinorum-Ficus thonningii* type:

This gallery forest type, *Euclea divinorum-Ficus thonningii*, was grouped as one type, since it was very hard to determine from photography which species was more dominant. These species are always present and occur together. *Croton dichogamus* is also present in this type, 50-70% of the time in relatively high cover. They occur mainly in the black clays, and occasionally with sandy loams and loamy clays. Bare soils are common and can be as high as 85%. Grass species are almost absent. Shannon diversity is very low at 0.3 and palatability is high.

4.3.2. Euclea trichocarpum-Ormocarpum type

Euclea divinorum is the dominant species and *Ormocarpum* co-dominant. They prefer sandy loams, and occasionally in black clays. They have high palatability. These shrubs can cover up to 80%. However, the species diversity is low, at 0.6. Grass cover is low and litter can be as high as 20%. However, bare patches are also common, sometimes 20%.

4.3.3. Tarchonanthus camphoratus type:

Tarchonanthus is dominant, but *Euclea* is co-dominant. It prefers sandy loams, but also in black clays. These shrubs reach upto50% dominance. However, grass cover is also relatively high, at times more than 50%. *Aristida* and *Bothriochloa* can be present in high cover, whereas, *Eragrostis tenuifolia* and *Hypoestes forskahlii* are always present in low cover. Bare patches are also as high as 50%. Stones and boulders are common in this grassland, sometimes up to 5 %. Palatability is 1, and Shannon diversity 0.74.

4.3.4. Croton dichogamus typicum:

Croton dominates and excludes all the other shrub species. The soils are black clays. The shrubs are normally thick, with as high as 80% cover. The only grass species present, and in relatively high covers are *Bothriochloa*, Harpachne *schimperi* and *Digitaria abyssinica*. No trees are present in this shrubland. Palatability is high (1), as well as Shannon diversity (1).

4.3.5. Acacia drepanolobium-Sida ovata type:

Acacia is dominant here as well as *Sida ovata*. They exclude all the other tree species. *Microchloa kunthii, Pennisetum hohenackeri, Eragrostis tenuifolia,* and *Enneapogon schimperanus* are present, 50-75%, in high cover, but not dominant. These shrubs cover 80% of the polygon, and bare soil stands at 60%. They prefer black clays and the palatability is high, 1, and the Shannon diversity is 0.9.

4.4. LEGEND PREPARATION CONSIDERING REMOTE SENSING AND FLORISTIC TYPES

The reason for conducting the fieldwork was to collect, and cluster floristic data, and relate the resulting types to the 71 classes MODIS image, and the longterm NDVI statistics (SD, Median and Trend). The legend is a summary of the data, which belongs to a certain class. Before a legend was generated in Ms Excel, the GPS points collected in the field for each sample was used to extract the longterm NDVI values for all layers (stated above), in ArcGIS 10.2. Since the landcover types had been already described, each complex/heterogeneous unit cover was entered in the right floristic type. Average Palatability, Shannon diversity index, grass height and growing season (annual or perennial) were added to the legend. All this information was related to vegetation types (see fig 9).Legend construction is a matrix with spatial units (polygons), in the rows, and the vegetation types (abstract), in columns, with the contribution of each vegetation type (expressed in %), to the complexes of cover types, present within a polygon.

Afterwards, the polygons with similar vegetation types were grouped together. For example, in the legend below, s4, s28 and s19, represents the *Aristida adoensis* grassland type, and therefore, they are grouped together. The cover types were given names based on the dominant species, and, if there was a co-dominant species, the name was added. However, the second names were arbitrary, and were just used to distinguish for example a grassland type with a typicum. *Euclea divinorum* and *Ficus thonningii* were grouped together as one forest type, due to their association i.e. always occurred together.

pixel no	71 classes	median	stdev	trend	Euclea divinorum-Ficus thonningii forest	Ormocarpum-Euclea trichocarpum shrubland	Tarchonanthus camphoratus shrubland	Tarchonanthus-Euclea shrubland	Cadaba farinosa shrubland	Croton dichogamus typicum	Acacia drepanolobium-Sida ovata shrubland	Croton dichogamus-Grewia shrubland	Aristida adoensis grassland	Bothriochloa insculpta grassland	Themeda triandra and typicum grassland	Eragrostis tenuifolia grassland	Eragrostis tenuifolia typicum grassland	Chloris gayana grassland	Chloris pycnothrix grassland	Enneapogon schimperanus grassland	Cymbopogon caesius grassland	Water	Bare soil	Weighted Palatability	Weighted Shannon Diversity Index	Grass heights	Annual/ Perennial
S4	18	10	5	3									20										80	1	0.70	3	Pe
S28	39	14	3	3	10								85										5	0.6	1.46	3	Pe
s19	25	12	5	4	20								80											1	1.06	2	Pe
s45	39	15	4	4						80				20										0.55	1.54	3	Pe
s43	52	16	2	4			40							60										1.3	1.05	3	Pe
s-52	48	14	4	4										70	30									0.2	1.41	20	Pe/A
s-44	52	16	3	4						65				35										1	0.63	3	Pe
s-31	39	14	4	4											100									0.69	1.38	3	Pe
s-39-2	48	16	5	3											100									0.34	1.37	50	Pe
s-39-1	48	15	4	4											100									0.34	1.37	40	Pe
s-40	48	15	4	3											100									0.58	1.36	50	Pe
s-38	48	15	4	3											100									0.51	1.28	30	Pe
s-46	48	15	4	3											100									0.52	1.26	40	Pe
s-47	48	16	5	4											100									0.52	1.30	50	Pe/A
s-41	48	15	5	3											100									0.81	1.28	40	Pe/A
s-51	48	15	5	4											100									0.44	1.09	40	Pe/A
w-2	48	14	5	4											100									0.29	1.79	40	Pe/A
s-42	48	15	6	4											100									0.44	1.77	10	Pe
s-33	48	14	6	4											100									0.66	1.58	10	Pe
s-26	35	13	5	4											100									1	1.52	3	Pe
w-3	39	14	4	3											100									1	1.03	3	Pe
s-16	25	12	4	3											100									1	1.44	3	Pe
s-25	39	13	5	3											100									1	1.00	2	Pe
s-8	25	11	4	3											80								20	0.5	1.62	2	Pe
s-6	25	11	3	3											90								10	0.5	1.62	2	Pe
w-4	25	11	4	4											100									0.5	1.30	3	Pe
w-6	25	12	3	4												100								0.9	0.92	3	Pe
s-15	48	12	3	4												70							30	0.8	0.72	3	Pe
s-11	25	11	5	4												100								1.1	1.20	3	Pe
s-22	35	13	3	4												100								3	1.41	3	Pe
s-23	35	13	4	3													100							3	1.07	3	Pe
s-2	18	10	4	3													65						35	0.5	1.46	3	Pe
s-27	35	14	2	4					25	15							60							3	1.04	3	Pe
s-10	25	11	5	3													85						15	3	1.38	3	Pe
s-18	25	12	5	3													80						20	3	0.83	3	Pe
s-17	25	12	4	4														100						0.93	1.04	3	Pe
s-1	18	10	3	4														60					40	0.1	1.15	3	Pe
s-13	25	12	2	4	40													60						0.77	1.28	3	Pe
s-5	25	11	2	4	20													80						1	1.40	3	Pe
s-14	35	12	3	3														100						1	1.25	3	Pe
w-5	35	12	4	3															100					0.4	1.19	2	Pe
s50	57	18	2	4	60					30												10		0.5	0.69	10	Pe
s7	25	11	3	4							100													0.5	1.44	5	Pe/A
s36	35	13	4	4						100														1	0.99	4	Pe
s49	52	17	4	4								100												0.5	1.61	10	Pe
s35	39	15	2	4			100																	0.5	0.80	30	Pe
s29	39	14	3	4			100																	0.5	1.05	3	Pe
S48	57	17	3	4						100														0.5	0.69	10	Pe
S29	39	14	3	4				100																0.5	1.05	3	Pe
s21	35	13	3	3						40					60									0.5	1.69	3	Pe
s5	25	11	2	4	20											80								1	1.40	2	Pe
s37	52	15	3	4	25							75												0.25	1.47	3	Pe
s32	48	14	5	4																	100			0.48	0.79	30	A
s-9	25	11	4	4																100				0.1	0.93	30	A

Table 7. The landcover types legend of the Maasai Mara Ecosystem, with longterm NDVI variables, average palatability and Shannon Diversity Index

4.4.1. VEGETATION MAP

This was the final stage of combining the legend with the map to display spatially, the resulting vegetation types. The matrix legend was converted into a .csv format in Ms excel and loaded into ArcGIS 10.2, where it was joined to the raster image containing 71 classes, SD, and Median. The vegetation types were used to for symbology, to display the different landcover types. All polygons with the same 72 class, median and SD were assigned that specific vegetation type, as in the legend.

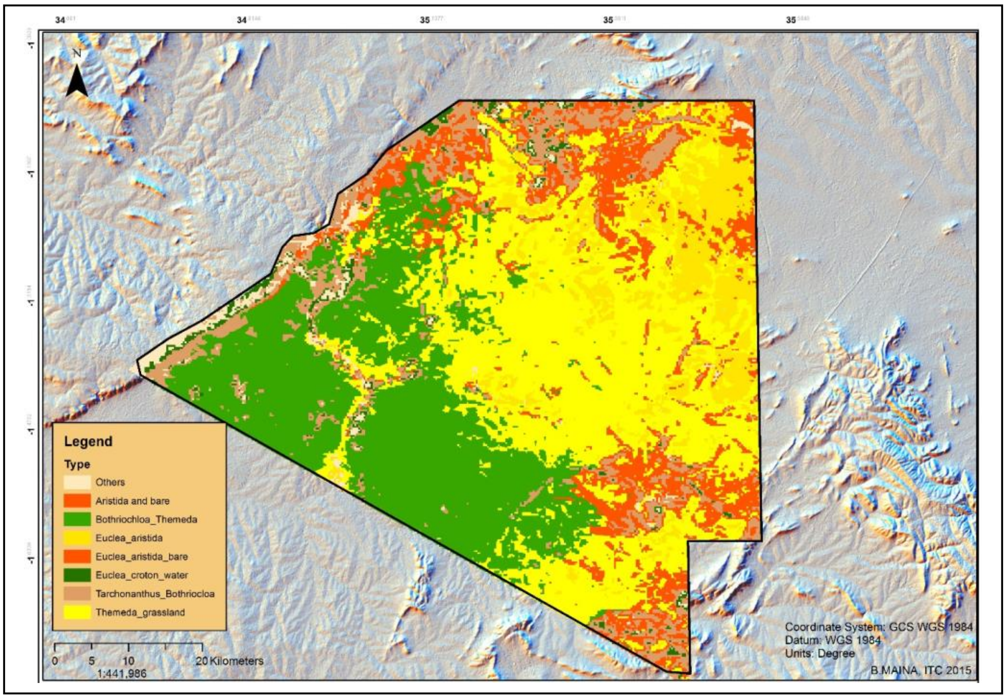


Fig 7. The vegetation map of the Maasai Mara Ecosystem. The dark green colour is the Themeda-Sporobolus grassland type, the red parts Aristida adoensis grassland mixed with bare patches, yellow represent Themeda triandra grassland, and Themeda typicum. The light brown colour is the Tarchonanthus shrubland mixed with Bothriochloa grassland. Patches of Euclea riverine vegetation along the Mara river area also visible. Other grasslands are not clearly visible at this scale.

4.4.1.1. Accuracy Assessment of the Vegetation Map

Based on the fieldwork executed, accuracy assessment is impossible. However, a quality assessment was done by analyzing the spatial patterns in relation to what was seen in the field and the google imagery, which uses ground truth.

4.4.1.2. VISUAL ASSESSMENT OF NDVI VARIABLES, AND GOOGLE EARTH, WITH THE VEGETATION MAP

The vegetation map that was produced from the floristic classification was compared to the trend and the results showed that highly palatable species are found in the conservancies or the communal areas. For example, there are vast areas of almost pure *Themeda* grasslands outside the MMNR, as opposed to the mix of *Themeda* and *Bothriochloa* inside the MMNR and in the degraded areas.

4.4.1.3. Trend map in relation to the Vegetation Map

The trend map has class 3 and 4, which were preselected. Class 3 represents areas that have a negative trend, while class 4 represent the stable and positive trend areas. Trend means that for the last 14 years, the areas that are in class 3 have been deteriorating, besides having enough rainfall. The NDVI has been receding in these areas, for the last 14 years. It is an indicator degradation.

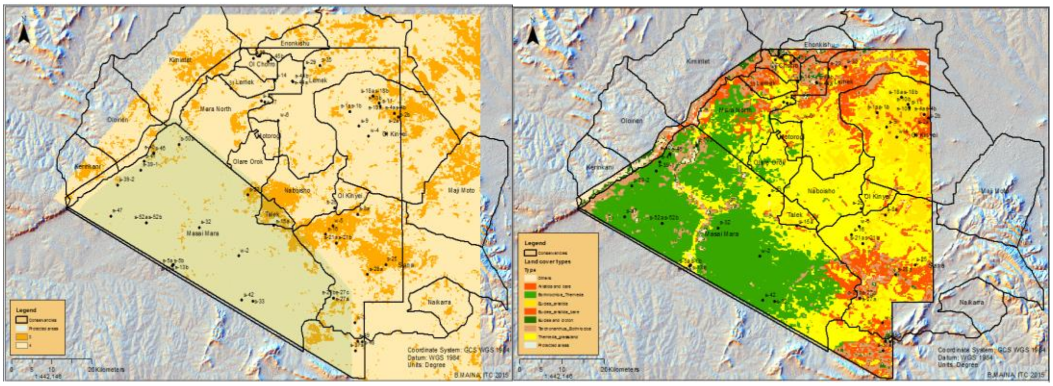


Fig 8. Map showing the trend map (left) and the landcover types map (right) of Maasai Mara Ecosystem. The trend map contain two classes 3 (dark brown), and class 4, (the beige colour), NB: from the landcover types map, highly palatable species Themeda triandra (in yellow) is dominant within the highly degraded areas. On the trend map it is clear that Siana and Ol-kinyei are highly affected and have a negative trend. The overlay is the MMNR boundary and conservancy boundaries

4.4.1.4. Median in relation to the Vegetation Map

The median values show areas that have had a high fluctuation trend within the last 14 years. Areas with high median values correspond with different types and vice versa. Areas which have a lot of bare (<70%), have low median values and thus reflect the degraded areas. The north eastern part with samples s-18a, s18b, s1a, s1b, s4a, s4b and s9, have high bare percentage (See appendix 1).

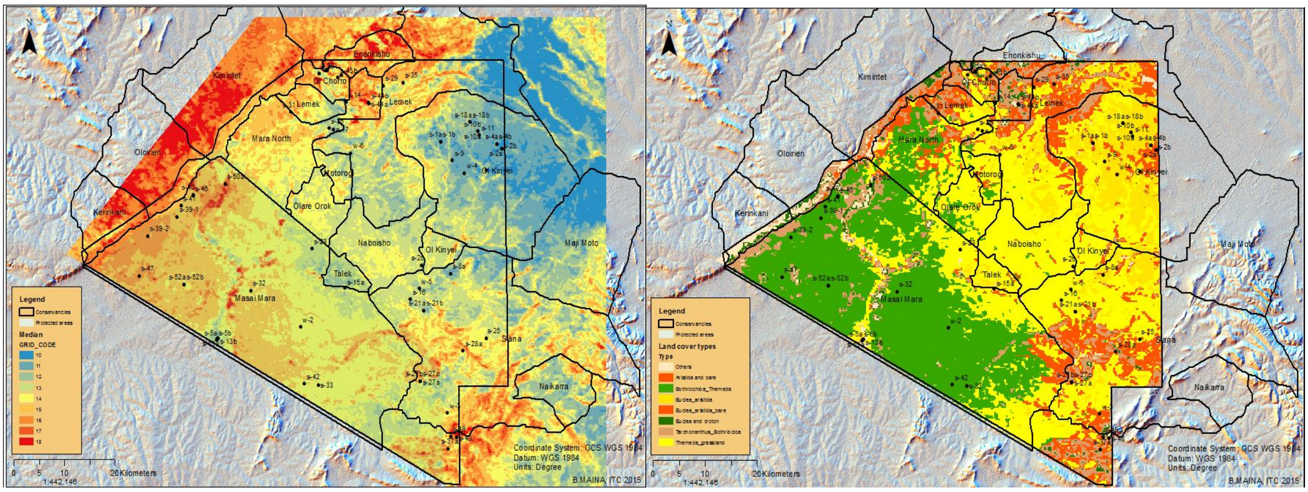


Fig 9. Map showing the median map (left) and the landcover type's map (right) of Maasai Mara Ecosystem. The legend of the median map has low to high values. Blue areas represent highly fluctuating areas, which are degraded. Red is vegetation with high NDVI values. See figure 5 for more information on Median. There is a clear pattern of vegetation types in both the median and the vegetation map. The overlay is the MMNR boundary and conservancy boundaries

4.4.1.5. Standard Deviation in relation to vegetation types

The standard deviation also shows relationship between the different vegetation types. Low standard corresponds to high median. It also shows a relationship with the different vegetation types.

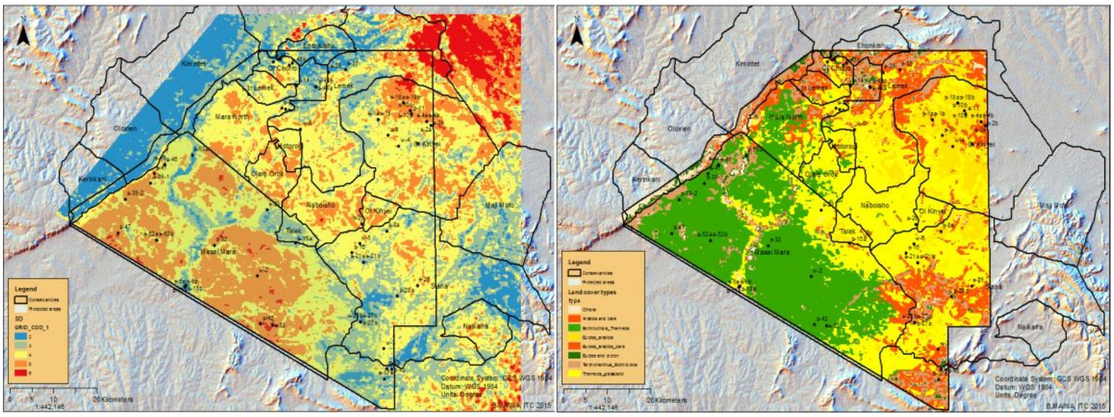


Fig 10. Map showing the SD map (left) and the landcover type's map (right) of Maasai Mara Ecosystem. The SD represents the differences between the various groups. In this case, the yellow parts represent degraded pastures, red and blue is agricultural land. Brown parts are the good rangelands. The overlay is the MMNR boundary and conservancy boundaries

4.4.1.6. Google Earth and the vegetation map

When the vegetation map is compared to Google earth image, some similar patterns are observed.

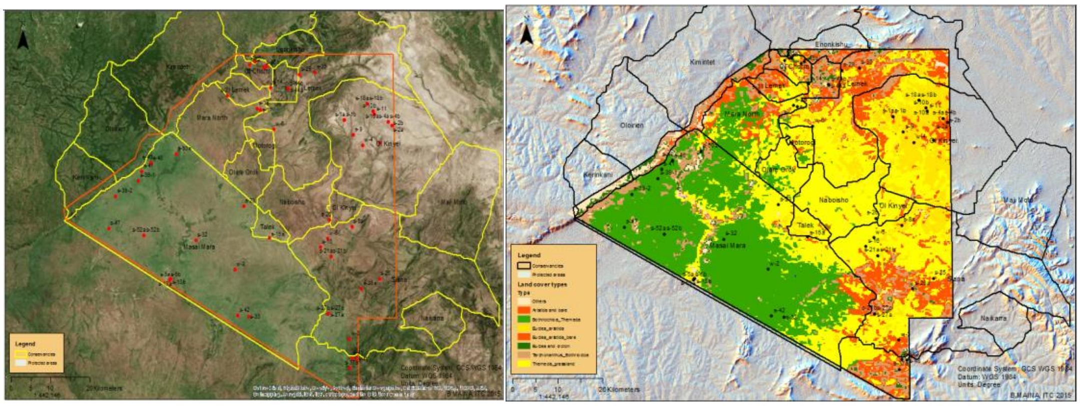


Fig 11. Map showing the Google Earth image (left) and the landcover type's map, (right) of Maasai Mara Ecosystem. The overlay is the MMNR boundary and conservancies boundaries. The light green part is the MMNR, which is rich in Themeda, Bothriochloa and Sporobolus grass species, which are shaded dark green in the map. The riverine vegetation along the Mara River is rich in Themeda from the vegetation map. The open plains in the north, which appear lighter in the Google map also forms a distinct pattern in the vegetation map. This pattern is a soil formation and rainfall gradient differences, in this ecosystem as described by (Victoria J. B., 2003)

5. DISCUSSION

5.1. FLORISTIC TYPES

The *Enneapogon schimperanus* grassland was based on only one sample (s-9), that made up 100% of the polygon, and thus was considered to be a type. The justification to for this was based on (Walker, 1979), observed that, when *Themeda* grasslands are overgrazed, *Enneapogon,* and other species can increase to gain dominance. *Chloris pycnothrix* grassland type (in sample w5) also had dominated the polygon, and for this same reason, it was grouped as grassland. McNaughton,(1983), describes it as an annual, which was dominant in his study in Serengeti. Least palatable species like *Eragrostis tenuifolia* were common and dominant. Some species like *Sporobolus pyramidalis* also occur mainly in the degrading *Themeda* grasslands too. (Walker, 1979). *Themeda Sporobolus* grassland type had the highest cover of tall perennial grass species. The main weakness in this study was the estimation of cover, with some estimations using odd numbers to for cover estimation. This in reality is hard to determine, and thus improvement in the future is critical.

The use NDVI variables, that was used to make the sampling scheme seems to be effective and robust (section 3.2.1). Therefore, in the future, a sample scheme with all vegetation types incorporated, represents a good chance to map types, which probably have not been known before. For example, hardly any literature mentions about the *Eragrostis tenuifolia* typicum which occurs in areas with high shrub, as opposed to *Eragrostis tenuifolia-Cynodon dactylon* grassland. This shows that it is either classified with other groups, or generalized, as an *Eragrostis tenuifolia* grassland type (see table 2). The unique characteristic of this grassland, is that, it excluded all other grassland types. It is common is areas with stones and boulders and high bare areas, which indicates degradation. This is an important finding that has not been reported before (see table 2). Another interesting finding, is the *Themeda triandra typicum* grassland predominantly with annuals, which occurs in both loamy clay soils, occasionally in black clays, and *Themeda triandra-Sporobolus pyramidalis,* predominantly in black clays, and contains both annual and perennial grasses. This difference due to the soil and rainfall gradient, pH, nitrogen content and bulk density (Victoria , 2003).

Previous research in this ecosystem corroborate with the results of this study. McNaughton (1983), working in the Mara-Serengeti ecosystem, found 17 grassland communities using a numerical clustering, the principal component analysis method. According to the author, *Themeda* was still the dominant grassland types with its subtypes, with 6 variants. *Themeda-sporobolus* grassland was still the dominant type on the open western part of MMNR, and this is similar to the outcome of this study. This area is important for the resident herbivores, that utilize the area in the wet season, and by the migratory wildbeeste, during the dry season. Other grassland types, that were clustered using different methods e.g ordination, were also achieved in this study. For example, the *Cymbopogon caesius* grassland, and in this case it was only one sample (S-32) . This grassland is least palatable, and is avoided by grazers. *Chloris pycnothrix* type was also a single sample (W-5), but previous studies confirm its indeed a type (McNaughton, 1983). This grassland is an annual common in disturbed areas, and its growth form, restricts it from grazing, making it a distubance grassland. It is highly palatable but has low grazing value (McNaughton, 1983).

According to (Wijngaarden, 1985), perennial grasses are preffered to annuals, after observing feeding behaviours of herbivores in Tsavo national park. Therefore, this might imply that areas where annuals are found might be of little value, and wildlife and livestock may fail to maximize their use. On the other hand, perrenials, especially those that can withstand grazing pressure, due to their physiological adaptations, thus eliminating herbs, which grow from the apex, and when grazed, cannot withstand the pressure (Sinclair & Griffiths, 1995). Most of the samples had perennial grass species, and this could be due to that explanation. Areas inhabited by communities on the north eastern side, have high concentration of palatable species like

Themeda. Palatable grass species escape grazing by growing between the least palatables, and thus they are avoided by the grazers (Sinclair & Griffiths, 1995). This is evident in the *Themeda-sporobolus* grassland type, which had a high concentration of *Sporobolus* and *Cymbopogon caesius*, which are least palatable. This is evident in samples (s-46,s-47,s-41,s-51,s-52a and w2). Herbs were present in most sites though in low cover, but in nearly all grasslands (see appendix 1).

Grazing intensity has been attributed to the different species composition, although it was not a subject of study in this particular study. McNaughton (1983) notes that herbivores have an effect on the species composition, because some species disappear if grazing stops. Therefore, overgrazing might explain the relatively high occurence of some rare species in some sites, which indicates degradation (Toxopeus, 1999). In areas with high livestock and wildlife density, the grass had been grazed to very low levels and occurence of invasive species like *Solanum incanum* was common (photo 2), as well as areas within the MMNR, with a high density of wildlbeestes. *Solanum incanum*, was present in the tall grasslands (See appendix). Sinclair & Griffith (1995) observed that, herbs have a negative impact on wildbeestes, because they inhibit grazing, hence reducing the pressure. This helps to stabilize their population. Bare type 1 also contains *Solanum incanum*. Since this herb is invasive, this is an indicator, that most areas could are deteriorating.

Palatability of the grasslands varied with the grasslands. *Eragrostis tenuifolia* typicum (species poor area), and *Enneopogon schimperanus* which are least palatable, are the only grassland types found to be entirely least palatable. Least palatable species could gain dominance in the some types. For example, s-32 is inside that MMNR, in an area dominated by *Themeda* and *Sporobolus*, but this sample had a very high cover of an annual, *Cymbopogon caesius*, which dominates when *Themeda* grasslands are disturbed. This could be attributed to off-road driving (Mundia & Murayama, 2009). *Themeda grassland* is very dominant in this region, whereas inside the MMNR, it is mixed with *Bothriochloa*, which is intermediate. This could be due to the resistance to grazing pressure, as well as association to fire resistant grass species (McNaughton,1983).
The statification of the areas into complexes, also made it possible to make the sampling more representative. The use of SD in the field to show where differences are likely to, because where difference were observed in the map, it was easy to visualize that and give The trend map shows these areas are on the downward trend (see table 7). Other studies (Muthoni, e*t al*, 2014), have found out that *Cynodon dactylon* produces cyanide, due to trampling and overgrazing by herbivores, as a defence mechanism from grazing. When livestock graze, it causes bloating.
Trees and high shrubs types (table 3), showed a relationship with environmental variables too. These variations in the types, can also be related to previous studies. Van Essen, 2002, using TWINSPAN to cluster woodlands, found six forest and shrubland types, *Diaspyros*, *Croton* riverine, *Croton* slope thicket, *Euclea* forest type, and *Grewia*. The focus of this study was on grasslands and limited sampling was done in the gallery forests, even when encoutered in the complexes. However, the only type not encountered, was *Diaspyros*, *Croton* riverine types.

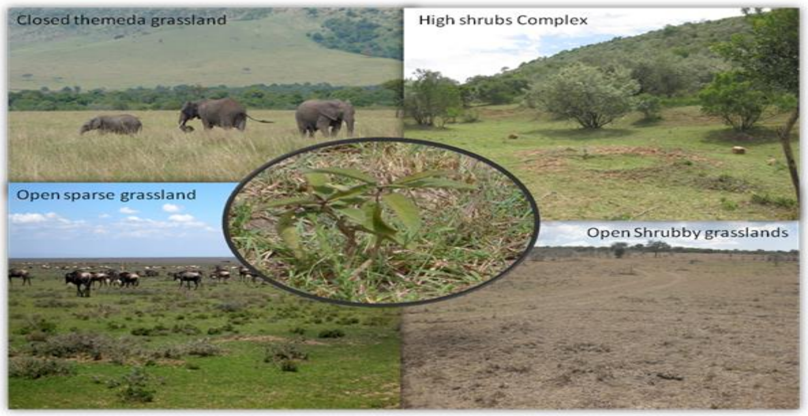


Photo 1. Different landcover types and Solanum incanum (center) which has inhabited the Mara ecosystem. Solanum is a common invader in the Mara, especially in the fields where wildebeests are common

5.2. THE MATRIX LEGEND

The legend contains four dimensional approach in discriminating vegetation types. Results from this study reveal that hyperspectral imagery holds a potential to map vegetation types, based on the NDVI variables (median, trend and SD), because they show a relationship with the different cover types. The median and standard deviation, show a pattern that can be related to the resulting vegetation map. However, in some cases, it cannot differentiate different vegetation types. A previous study conducted in this ecosystem by (Oindo *et al*., 2003), for estimating species richness, using the same approach of Braun Blanquet and Landsat TM imagery, was able to discriminate 6 landcover types. Reed *et al*., 2009, used a posteriori legend and classified the vegetation types in the Mara-Serengeti ecosystem, using Landsat 7 ETM. However, the output did not account for rainfall variability, and the classification of the vegetation types was much generalized. Longterm NDVI variables of MODIS, played a role in discriminating differences broad land cover types. The 71 classes image, had an additional power relating to the discrimination, where the SD and Median could not discriminate. For example, the *Themeda-Sporobolus* grasslands in the MMNR, could be discriminated easily using class 48. Apparently, this concided with grass height (see table 7). They all had an input in distinguishing some types, which would have been impossible with the traditional mapping approaches. On the other hand, the median was able to discriminate a croton shrubland types, despite it being dense, from other high shrubs and trees, probably because its not evergreen.

The ability of the trend to show the deteriorating areas, is of concern, because it can be used for ecological studies, especially to monitor ecological hotspots. Pettorelli *et al*., 2005, highlighted on the need for more research on vegetation distribution to monitor fragmentation and land degradation, and emphasized on the need to use NDVI to monitor vegetation dynamics. Since the Mara ecosystem is rich in species, this is invaluable information for ecologists. Palatability and Shannon diversity index are important aspects in monitoring. Most sites had a weighted palatability of 0.5, which is close to 1(highly palatable). The Shannon diversity ranged from 0.6-.1.7. This shows that some site are more species rich than others. This information was added to the matrix legend (Table 7), because palatability and Shannon diversity index relate directly to the vegetation types. It can be traced in the future, to show which areas have improved or deteriorated. Küchler & Zonneveld, 1988, support this idea, and emphasize that, a vegetation map is made more meaningful, if environmental process taking place at that time, since it makes the vegetation map dynamic.

Photo 2. Grasslands showing the different NDVI classes, and the different floristic types, that they discriminated (inset is a Croton dichogamus shrubland within a complex), Class 25 is sample s-19, Class 48 is s-38-c, Class 39 is sample 45-1b and Class 18 is s-4b (photo credits; Kees and Bert)

5.3. VEGETATION MAP

The vegetation map (Fig. 7), was the final output that was produced from the floristic and NDVI variables. It coincides with what was collected on the ground. The map clearly shows that is a similar pattern of vegetation, with the Google Earth Image, which can even be delineated. This landcover pattern observed, is as a result of soil and rainfall gradient (Victoria J. B., 2003). This shows that, longterm NDVI statistics and floristic types, could be related to in most cases, and therefore, could be a shift from the existing of mapping floristics, and landcover types, using only MODIS images alone (De Bie & Skidmore, 2010, Ali *et al.*, 2013) .However, it is hard to discriminate different landcover types based on the SD, Median and Trend values, and therefore the 71 classes has to be used. The vegetation map however, is a clear indication that it is possible to that the clustered vegetation could be related to NDVI variables. Viña et al., 2012, were able to assess floristic diversity, using MODIS, and concluded that similar areas have similar floristic characterises, and phenology. In this study, floristics have been clustered manually, and using environmental variables. It was not expected what would be on the ground, even after designing the sampling scheme. This shows that the clustering was also a success. The fieldwork was conducted during the end of the dry season, June-October, and it is clear that probably there would have been better results, if it was conducted when the vegetation is at its peak, during the rainy season. Moreover, the methods used to map in this ecosystem have had effects of rainfall which has been filtered by using the NDVI variables. The time aspect of the hyperspectral imagery, can enable monitoring to be done, and it can be traced back. This exclusion of weather variability also enables this map to be more relevant. Manual clustering of vegetation seems to produce good results, due to understanding of the clusters behaviour. The data used for this study was limited due to the time spent in the field (see appendix 1), but this holds a promise that with more data collection in the future, the results can be improved.

6. CONCLUSIONS AND RECOMMENDATIONS

Monitoring of ecosystems require consistent and longterm information, that provides an overview of the changes that taking place at a particular time. This is more specifically because, natural resource managers need to be on the alert on what is happening on the ground, so that they can be able to make good policies that safeguard the available resources. The Maasai Mara ecosystem has a wealth of biodiversity, which is a major foreign exchange earner, besides supporting livelihoods to the local communities.

This study has demonstrated a way of combining traditional floristic classification using manual clustering, and the resulting landcover types combined with hyper-spectral NDVI variables (71 classes, trend, median and standard deviation), to produce a legend and a vegetation map. Longterm NDVI statistics which are, to map landcover types. The most striking thing about these longterm NDVI variables, is their power to filter out the effects of rainfall, which have hampered vegetation mapping in this ecosystem. Therefore areas with rainfall variability effects, that have affected earlier mapping efforts, can now use this approach. MODIS imagery, has high temporal resolution and therefore, this longterm availability can be utilized to monitor ecologically sensitive areas like the Maasai Mara Ecosystem. The SD, Median and Trend, with their power to distinguish various features, adds to the wealth of information that can be used. The data is four dimensional, and therefore can be used to study different environmental aspects. The sampling scheme that was designed from these images, provided an effective way of sampling in representative areas, without necessarily traversing into areas that otherwise would be dangerous. The resulting landcover types corroborated with previous studies, and added value, since these tools were able to discriminate the vegetation well, even after generalizing them. This approach saves time and resources, because, sampling can be done very close to the roads, and provide valuable results.

6.1. RECOMMENDATIONS

Longterm monitoring of vegetation can be done successfully using hyperspectral remote sensing. MODIS offers the best alternative to traditional mapping approaches, due to its regular availability at a low cost. The results found in this study can be improved by collecting more data, to improve on the results that were found, hence improving the vegetation map. The relationship between longterm NDVI variables, environmental variables in the preparation on the legend, based on floristic structure and types, should be focused on, in future research. The legend, can also be enriched by adding information on other ecological aspects such as rangeland condition. This could provide valuable ecological information and as well as inform the best policies to put in place, in the MMNR, Conservancies and the communal ranches within this ecosystem. Furthermore, the results of this study, can be replicated to other areas, and a different scale, and more additional information added. This is very crucial because change in a particular landscape in both space and time could lead to changes in vegetation structure and species composition.

Rangeland condition assessment should also be a focus, find out the relationship between landcover structure, floristics and land degradation. Natural resource managers, pastoral communities and other stakeholders, can benefit from the output of such results, to guide them where pastures are available for their stock. Further research using the hypertemporal approach, can improve the results from this output, by collecting more samples, which will add more value to the vegetation map.

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APPENDICES

Appendix: 1 (see at the end)

Appendix 2 : Plant species Composition

GRASSES	HERBS	SHRUBS	TREES
Aristida adoensis	*Tragus berteronianus*	*Euclea divinorum*	*Euclea divinorum*
Microchloa kunthii	*Abildgaardia ovata*	*Ormocarpum trichocarpum*	*Ficus thorningii*
Bothriochloa insculpta	*Kyllinga nervosa*	*Tarchonanthus camphoratus*	*Lannea schweinfurthii*
Sporobolus pyramidalis	*Orthosiphon parvifolius*	*Croton dichogamus*	*Haplocoelum foliosum*
Themeda triandra	*Barleria argentea*	*Combretum molle*	*Acacia gerrardii*
Pennisetum hohenackeri	*Agave americana*	*Grewia similis*	*Boscia coriacea*
Cymbopogon caesius	*Maytenus putterlickioides*	*Cadaba farinosa*	*Olea europaea ssp. africana*
Setaria plicatilis	*Sida tenuicarpa*	*Sida ovata*	*Cordia monoica*
Cynodon dactylon	*Indigofera volkensii*	*Acacia drepanolobium*	*Acacia drepanolobium*
Pennisetum mezianum	*Cucumis aculeatus*	*Acacia kirkii*	*Acacia kirkii*
Eragrostis tenuifolia	*Ipomoea kituensis*	*Dichrostachys cinerea*	*Acacia xanthophloea*
Chloris gayana	*Cissus rotundifolia*	*Acacia nilotica*	*Rhus natalensis*
Chloris pycnothrix	*Psiadia punctulata*	*Acacia brevispica*	
Enneapogon schimperanus	*Hypoestes forskahlii*	*Aloe kedongensis*	
Harpachne schimperi	*Kalanchoe densiflora*	*Tinnea aethiopica*	
Eragrostis paniciformis	*Ipomoea kituensis*	*Psychotria kirkii*	
Digitaria abyssinica	*Barleria eranthemoides*	*Erythrococca bongensis*	
Heteropogon contortus	*Blepharis edulis*	*Commiphora africana*	
Abildgaardia ovata	*Blepharis integrifolia*	*Zanzaveria parva*	
Eustachys paspaloides	*Crabbea velutina*	*Maytenus heterophylla*	
Chrysochloa orientalis	*Psilotrichum elliotii*	*Hypoestes forskahlii*	
Eragrostis chapelieri	*Euphorbia chordata*	*Justicia elliotii*	
Cymbopogon pospischilii		*Solanum incanum*	
Eragrostis cilianensis		*Sida acuta*	
Cycnium herzfeldianum		*Psilotrichum elliotii*	
Digitaria velutina		*Lippia kituiensis*	
Eragrostis cilianensis		*Acacia gerrardii*	
Trifolium baccarinii		*Hermannia uhligii*	
		Balanites aegyptiaca	
		Boscia coriacea	
		Balanites aegyptiaca	
		Maerua decumbens	
		Solanum arundo	

Sample no.	Species	Cover	Palatability	Code	Weighted Average	Cover	Code	nted palata	Average P
s-4	*Aristida adoensis*	60	Intermediate	2	85.71	60	2	1.71	1.000
	Aristida adoensis	10	Intermediate	2	14.29	10	2	0.29	
					100.00	70			
S28	*Aristida adoensis*	20	Intermediate	2	100.00	20	2	0.67	
						20			
s19	*Aristida adoensis*	10	Intermediate	2	33.33	10	2	0.67	1.000
	Aristida adoensis	20	Intermediate	2	66.67	20	2	1.33	
						30			
s45	*Bothriochloa insculpta*	40	Intermediate	2	53.33	40	2	1.07	
	Cynodon dactylon	15	Highly palatable	1	20.00	15	1	0.20	0.556
	Eragrostis tenuifolia	10	Least palatable	3	13.33	10	3	0.40	
	Digitaria abyssinica	10	Highly palatable	1	13.33	10	1		
					100.00	75			
s43	*Bothriochloa insculpta*	25	Intermediate	2	83.33	25	2	1.67	
	Sporobolus pyramidalis	15	Intermediate	2	50.00	15	2	1.00	1.333
						30			
s-52	*Sporobolus pyramidalis*	10	Intermediate	2	6.45	10	2	0.20	
	Themeda triandra	60	Highly palatable	3	38.71	60	1	0.60	
	Pennisetum hohenackeri	20	Intermediate	2	12.90	20	2	0.40	
	Cymbopogon caesius	25	Intermediate	2	16.13	25	2	0.32	
	Sporobolus pyramidalis	20	Intermediate	2	12.90	20	2	0.26	0.280
	Cymbopogon caesius	20	Intermediate	2	12.90	20	2	0.26	
					100.00	155			
s-44	*Bothriochloa insculpta*	85	Intermediate	2	62.96	85	2	1.26	
	Bothriochloa insculpta	50	Intermediate	2	37.04	50	2	0.74	1.000
					100.00	135			
s-31	*Bothriochloa insculpta*	30	Intermediate	2	54.55	30	2	1.09	
	Themeda triandra	10	Highly palatable	1	18.18	10	1	0.18	
	Eragrostis tenuifolia	15	Least palatable	3	27.27	15	3	0.82	0.697
					100.00	55			
s-39-2	*Bothriochloa insculpta*	20	Intermediate	2	21.05	20	2	0.42	
	Sporobolus pyramidalis	15	Intermediate	2	15.79	15	2	0.32	
	Themeda triandra	50	Highly palatable	1	52.63	50	1	0.53	0.342
	Cynodon dactylon	10	Highly palatable	1	10.53	10	1	0.11	
					100.00	95			
s-39-1	*Bothriochloa insculpta*	20	Intermediate	2	21.05	20	2	0.42	
	Sporobolus pyramidalis	15	Intermediate	2	15.79	15	2	0.32	
	Themeda triandra	50	Highly palatable	1	52.63	50	1	0.53	0.342
	Cynodon dactylon	10	Highly palatable	1	10.53	10	1	0.11	
					100.00	95			
s-40	*Bothriochloa insculpta*	20	Intermediate	2	23.53	20	2	0.47	
	Themeda triandra	20	Highly palatable	1	23.53	20	1	0.24	0.588
	Pennisetum hohenackeri	45	Intermediate	2	52.94	45	2	1.06	
					100.00	85			
s-38	*Sporobolus pyramidalis*	40	Intermediate	2	44.44	40	2	0.89	
	Themeda triandra	40	Highly palatable	1	44.44	40	1	0.44	
	Pennisetum hohenackeri	10	Intermediate	2	11.11	10	2	0.22	0.519
					100.00	90			
s-46	*Sporobolus pyramidalis*	40	Intermediate	2	47.06	40	2	0.94	
	Themeda triandra	35	Highly palatable	1	41.18	35	1	0.41	
	Pennisetum hohenackeri	10	Intermediate	2	11.76	10	2	0.24	0.529
					100.00	85			
s-47	*Sporobolus pyramidalis*	40	Intermediate	2	47.06	40	2	0.94	
	Themeda triandra	35	Highly palatable	1	41.18	35	1	0.41	
	Pennisetum hohenackeri	10	Intermediate	2	11.76	10	2	0.24	0.529
					100.00	85			
s-41	*Bothriochloa insculpta*	10	Intermediate	2	11.49	10	2	0.23	
	Themeda triandra	39	Highly palatable	1	44.83	39	3	1.34	
	Cymbopogon caesius	38	Intermediate	2	43.68	38	2	0.87	0.816
						87			
s-51	*Sporobolus pyramidalis*	10	Intermediate	2	11.11	10	2	0.22	
	Themeda triandra	60	Highly palatable	1	66.67	60	1	0.67	

TREES AND HIGH BUSHES									
s50	Croton dichogamus		Highly palatable	1	66.67	80	1	0.67	
	Euclea divinorum/ficus thorningii		Highly palatable	1	33.33	40	1	0.33	0.500
					100.00	120			
s7	Sida ovata		Highly palatable	1	25.00	20	1	0.25	
	Acacia drepanolobium		Highly palatable	1	75.00	60	1	0.75	0.500
					100.00	80			
s36	Acacia kirkii		Highly palatable	1	100.00	65	1	1.00	1.000
					100.00	65			
s49	Croton dichogamus		Highly palatable	1	75.00	60	1	0.75	
	Grewia similis		Highly palatable	1	25.00	20	1	0.25	0.500
					100.00	80			
s35	Tarchonanthus camphoratus		Highly palatable	1	70.00	35	1	0.70	
	Croton dichogamus		Highly palatable	1	30.00	15	1	0.30	0.500
					100.00	50			
s29	Euclea divinorum		Highly palatable	1	25.00	5	1	0.25	
	Tarchonanthus camphoratus		Highly palatable	1	75.00	15	1	0.75	0.500
					100.00	20			
S48	Croton dichogamus		Highly palatable	1	89.47	85	1	0.89	
	Cadaba farinosa		Highly palatable	1	10.53	10	1	0.11	0.500
					100.00	95			
s21	Croton dichogamus		Highly palatable	1	90.00	45	1	0.90	
	Grewia similis		Highly palatable	1	10.00	5	1	0.10	0.500
						50			
s5	Eragrostis tenuifolia		Least palatable	3	50.00	12	3	1.50	
	Chloris gayana		Highly palatable	1	50.00	12	1	0.50	1.000
						24			
s37	Croton dichogamus		Highly palatable	1	43.75	35	1	0.44	
	Combretum molle		Highly palatable	1	12.50	10	1	0.13	
	Euclea divinorum		Highly palatable	1	31.25	25	1	0.31	
	Ficus thorningii		Highly palatable	1	12.50	10	1	0.13	0.250
					100.00	80			
s12b	Themeda triandra		Highly palatable	1	100.00	10	1	1.00	
						10			
s27b	Cadaba farinosa		Highly palatable	1	74.07	20	1	0.74	
	Croton dichogamus		Highly palatable	1	25.93	7	1	0.26	0.500
						27			
s45b	Croton dichogamus		Highly palatable	1	100.00	60	1	1.00	
						60			
s44b	Euclea divinorum		Highly palatable	1	44.44	20	1	0.44	
	Tarchonanthus camphoratus		Highly palatable	1	55.56	25	1	0.56	0.500
						45			
s43a	Euclea divinorum		Highly palatable	1	62.50	50	1	0.63	
	Ormocarpum trichocarpum		Highly palatable	1	37.50	30	1	0.38	0.500
						80			
s27c	Euclea divinorum		Highly palatable	1	62.50	50	1	0.63	
	Ormocarpum trichocarpum		Highly palatable	1	37.50	30	1	0.38	0.500
						80			
s19a	Euclea divinorum		Highly palatable	1	25.00	10	1	0.25	
	Ficus thorningii		Highly palatable	1	75.00	30	1	0.75	0.500
						40			
s-50b	Euclea divinorum/ficus thorningii		Highly palatable	1	100.00	80	1	1.00	1.000
						80			
s13a	Euclea divinorum/ficus thorningii		Highly palatable	1	100.00	40	1	1.00	1.000
						40			

Appendix: 3 Grass species Palatability calculations

Appendix 3: Sample Data Sheets used

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)

A. LAND COVER/USE DATA – (semi-)natural or planted						
SAMPLE PLOT				POLYGON		
				General cover/use type (if complex, estimate % cover of each type)		
STRATA	HEIGHT	COVER %	DORMINANT SPECIES (for details p.to.)	TYPE	DESCRIPTION	%AGE
Trees						
Shrubs						
Herbs						
Grass						
Litter cover						
Bare soil						
Stones/rocky boulders						
ACTUAL LAND COVER				ACTUAL LAND USE		
OBSERVATIONS:						

B. PLANT SPECIES LIST						SCALE FOR COVER ESTIMATION
PLANT CODE	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% 6 = 55-65% 2 = 15-25% 7 = 65-75% 3 = 25-35% 8 = 75-85% 4 = 35-45% 9 = 85-95% 5 = 45- 55% 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. Range condition: 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. Termite molds							
4. Water: 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	Y	N	Domestic / Wild	7. Mechanized Agriculture 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 herd/wildlife: Count________ Movement: Free________ Restricted________ Interaction: YES/NO Frequency: Dry Season________ Wet season________ Mixed animals: YES/NO 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

	AREA AFFECTED	
EROSION: 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%		