TIME SERIES MONITORING OF BUSH ENCROACHMENT BY *EUCLEA DIVINORUM* IN OL PEJETA CONSERVANCY LAIKIPIA, KENYA

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Dedication

I dedicate this work to my Dad and Mum for the support and encouragement through the course, my siblings for their steadfast support and concern.

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Abstract

Savannah landscapes are extensively social-economically important ecosystems which support livelihoods. Despite their importance, they are facing a biome shift due to natural and anthropogenic induced perturbations leading to increase in woody species, a phenomenon referred to as bush encroachment. In Ol Pejeta Conservancy (OPC), *Euclea divinorum*, unpalatable woody species has become a concern due to its invasion into other habitat types which can potentially affect resources for various feeding guilds, consequently affecting ecosystem services. This study examined vegetation cover changes from 1987 to 2016, topographic features attributable to these cover changes, differences in species diversity and composition in encroached and non-encroached habitats as well as habitat preference or avoidance by wild animals in the conservancy. Landsat images acquired during dry seasons were processed and classified into various vegetation cover types. Infra-red motion triggered camera traps were deployed in 2km by 2km grids for 14 days and nights in June 2016 to examine species diversity, composition and habitat preference or avoidance by various feedings guilds in OPC. Results revealed that *E. divinorum* cover increased upward significantly from 1987-2016 (Mann Kendall test for trend analysis *tau 1, n=6, p = 0.009*). Further, digital elevation models, contours and slope based normalized difference vegetation index had influence on encroachment patterns by *E. divinorum.* Shannon Weiner diversity showed that species diversity and richness was higher in *E. divinorum* and lowest in Open grassland dominated areas while Hierarchical Cluster Analysis revealed that species composition similarity percentage was highest between *E. divinorum* and mixed bushland habitats. Jacobs' Index means revealed that *E. divinorum* habitat was significantly avoided by all feeding guilds ($t_1=2.253$, $d.f=3$, $p<0.001$) while *A. drepanolobium* dominated habitats were significantly preferred ($t_1=2.353$, $d.f= 3$, $p =0.030$). The findings show that increase in *E. divinorum* cover, which has higher species diversity and evenness, however is avoided by all feeding guilds in OPC. As such, there is need to actively manage encroaching species as well as further research on impacts of encroachment on grass biomass and diversity. These findings are beneficial to policy makers regarding management of healthy ecosystems.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ASL	Above Sea Level
DEM	Digital Elevation Models
DOS	Dark Object Subtraction
EDA	Exploratory Data Analysis
EMU	Ecological Monitoring Unit
ESRI	Environmental Systems and Research Institute
ETM	Enhanced Thematic Mapper
GIS	Geographic Information Systems
GLM	Generalized Linear Models
GPS	Global Positioning Systems
Ha	Hectares
HCA	Hierarchical Cluster Analysis
IUCN	International Union for Conservation of Nature
KML	Keyhole Markup Language
LAI	Leaf Area Index
LiDAR	Light Detection and Ranging
MODIS	Moderate-Resolution Imaging Spectroradiometer

NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-red
NPP	Net Primary Production
OLI	Operational Land Imager
OPC	Ol Pejeta Conservancy
PA	Protected Area
PAST	Paleontological Statistic Software Package for Education and Data Analysis
QGIS	Quantum Geographic Information Systems
ROI	Region of Interest
SCP	Semi-Automatic Classification Plugin
SPOT	Satellite Pour l'Observation de la Terre
TM	Thematic Mapper
TOA	Top of Atmosphere
USGS	United States Geological Survey
UTM	Universal Traverse Mercator
VIS	Visible wavelength
WGS	World Geodetic System

CHAPTER 1

INTRODUCTION

1.1 Background

Woody species are increasingly encroaching grasslands and open bush land globally (Dickie *et al*., 2007). These invaders often form persistent patches which alter composition and structure of the plant community in savannah (Wangen and Webster, 2006). Savannahs are defined as tropical seasonal ecosystems with continuous grass layer, mixed with forbs and sedges with variable cover of trees and shrubs. They are characterized by distinct dry and wet seasons. In Africa, savannah ecosystems have been widely relied on for livestock production and wildlife conservation especially wild herbivores. According to earlier research on these ecosystems, evidence accumulated has suggested that all over the world savannah ecosystems are declining/ altered by a phenomenon called “bush encroachment”. Bush encroachment is increase in woody vegetation density, cover and biomass in savannah and rangeland ecosystems (Oba 2000).

The increase in woody cover is attributed to overgrazing due to positive correlation between grazing pressure and increased woody cover in savannah. Other possible causes are increased precipitation rates (Joubert *et al*., 2008), fire suppression and favourable edaphic conditions (Sankaran *et al*., 2008, Oba 2000). However, moisture is a limiting factor in these savannah ecosystems exacerbated by low or erratic precipitation patterns. Hence, savannahs are fragile ecosystems that are sensitive to perturbations resulting to bush encroachment or habitat quality degradation.

Increase in woody species varies remarkably, such as landcover change from grassland to forested bushlands resulting to decreased grass biomass and by extension increase in fire intolerant woody species that can potentially affect species composition. It is more difficult to reverse woody encroachment than to control species abundance in an ecosystem (Khavhagali and Bond, 2008). Woody encroachment in savannah ecosystems is emerging as new threat in these landscapes with respect to land use. At the extreme, land cover changes in these ecosystems leads to reduced penetrability by medium to large herbivores. Increasingly, *E. divinorum* a woody species is considered as an encroacher species within its range in many parts. It is fast growing, unpalatable and fire resistant woody species (Sharam *et al*., 2006).

In Ol Pejeta Conservancy, here in after referred to as OPC in Laikipia Kenya, *E. divinorum* is regarded as an encroacher species locally. In most areas in the conservancy, this plant species is present and higher in areas such as valley bottoms and drainage channels where soil depth and moisture content are significantly high (Wahungu *et al*., 2013). Encroachment in isolated ecosystems may result to decline and/or extinction of native species and can potentially affect species diversity, distribution, abundance (Towns *et al*., 2006). As such, invasion has become a great concern and threat to conservation efforts, a wide spread ecological problem affecting savannah due to its associated costs in eradicating established invasive/encroaching species. It is worth acknowledging that no single approach can be employed to prevent, eradicate, manage or control invasive/encroacher species hence a combination of various techniques is preferred where its applicability is best. In most cases, mechanical, chemical and biological control techniques have been used widely to manage invasive species and restore degraded ecosystems.

Fire as a management tool has been used to control invasive species. In OPC, prescribed burning was employed as a way of controlling *E. divinorum* encroachment but abandoned when a study conducted revealed deleterious effects fire had on other plant species (Wahungu *et al*., 2009). Furthermore, use of fire despite many associated benefits such as removal of moribund grass, remains a debatable subject (Sharam *et al*., 2006).

1.2 Statement of the problem

Increase in woody species through encroachment in savannah ecosystems poses a serious threat to ecosystems function especially tree-grass coexistence. Grass-tree balance influence grassland/rangeland economic services, biodiversity conservation and ecosystem function at local and landscape scales (Gamedo *et al*., 2006). In OPC, a property which is actively managed for livestock production and wildlife conservation, encroaching species are becoming a major concern for management. *E. divinorum* encroachment towards *Acacia drepanobium,* grasslands and other open bush land vegetation cover types can potentially affect food resources for mega faunas in these ecosystems especially the critically endangered Eastern Black Rhino (*Diceros bicornis*, International Union for Conservation of Nature (IUCN 2011 Red Listing) and African Elephants (*Loxodonta africana*, vulnerable IUCN 2008 Red Listing) among other herbivores. This encroachment can as well potentially reduce the available ranging lands and to some extend exterminate some of the wild flora and fauna.

1.3 Justification and significance

Monitoring of ecosystems function and health is critical for ecosystems service realization. *E. divinorum* is an encroacher species (locally) and interferes with species diversity (Towns *et al*., 2006) in savannah ecosystems hence, understanding factors that contribute to its encroachment as well as impacts on other habitat types are important for management of these landscapes. As such, the research findings are crucial for wildlife and rangeland managers to inform sound decision making regarding management of these ecosystems for sustainable development.

1.4 Study objectives

1. To determine changes in the area under *E. divinorum* vegetation over time from 1987 to-2016 in OPC.
2. To examine topographic features attributable to the *E. divinorum* cover change in OPC.
3. To assess wildlife species diversity and composition in encroached habitats and “non- encroached” habitats in OPC.
4. To determine habitat preference or avoidance in encroached and “non-encroached” habitat by various feeding guilds in OPC.

1.5 Statistical Hypothesis

H_{01}: The area under *E. divinorum* vegetation cover has not changed significantly from 1987 to 2016 in OPC.

H_{02}: Wildlife species diversity and composition is the same in encroached and “non-encroached” habitats in OPC.

H_{03}: There is no significant difference in habitat preference or avoidance by various feeding guilds in OPC

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

African savannahs contribute significant revenue from game viewing in tourism industry as well as provide Ideal rangelands as grazing fields thus livestock production and further to larger extend as it is being observed currently, these landscapes are being converted for irrigated agriculture to support the burgeoning human population. Their attached utility value by local communities especially nomadic cannot be underscored due to its enormous contribution to their wellbeing. Changes in these ecosystems such as bush encroachment among others have led to rise in recurrent conflicts over grazing resources. Further, conflicts have also been witnessed between conservationists and pastoralists over the same resources. These conflicts are expected to occur occasionally if these land cover changes that alter/limit availability of a central resource continue to take place in these ecosystems. Bush encroachment is proliferation of often unpalatable woody species to both domestic and wild herbivores suppressing grass/leaves for grazers/browsers and to the extreme resulting to closed habitats thus impenetrable by these feeding guilds. This phenomenon leads to reduction in carrying capacity of these savannahs Ward (2005) thus artificial shrinking of the available ranging land.

2.2 Bush encroachment in savannah and its implications

Savannah structure and dynamics are driven by an array of factors which determines vegetation structure and composition. Chiefly, they can be grouped in two main driving factors thus; primary and secondary factors. Primary regulators can be available moisture, soil types, nutrients and topographical gradients which vary on temporal and spatial scales from local to global scales (Joubert *et al.*, 2008) while secondary determinants can be fire regimes (frequency, severity and duration), as well as herbivory (Van Langevelde *et al*., 2003). In this regard, structure and dynamism in savannah occurs as a function of secondary factors (disturbances) acting within the constraints of primary factors.

Although savannah ecosystems support an enormous community of both plant and animal species, they have continuously been exploited for livestock production, fuelwood, agroforestry, agriculture and infrastructural developments. As a result of these often-uncontrolled human economic exploitation of these ecosystems there has been drastic changes in vegetation structure, composition and productivity, biodiversity and distribution (Hudak *at al*.,2004, Foley *et al*., 2005).

As a response to these changes in savannah, protected areas (PA) have been designated for biodiversity conservation to curb further alteration and maintain savannahs in their pristine conditions. Nevertheless, these PA are experiencing characteristically unstable vegetation structure and composition due to the earlier mentioned dynamistic effects of both primary and secondary drivers of savannah landscapes (Hudak & Wessman 2001, Hudak *et al.* 2003, Hudak *et al.* 2004).

Woody cover in savannah ecosystems is a very important biophysical variable in determining the status of savannah (Gareth *et al.* 2007). As such, investigations in to spatial context of woody cover resource has been considered a key component in understanding patterns and distribution of species habitat requirement or habitat preference hence species density and diversity. (Mutanga *et al.*, 2004, Mutanga & Rugege 2006).

Encroachment of savannah ecosystems is becoming an ecological problem, a challenge for habitat ecologists and natural resource managers. Bush encroachment is typically a gradual replacement of grass and forbs by woody species (Van Auken, 2009) sometimes unpalatable to wild animals which can span from decades to centuries. Further, encroachment is considered as the most extensive and threatening life form in range degradation (Briggs *et al*., 2005, Blaum *et al*., 2007) whose implications can span vast areas of arid and semiarid landscapes globally (Asner *et al*., 2012). According to Ward (2005), bush encroachment significantly reduces carrying capacity of land for both livestock and wild herbivores as well browsers if their key resources are replaced, (Wessels *et al.*, 2006, Mutanga & Rugege 2006) typical examples of some wild animals affected include but not limited to black rhinos and elephants to mention but a few (*Acacia drepanolobium* forms a key diet hence its decline potentially affects their survival triggering management interventions). Further, encroachment by woody resources may influence fire regimes thus occurrence, severity, intensity and duration in savannah ecosystems (Hudak & Brockett 2004). As such, these land cover changes can potentially change persistence of biodiversity, soil moisture content levels, climate change and climate variability at temporal and spatial scales (Li *et al*., 2007). Increase in woody cover translates to increase in water demand and/or use by plants (Kim and Jackson, 2011, Nosetto *et al*., 2012), and consequently affect/ alter energy balance through changes in albedo (amount of reflected energy (Beltran Przekurat *et al*., 2008). In particular, in protected area, ecotourism is a major source of conservation income as such, due to bush encroachment it may suffer significantly if there is poor visibility for game viewing (Wigley *et al*., 2009). However, from another stand point it is worth noting that proliferation by woody species can also be beneficial to other people economic endeavours depending on land uses. Increased woody species translates to increased timber/wood for construction of shelters, fencing and firewood among other uses (Wigley *et al*., 2009). Further, in conservation areas, increase in woody species can increase food for browsing wild animals and increased avifauna diversity especially those which rely on woody species for shelter and fruits for food as their main source of diet (Wigley *et al*., 2009).

In other areas, prone to soil erosion such as riparian zones and water shades, increase in woody species controls soil erosion through soil anchoring by roots. Presence or absence of encroaching woody species and their positive or negative associated impacts on the ecosystems are debatable. To this end, drivers of encroachment are poorly documented with little existing literature highlighting possible drivers such climatic factors, land use practices and wild fires (Joubert 2007).

2.3 Fire and herbivory as forms of disturbance in savannah ecosystems

African continent is referred as "fire continent" with wide spread biomass burning forming an integral part of functioning African grasslands and savannah (Ward 2005). Climatic conditions are the driving form of fire ecology in African savannahs which have distinct dry and wet seasons, natural ignition sources as lightening and flammable fuels loads during the dry seasons (Ward 2005). Fire ecology is defined as response of biotic and abiotic components of the ecosystems after fire regimes (ward 2005). Fire regimes have changed with increasing population where natural fires have successively been suppressed by anthropogenic fires. In most tropical savannah, fires are initiated and controlled by humans hence occur frequently.

African savannah ecosystems are prone to fires which plays a vital role in determining composition and structure of these ecosystems. In the absence of fire, several savannahs could potentially develop in to closed thickets and forest, however over period this has seen development of fire tolerant species and fire depended flora (Bond *et al*., 2005). Fire has the ability to dictate changes that occur in savannah plant composition hence success of using fire relies on understanding fire and its impacts (fire and tree mortality). Pastoralists and rangeland managers have widely used fire to manipulate tree grass cover ratios (Oba 2000). Pastoralists or conservationists burn grasslands and savannah ecosystem in African to remove moribund grass/unpalatable resources to improve quality of grazing resource for domestic and wild animals. Another reason for burning is the need to remove/ suppress spread of encroaching woody species which have been identified to have deleterious effect on grazing resources. This has been achieved through prescribed burning and understanding fire regimes, fire intensity and fire severity by controlling fuel loads comprising of dry biomass (plant debris). Several fire parameters are used to understand fire ecology though direct measurement of fire is difficult hence post fire indicators such as leaves and bark scorch height and percentage of top kill are mostly used as surrogate measures (Navashni *et al*., 2006).

There are different types of fires. The most common types of fires in savannah are surface fires which burn as either back fire or head fire (Trollope 2011). Under extreme fire conditions, crown fires can also occur and are sustained by abundance and continuity of aerial fuel loads. Research work investigating effects of surface fires on grass swards reported significant differences. Back fires significantly suppressed regrowth of grass compared to head fires (Trollope 2011). This is due to critical threshold temperatures maintained at 95ºC for approximately 20 seconds longer compared to head fires according to Trollope (2011). Further, more heat was released to the ground by back fires compared to head fires and the implications are that shoot apices of grass are adversely affected during back fires than during head fires (Trollope 2011). As such, different fire types have different impacts on grass swards (Trollope *et al.*, 2003). Height of fire flames contributes to increase in temperatures hence top kill is severe during head fires as opposed to back fires due to differences in height of the flames. Understanding of the fire ecology can be relied on especially during prescribed burning meant to control or suppress encroachment by woody species.

However, despite these numerous benefits of fire in management of savannah ecosystems, they do contribute significantly to woody vegetation perturbations. Impacts of fire on other plant species are poorly documented since most fire managers focus on achieving certain objectives as opposed to overall ecosystem integrity.

Savannah ecosystems support wildlife conservation and livestock production (Grace *et al.*, 2006). In some cases, savannahs are purely managed for livestock production or wildlife conservation. However, recently both livestock production and wildlife conservation are being practiced under same land to maximize profits. Whenever carrying capacities are exceeded, tree/grass ratio is affected thus altering plant community composition as such, a form of disturbance is impacted on these ecosystems. Further, wild animals especially mega fauna such as elephants are known drivers of changes in savannah ecosystems (Bond 2008, Pringle *et al.*, 2015). This is due to their ability to open up closed habitats by knocking down trees. These forms of disturbances may by pass human eye since their cumulative impacts will need longer periods to be detectable. Using modern technology to process satellite images, these disturbances can be flagged out and enhance better understanding of these ecosystems.

2.4 Remote sensing and Geographic Information Systems (GIS) in habitat monitoring

Intensive ground surveys cannot keep pace with rapid land cover/change over large areas since they involve "wait and see" protocol hence new technologies are necessary (De Sherbinin 2005). These on-site field measurements require lots of resources thus funds and human capital investment which may be nearly impossible to obtain in the long run. Information and data needs have been growing in scope and complexity (De Sherbinin 2005).

Collecting information about a given object through non-conduct approach has led to revolution in monitoring and management of ecosystems. This approach is referred to as remote sensing. Ecological remote sensing can be divided in to three main parts. First, land cover classification which is the physiographical characteristics of the surface environment based on land cover types (Imam *et al*., 2009). It entails clustering of image pixel in to relatively similar pixel with same properties. Secondly, measurement of ecosystems functions at spatial scales such as leaf area index (LAI) and net primary productivity (NPP) through normalized difference vegetation index (NDVI) (Tageson *et al*., 2009) and thirdly, change detection thus flagging out land cover changes over a series of time for a given area hence providing an Ideal way of monitoring significantly large ecosystems (Pellikka *et al*., 2009). All the above-mentioned approaches, can be used to study an ecosystem for better management. Different satellite sensors offer data in different spatial and temporal resolution hence limitations in applicability of the data with respect to purpose. One the limiting factor is commercially of high resolution spatial data and supporting processing software. Further to this geometric scale has become a hindrance especially if the area under study is small hence data acquired by satellite with high spatial resolution are required. Land cover change and land use information can be obtained from the medium to course resolution acquired from satellites such as Landsat, Satellite Pour l'Observation de la Terre (SPOT) and Moderate Resolution Imaging Spectroradiometer (MODIS) (Wulder *et al.,* 2004) whilst fine scale disturbance/ cover changes can be monitored using fine scale spatial and temporal resolution sensors. As a result, high resolution remote sensed data sets reduce the problem of pixel mixture which is a pronounced challenge with medium to course resolutions (Hirose *et al.*, 2004, Lu & Weng, 2007). Often, this involves high cost in getting such data for instance, Quickbird which is among those with finest resolution such as IKONOS though too expensive to acquire. Several methods can be explored in order to derive desired outputs. Light Detection and Ranging (LiDAR), geometrical-optical method with high optical and resolution can be used to detect fine scale disturbances. Landsat Images supported by Google Earth Engine can be used to study vegetation cover over time as well.

2.5 Species Richness and Diversity: Camera Trap Approach

Land use and land cover change has profound implication on species composition and distribution (Ward 2005). Synergistic interaction (primary and secondary drivers of ecosystem) in savannah ecosystems can alter ecological services and functions whose consequence can modify species habitat utilisation and behaviour. In monitoring of species diversity and richness several approaches have been employed (Mounir and ZuhAir 2012) however there exists some drawbacks involved. Among the difficulties two are more bulging: inability to survey the entire area of interest and inability to detect all animals (Thompson 2004).

With advancement in technology, new methods have been developed to reduce disturbance, cost and document even rare and elusive wild animal species (Rowcliffe & Carbone 2008). This has led to development of camera traps that are infra-red and motion triggered or body heat triggered (Balme *et al*., 2009, Mccarthy *et al*., 2008). Interests and increase in camera trap use success has led to dramatic increase in number of publications involving their application (Rowcliffe & Carbone 2008). Camera traps have and are still being used to understand habitat preference and occupancy (Bowkett *et al.* 2007). Infra-red camera trap varies in size, functionality and use. In regard to these differences, they are different in prices hence factor that can hinder getting quality data for ecological monitoring work.

Cameras traps are efficient in conditions that hinder direct observation or ineffective direct surveys hence it has been made to possible study nocturnal animals or those that warry of human being or use microsites within a given habitat (Larrucea *et al.*, 2007, Mccarthy *et al*., 2008). They can provide nearly accurate estimation of species abundance especially terrestrial mammals and birds >1 kg though this will rely mostly on camera trap position and settings. Further, they can allow study of species diversity in a given habitat. Despite their use in species abundance estimation there are potential for biasness due to differential detectability of the species. In case baits are used animals may spend more time in front the camera resulting to numerous photo which may misinform the researcher and to deal with this problem one can discard photos of same species captured within a set time (Larrucea *et al.*, 2007, Tobler *et al.*, 2008, Zug, 2009).

Going forward camera traps offer ideal approach to survey of mammals especially if vast areas are to be covered and long term monitoring as opposed to direct survey. Cost wise is also way below compared to amount of finances required for long term monitoring using conventional ways.

CHAPTER 3

METHODS AND MATERIALS

3.1 Study area

The project site was Ol Pejeta Conservancy (OPC) which covers 90,000 acres (360km^2), a classic example of an African savannah. It lies between Mt. Kenya and the Aberdare Mountains (0^0 7.288’N,36^{0}42.384’E and 0^0 8.634’N, 37^0 0.605’E) (0^{0}1.831’S, 36^{0}46.578’E and 0^{0}5.7025’S 37^{0}2.492’E), at an average altitude of 1810m, mean annual rainfall of 739mm, mean maximum and minimum temperatures of 28^{o}C and 12^{o}C, respectively.

This is a privately-owned conservancy primarily established as a black rhino sanctuary but currently it has abundant wildlife, including Elephants (*Loxodonta Africana)*, Black Rhino (*Diceros bicornis)*, Northern White Rhino (*Ceratotherium simum cottoni*), Buffaloes (*Syncerus caffer*), Grevy’s Zebra (*Equus grevyi*), Plains Zebra (*Equus burchellii)*, several species of medium-sized gazelles, Lions (*Panthera leo*), Cheetahs (*Acinonyx jubatus*), Spotted hyaena (*Crocuta crocuta*), Striped hyaena (*Hyaena hyaena*), and Black backed Jackals (*Canis mesomelas*), among others.

It is also a chimpanzee sanctuary providing refuge for rescued chimpanzee from black markets. The conservancy has become a successful conservation site with integrated livestock production. There are several seasonal rivers and one permanent river Ewaso Nyiro River with its source at Mt Kenya and drains to Lorian Swamp, several boreholes and man-made dams.

Major land cover types include grasslands, *Acacia drepanolobium*, *Acacia xanthophloea, Euclea divinorum*, and mixed woodlands. The conservancy is surrounded by an electric fence with three "corridors" to allow movement of wild animals in and out of OPC (but movement of rhino species is prevented due to the risks involved). The conservancy is surrounded by agro-pastoral communities and towards the north by other adjoining conservancies. Location of the study site map showing the location of OPC within Laikipia County, Major towns and other facilities as shown in figure 1.

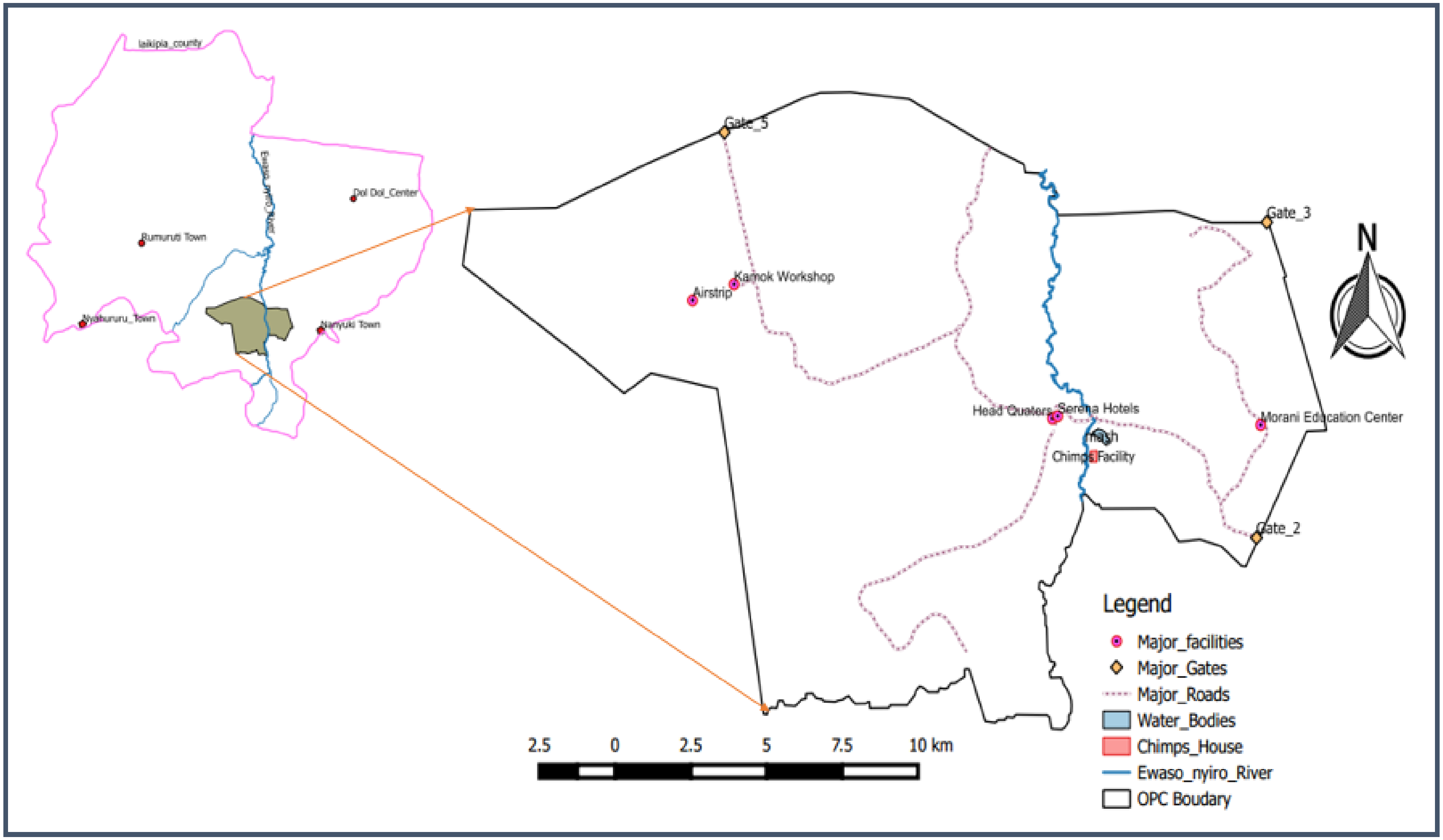


Figure 1: Map of Ol Pejeta Conservancy

3.2 Methods for Image Acquisition

Land cover thematic shapefiles of the Ol Pejeta Conservancy (OPC) created by Ecological Monitoring Unit, a research unit in OPC with support from Environmental Systems Research Institute (ESRI) were used to demarcate the study area. An overlay of the shapefiles on the Google Earth Satellite Layer on a Quantum Geographic Information Systems (QGIS) platform was used for creation of new layers based on observable features for the year 2016. Global Positioning Systems (GPS) points were collected on current areas colonized by *E. divinorum*. To allow perfect overlay of the features, the shapefiles were projected to the Universal Transverse Mercator (UTM) Zone 37N. The GPS points were converted to polygons and edited to precisely show areas currently occupied by *E. divinorum* species using a current Google Earth Satellite Layer (for 2016) as the reference.

3.2.1 Landsat Imagery Data Source and Materials

Here, Landsat Imagery time series data were obtained from United States Geological Survey website (USGS, 2016) as the primary data source for general land cover classification. Landsat imageries acquired during dry season either February or March and cloud free (< 3%) in the year 1987, 1995, 2000, 2005, 2010 and 2016 provided multitemporal data. The Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM)+ and Landsat 8 Operational Land Imager (OLI) were appropriate for general land cover trends and change analysis. The sensors had spatial (pixel) resolution of 30m.

Details of the images used in this study are given in table 1.

Table 1: Details of images used in the study

Satellite/Sensor	Date of acquisition	Path/Row	Spatial/ Temporal resolution
Landsat_5/TM	Feb_25_1987	168/60	30m/16 days
Landsat_5/TM	May_22_1995	168/60	30m/16 days
Landsat_7/ETM +	Feb_02_2000	168/60	30m/16 days
Landsat_7/ETM+	Feb_02_2005	168/60	30m/16 days
Landsat_5/TM	Feb_02_2010	168/60	30m/16 days
Landsat_8 OLI	March_28_2016	168/60	30m/16 days

Source: USGS website (USGS, 2016)

3.3 Pre-Classification of Digital Images Processing

3.3.1 Top of Atmosphere (TOA) Reflectance

As the light passes through the atmosphere, it interacts with other particulate maters such as haze, water vapour and smoke among others, hence can considerably affect the signal before and after interacting with the object in question (Chavez 1996, Lillesand *et al*., 2004). As a result, this may necessitate in situ atmospheric correction. In order to achieve better and clear Landsat scenes, TOA reflectance was performed using the algorithms as developed for Semi-Automatic Classification (SCP) Plugin Version 5.0 of QGIS software.

3.3.2 Dark Object Subtraction (DOS1)

Dark object subtraction (DOS) is a family of image based atmospheric correction techniques which include DOS1, DOS2, DOS3, DOS4. These techniques have one assumption according to Chavez (1996) that, within an image some pixels are incomplete shadows which are received by satellite as a function of atmospheric scattering. This assumption leverages the fact that on the earth surface, few target may be black or assumed one percent reflectance which is better that zero. Here, for the purpose of this study DOS1 technique was used as described by Luca, 2016 (Semi-Automatic Classification Plugin in QGIS release 4.8.0.1).

3.3.3 Image Re-Projection and Band Compositing

After the various image corrections, all images were re-projected to World Geodetic System (WGS) 84 Universal Traverse Mercator (UTM) Zone_37N and other vector data were re-projected to this projection system. The raster images were then clipped using a vector mask boundary of the study area.

3.3.4 Image Classification

Multitemporal Landsat images TM, ETM+ and OLI of 1987, 1995, 2000, 2005, 2010 and 2016 were used to study Land cover dynamics with more focus on changes in *E. divinorum* as the species of concern for this study. Here, classification used supervised classification technique which is an algorithm that uses spectral signature to identify different materials in an image and finally generate a thematic map of the land cover. In order to minimise potential of vegetation cover type mix up while classifying, google earth image satellite layer 2016 was used to precisely map different cover types. Further, an option in the classification plugin for Normalised Difference Vegetation Index (NDVI) was activated to display NDVI values of different cover types. This was used to enhance classification accuracy. This was the starting point to enhance classification accuracy. Further to this, 20 ground truthing sites were generated randomly, coordinates loaded in to GPS and visited to compare similarity between spectral output from Landsat and on ground reality. In order to analyse images through supervised classification semi-automatic classification for QGIS (also known as supervised classification) was used. This process requires creation of temporary region of interest (ROI) as vector file(s) which is saved as classification signature file in the plugin. Vegetation cover was assigned one macro class identity and separated finer in to five micro class identities to achieve desired results. Maximum likelihood algorithm which calculates probability distribution for the classes, using the Bayes' theorem estimating if a pixel belongs to a particular land cover class was used (Richards & Jia, 2006). This classification algorithm is preferred over the other algorithms due to its ability to use well developed probability theory. Assessment of spectral distance (spectral separability) to minimise classification errors was executed using Jefferies-Mutusita Distance where if asymptotic distance is 2 the signatures are completely different whilst, if it is 0 signatures are identical (Richards & Jia, 2006).

3.3.5 Accuracy Assessment and Classification Report

In order to evaluate the reliability/correctness of the classification output, the random ROI creation option in SCP was used to generate a total of 30 samples for reference purposes for error matrix calculation (Luca 2016). Here, overall classification for classification report 1987 was 80%, 1995 86% 2000 84% 2005 87% 2010 89% and 2016 88%. Finally, a classification report was generated giving proportion of each land cover and total areas occupied by each class in Hectares. Image processing and classification were done using Open source software QGIS.

3.4 Topographic features attributable to encroachment

3.4.1 Slope based Normalized difference vegetation index

Topographic features were examined using Normalized Difference Vegetation Index (NDVI) with reference to slope in OPC. Here, the NDVI equation was used to compute NDVI values as shown (Rouse *et al*., 1974)

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{VIS})}{(\mathrm{NIR} + \mathrm{VIS})}$$

Where NIR and VIS stands for spectral reflectance measurements acquired in near infra-red and visible regions respectively. Values range from -1 to +1 where values close to +1 are an indication of dense canopy with high chlorophyll content whilst close to -1 are land cover/or bodies with low chlorophyll content and those without chlorophyll content such as water bodies and bare soils.

3.4.2 Contours and Elevation overlaid on vegetation map

Here, contours and elevation map were created using Google Earth to generate coordinates and altitude of various points in OPC. A path was run over the google earth layer covering the area of interest. A file in Keyhole Markup Language (KML) format was generated which was uploaded to TCX converter (a freeware software for extraction of elevation) for extraction of the altitude. The file was converted in to recognizable file in QGIS and digital elevation models (DEM) as well as contours generated.

3.5 Wildlife Survey for Diversity, Richness Assessment and species composition

To examine species diversity and richness and compare between encroached and non-encroached sites, the entire OPC map was divided in to 2x2km grid for infra-red motion triggered camera trap deployment and further in three sectors namely Eastern, Southern and Northern. Camera traps Reconyx RM45 Hyperfire model and Bushnell Model were deployed systematically at the centroid of each grid within a given Land cover type taking cognize of animals' trails or paths to maximize animal photo captures. Camera traps were either mounted on a tree or housed in a metal cage for the case of open grassland and placed at knee height (50cm) above the ground surface. They were set to remain active for 24hrs with no delay in between photo taking session and in rapid fire mode.

Traps remained in the field for 14 consecutive days and nights and serviced after the seventh day to check cameras' battery level, memory card storage status and general condition of the camera trap. In between the two deployment sessions, there was a break of three days to allow for battery charging and cleaning of the storage cards in preparation for the next deployment event. Finally, all the data recording camera trap location, habitat type, species names, number of individuals and time, were downloaded from the memory card and cleaned (removing false triggers, duplicates, and blurred images) in readiness for analyses (Rowcliffe & Carbone 2008).

A total of 36 camera traps were deployed in the entire study area where 9 camera traps were used in each of the four vegetation classes under consideration thus *E. divinorum*, A. *drepanolobium*, Open grassland and Mixed bushland.

Total sampling effort was calculated as total number to cameras used multiplied by 24hrs they were set active multiplied by number of days they remained in the field hence;

Totals sampling effort 36 camera traps x 24hrs x 14 days = 12096 Hours

3.6 Data analyses

3.6.1 Landsat Image Analysis

Preliminary analyses of the Landsat classification output results were done in QGIS using the default user options in the SCP plugin version 5.0 (Luca 2016). Here, results such as land cover class proportions for further analyses were generated. Further, exploratory data analyses (EDA), Mann Kendall test for trend analysis as described by Gilbert, O (1987) and statistical models via Generalised Linear Models (GLM) to analyses time series land cover results were performed using R statistical software (R Studio Core Team development, version 3.1.2 2013).

3.6.2 Species richness and dominance across habitat types

Species richness is defined as variety of species/number of different species in a given habitat under consideration whilst species dominance is defined as most conspicuous and abundant species in a given habitat under consideration. (Shannon 1949)

Simpson’s index of dominance (C) (Shannon 1949) is calculated as

$$\mathbf{C=\Sigma(P_i)^2}$$

Where C = is the Simpson’s index of dominance

P_i = proportion of species i in the community

This is interpreted using the theoretical values ranging from 0 to 1 where, if values are close to 0 it’s an indication of a more even community while high values indicate less even or more dominated community.

3.6.3 Species diversity and evenness

Species diversity and evenness were computed using the Shannon wiener index (Shannon &Weinner, 1949) which is a robust index since it takes in to account for both species abundance and evenness on the species present (Krebbs 1999). Species evenness refers to how close in numbers each species in an environment is. It’s a measure of biodiversity which quantifies how equal a community is numerically.

Shannon Weiner index is calculated as;

$$H = \sum_{i=1}^{s} -(P_i * \ln P_i)$$

Where,

H = the Shannon diversity index

P_i = fraction of the entire population made up of species i

S = numbers of species encountered

$\sum$ = sum from species 1 to species S

This was executed using Paleontological Statistic Software Package for Education and Data Analysis version 1.0.0.0 (PAST).

3.6.4 Species Composition

Species composition refers to identity of all species that make up a community in a given ecosystem. Hierarchical Cluster Analysis (HCA), a multivariate test which groups observations by dissimilarity or similarity (Gauch 1982) was used to compare species composition in the four habitats cover types namely *Euclea divinorum* dominated area, *Acacia drepanolobium* dominated, Open grassland and mixed bushland. Linkage method was performed using Bray Curtis similarity analysis which uses species abundance data was performed and consequently cluster analysis used to generate dendrogram showing species composition similarity across the vegetation cover types.

3.6.5 Habitat preference or avoidance analysis by various feeding guilds in OPC

Preference and avoidance of habitat was tested using Jacobs' Index (Jacobs 1974) modification of a simple Ivlev Index (1961) which is a more robust test and is not affected by bias to rare habitat types and nonlinearity. Further, increasing heterogeneity is bound, defined and does not lack symmetry between selected and rejected values, hence Jacobs' index was deemed appropriate (Jacobs 1974). Jacobs' index is expressed as:

$$D_i = \frac{r_i - p_i}{r_i + p_i - 2 r_i p_i}$$

Where; r*i* proportion of observations in habitat *i* (habitat utilised) of that species and p*i* is the proportion of habitat *i* available in the study area.

Mean value Jacobs' indices for each habitat were tested using one sample t-test for significance preference or avoidance against a mean of 0. Further, one way analysis of variance was used to test significance avoidance or preference across the four vegetation types that were considered. Prior to these tests normality tests were performed to ascertain that data did not violate assumptions for parametric test (Palomares *et al.*2001) The Jacobs' Index values ranges from -1 for avoidance through 0 for random selection to +1 for preference.

CHAPTER 4

RESULTS

4.1 Vegetation map of OPC

Landsat image of 2016 produced the five major land cover types of focus which include *A_xanthophloea*, *E. divinorum*, Open grassland, *A. drepanolobium*, and Mixed bushland. These vegetation land cover types were in the following proportions; *E. divinorum* 49.65%, Open grassland 24.22%, *A. Drepanolobium* 17.00%, mixed bushland 8.84% and *A_xanthophloea* 0.29%. Further, area coverage for each vegetation cover type is as shown in table 2 while the vegetation map is as shown in figure 2.

Table 2: Proportion of various cover types for year 2016

Cover type	***Area Cover (Ha)***	***(% of vegetation type)***
E.divinorum	14455.98	49.65
Open grassland	7051.69	24.22
A. drepanolobium	4950.32	17.00
Mixed_bushland	2573.97	8.84
A. xanthophloea	85.45	0.29
Total	**29117.41**	**100%**

Further as shown in fig.2 *E. divinorum* has significant cover in eastern and southern parts of the conservancy. Additionally, it is found in areas along deep valleys and thus in areas with low elevation and deep black cotton soils. Northern sector of the conservancy has less cover of *E. divinorum* hence highly dominated by *A. drepanolobium,* open grassland and mixed bushland towards the north-west direction.

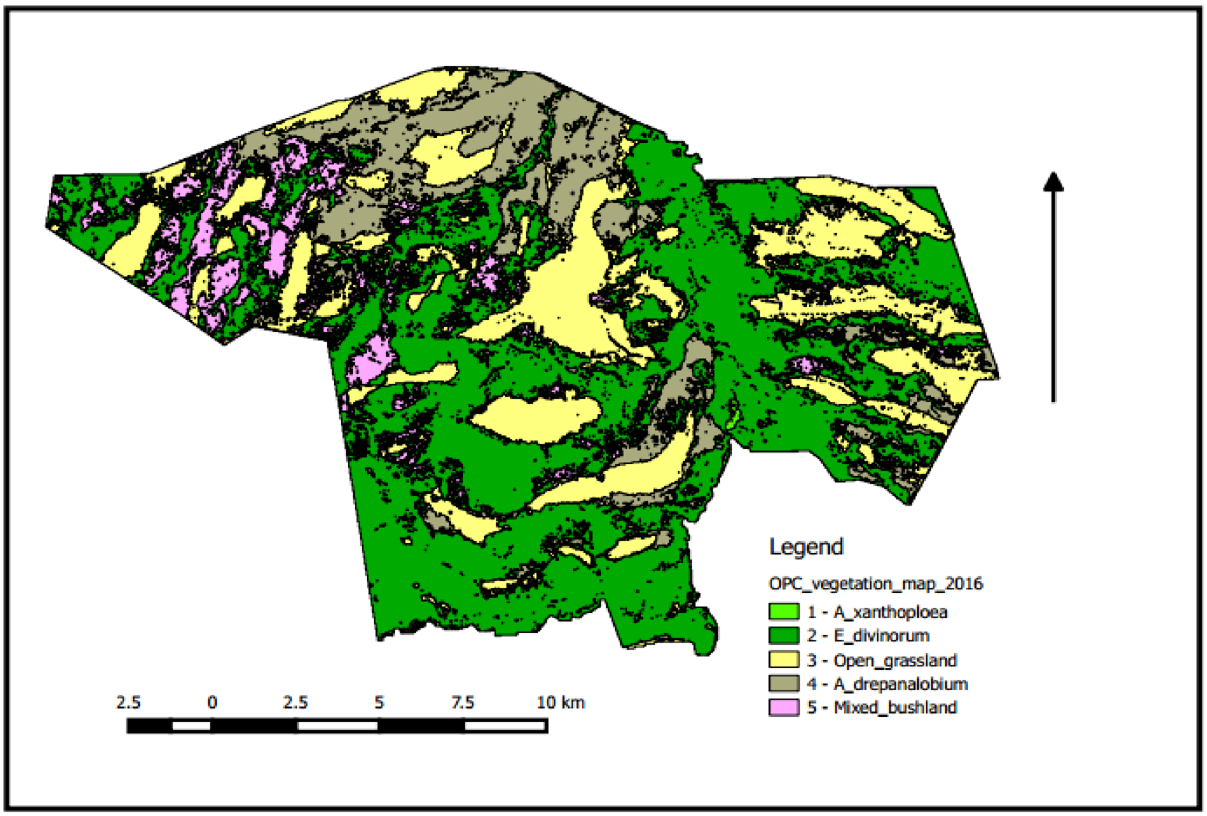


Figure 2: Vegetation cover map of OPC 2016

4.1.1 Land cover Changes with Reference to *E. divinorum*

Vegetation classes produced from image analysis include Open grassland, *A. drepanolobium*, *E. divinorum*, mixed bushland and *A. Xanthophloea* a riverine vegetation. However, in some images more classes were identified such as swamps and water bodies (with insignificant cover) which came to existence as a function of human intervention to provide more water for animals recently. Figure 3 shows *E. divinorum* cover in OPC in different years from 1987 to 2016.

Between the year(s) 1987 and 1995 the area of *E.divinorum* cover increased by 531.43 Ha. Between years(s) 1995 and 2000 the area of *E. divinorum* cover increased by 806.87 Ha. while between 2000 and 2005 the area in *E. divinorum* cover increased by 1909.95Ha. Between 2005 and 2010 there was increase in area coverage by *E. divnorum* by 5121.14Ha and between 2010 and 2016 there was an increase in area by 2491.39Ha. This increase was gradual but increased after 2000 whilst the greatest change in cover was between 2005 and 2010 as shown in figure 3.

Statistical analysis using Mann Kendall test for trend analysis was performed which revealed a significant monotonic (upward) increase in *E. divinorum* cover from 1987 to 2016 (tau 1, $p = < 0.01$).

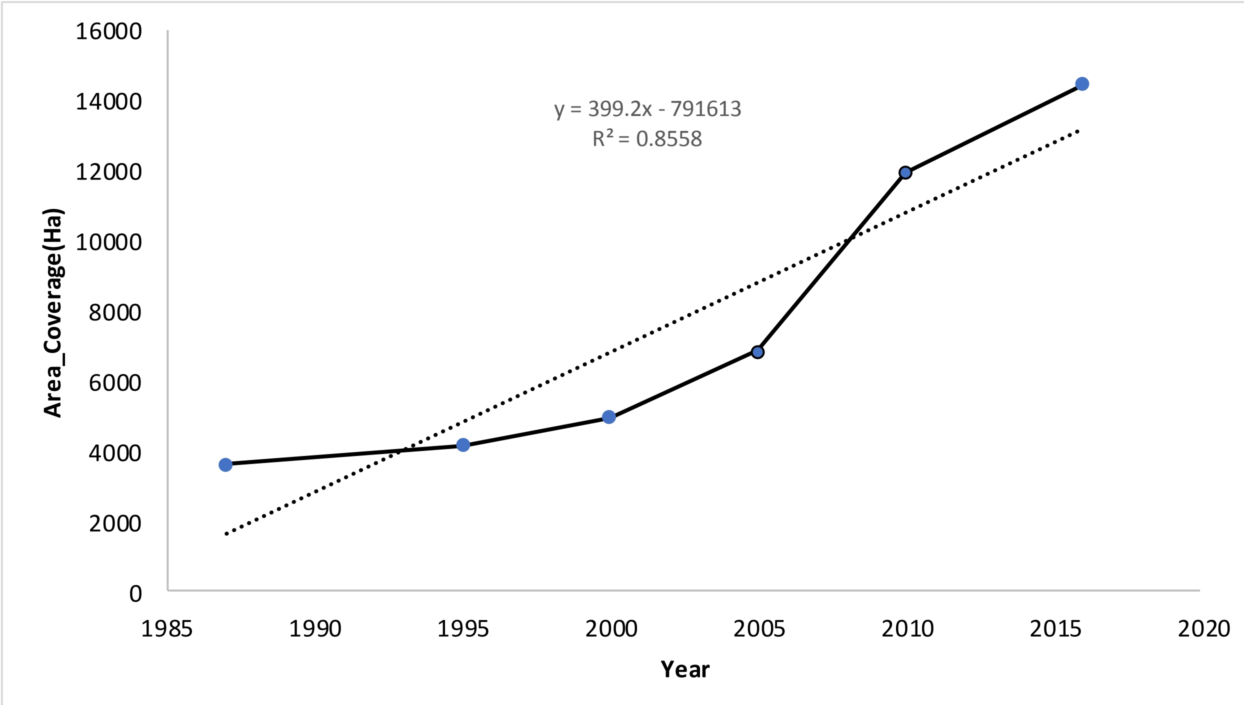


Figure 3: *Euclea divinorum* cover trends in OPC between 1987 and 2016

The rate of change between 1987 and 1995 annual increment was 66.42 Hectares/Yr. whilst annual increment rate between 1995 and 2000 and between 2000 and 2005 were at 161.374 Ha/Yr and 381.55Ha/Yr, respectively. Rates of change between 2005 and 2010 and between 2010 and 2016 were 1024.228 Ha/Yr and 415.232 Ha/Yr. The equation is as shown below

Area *(E.divinorum)* = - 791613 + 399*Year

R^2= 85.6%

4.1.2 Overall Land Cover Changes on OPC

It was evident from the study that, some land cover classes continuously increased in cover while others showed decrease between the first two years and increased in cover in the subsequent years. Further, the Land cover class of riverine *A. xanthophloea* was nearly completely lost <1% cover by the year 2016. Overall vegetation cover changes and trends in OPC for the study period are as shown in figure 4.

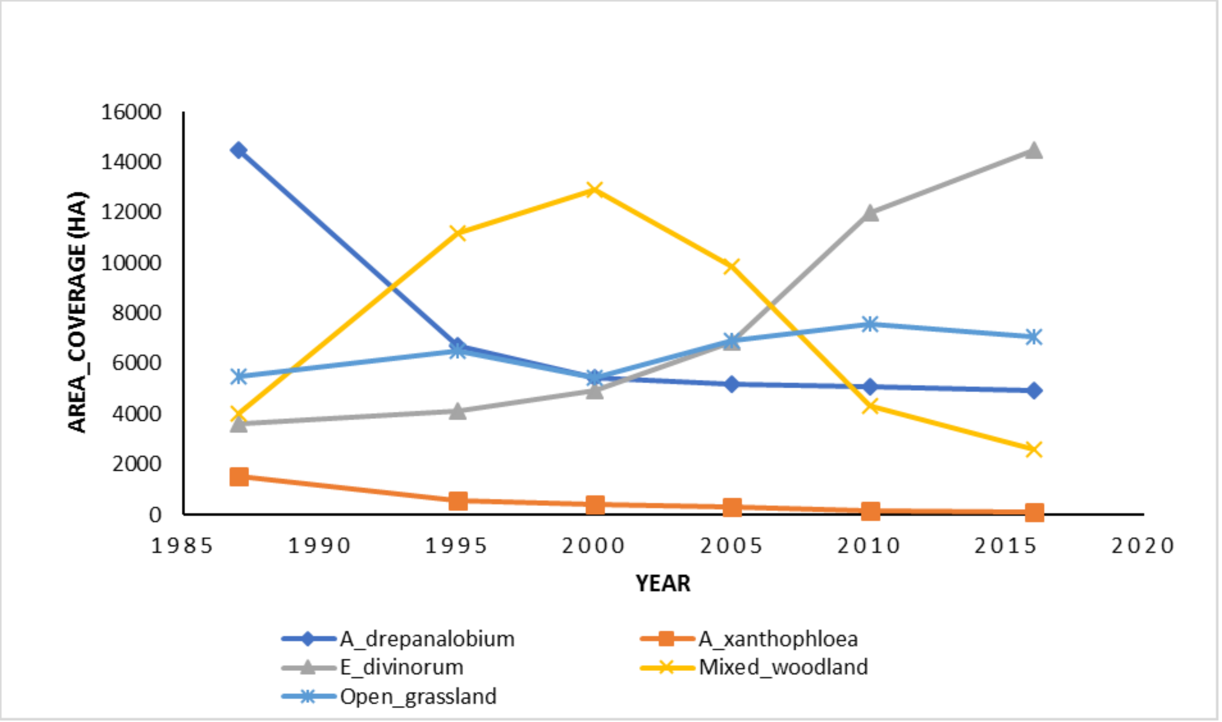


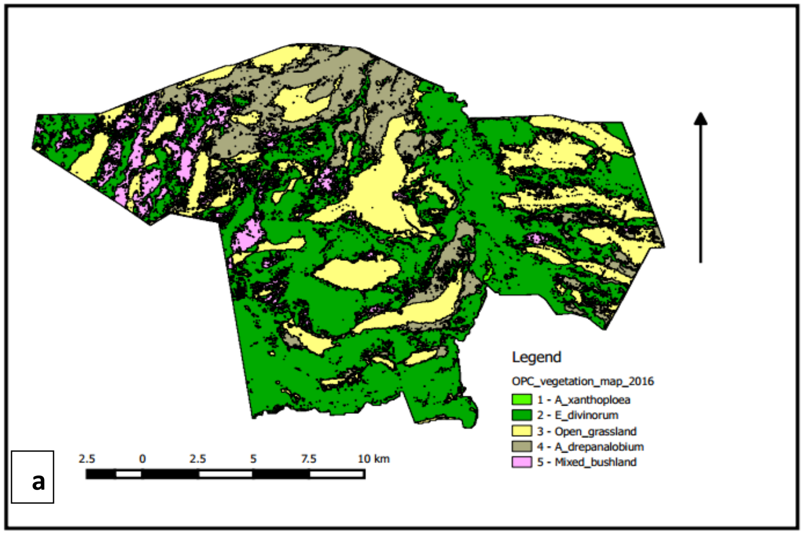
Figure 4: Overall vegetation cover types trends in OPC

From the exploratory land cover changes in the figure 4, it's evident that land cover changes are quite dynamic in the sense that there is increase or decrease in certain land cover classes or continuous decrease/increase in class cover. Particularly, *E_divinorum* has increased in cover throughout the study period where as *A_drepanolobium* and *A_xanthophloea* have decreased in cover over time throughout. On the other hand, Open grassland, and mixed bushland have either increased or decreased in cover in different time periods. Open grassland class, between 1987 and 1995 there was increase in cover +1025.63Ha followed by a decrease between 1995 and 2000 by -1060.47Ha and an increase in between 2000 and 2005 by +1665.406Ha, between 2005 and 2010 645.1346Ha and finally a decrease between 2010 and 2016 by -511.016 Ha. Overall there was an increase in open grass cover in the entire study period 1987-2016 by +1558.68 Ha.

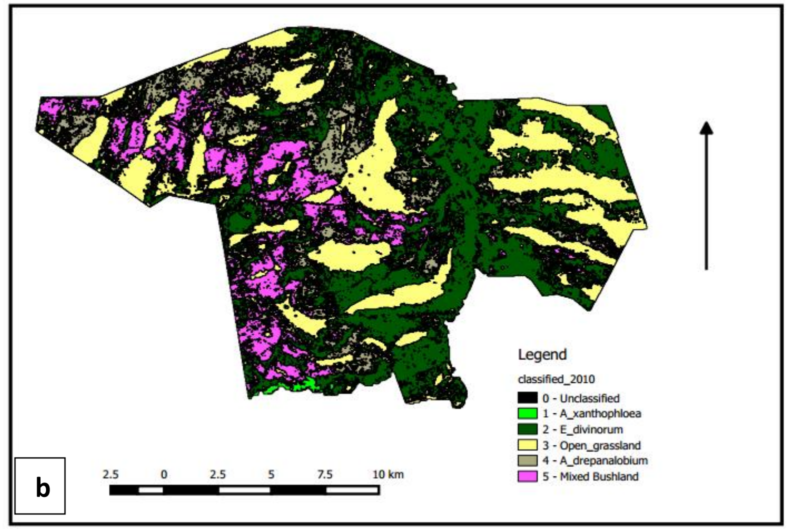
Another class cover under consideration is the mixed bushland, here there was increase in cover between 1987 and 1995 and between 1995 and 2000 by 7184.7 Ha and 1691.54 Ha, respectively followed by decrease from 2000-2005 by -3001.33 Ha, 2005-2010 a decrease by -5556.69 Ha and a further decrease between 2010 and 2016 by 1747.85 Ha. However, there was an overall decrease in class cover in the entire study period by 1429.73 Ha.

In proportions, different land cover classes were as reported in different years. In the year 1987 *A. drepanolobium* covered 49.72%, Open grassland 18.87%, mixed bushland at 13.75% followed closely by *E. divinorum* at 12.35% and least *A. xanthopholea* at 5.31%. in the year 1995 difference landcover proportions were as follows mixed bushland at 38.42%, *A. drepanolobium* at 23.09%, Open grassland at 22.39%, *E. divinorum* at 14.17% and finally *A. xanthophloea* at 1.92%. In the year 2000 cover proportions were as follows: mixed bushland covered 44.23%, Open grassland covered 18.72% followed closely by *A. drepanolobium* at 18.62, *E. divinorum* covered 16.94 while *A. xanthophloea* came distance at 1.48%. In the year 2005 Mixed bushland covered 33.93%, Open grassland at 23.76% followed closely by *E. divinorum* at 23.50%, *A. drepanolobium* at 17.77% and finally *A. xanthoploea* 1.04%. In the year 2010 cover proportions were as follows *E. divinorum* at 41.12%, followed by Open grassland at 25.99%, *A. drepanolobium* at 17.50%, mixed bushland at 14.85% and finally *A. xanthophloea* at 0.54%. Lastly, the year 2016 cover proportions were as follows: *E. divinorum* at 49.63%, Open grassland at24.22%, *A. drepanolobium* at

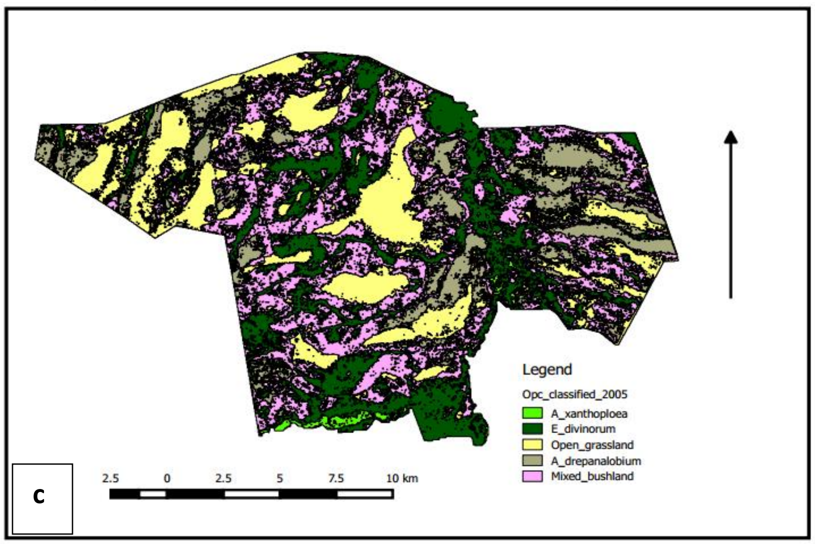
17.00%, mixed bushland 8.84% and finally *A. xanthophloea* at0.29%. The different land cover in various years are shown in figure 5 ab,c,d,e,andf



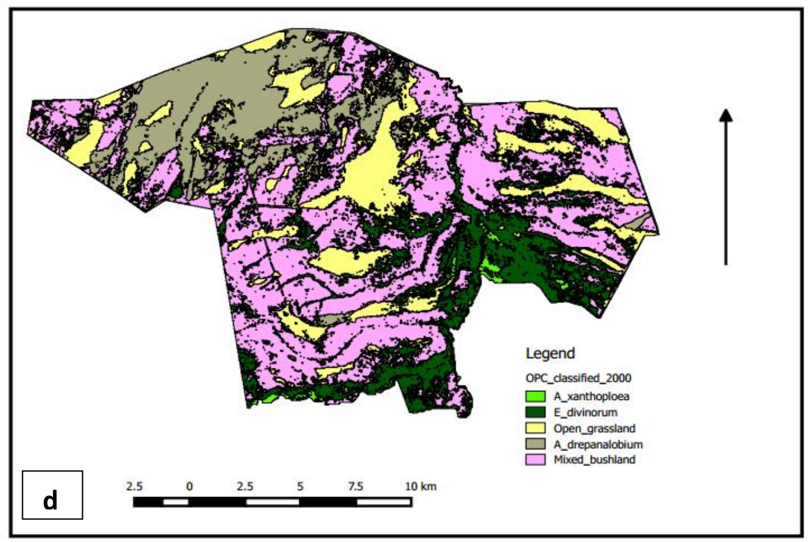
OPC Vegetation map for the year 2016 Landsat image OLI



OPC Vegetation map for the year 2010 Landsat Image TM

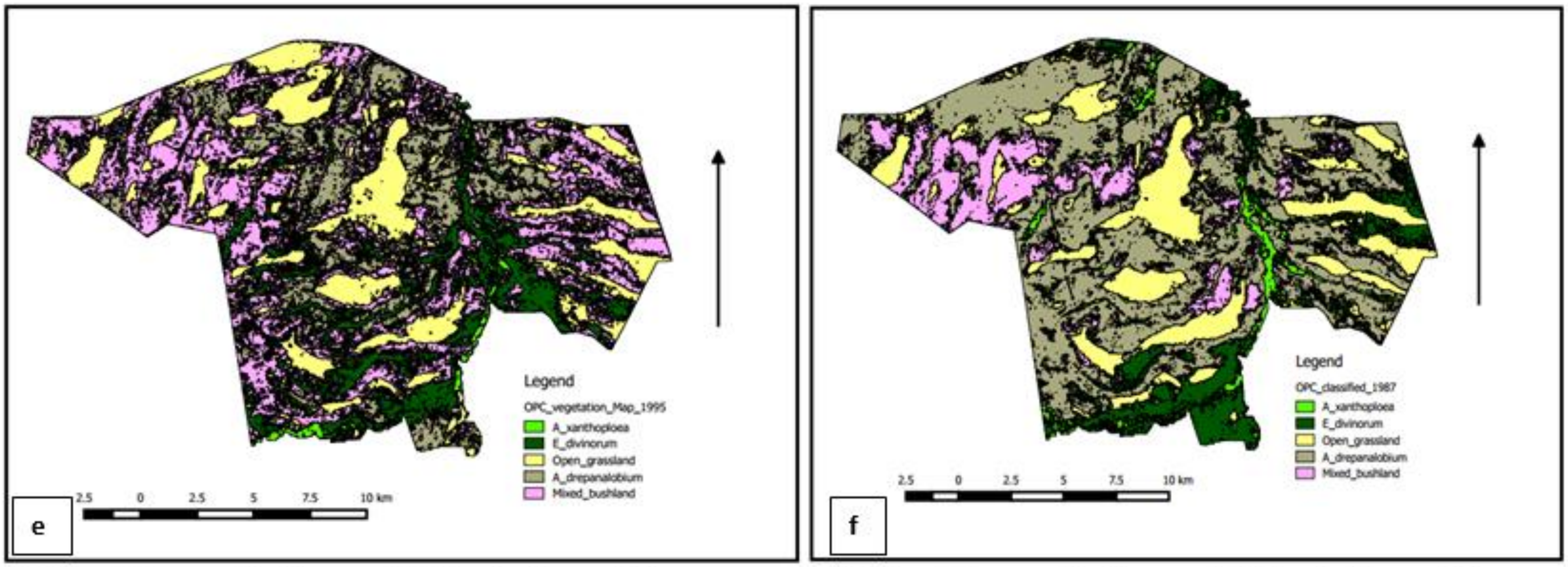


OPC Vegetation map for the year 2005 Landsat image ETM+



OPC Vegetation map for the year 2000 Landsat Image TM

Figure 5a: OPC vegetation maps for 2000, 2005, 2010 and 2016



OPC Vegetation map for the year 1995 Landsat image TM

OPC Vegetation map for the year 1987 Landsat image TM

Figure 5b: OPC Vegetation maps for 1987 and 1995

4.2. Topographic feature (s) attributable to encroachment by *E. divinorum*

This was performed to examine any attribution of slope to encroachment patterns by *E. divinorum* OPC. The results showed that areas with high NDVI value (NDVI maps 1987, 1995 2005 and 2016) were those along deep channels and valleys ideally areas in low elevation were covered by dense *E. divinorum* as in figure 6 a,b,c and d

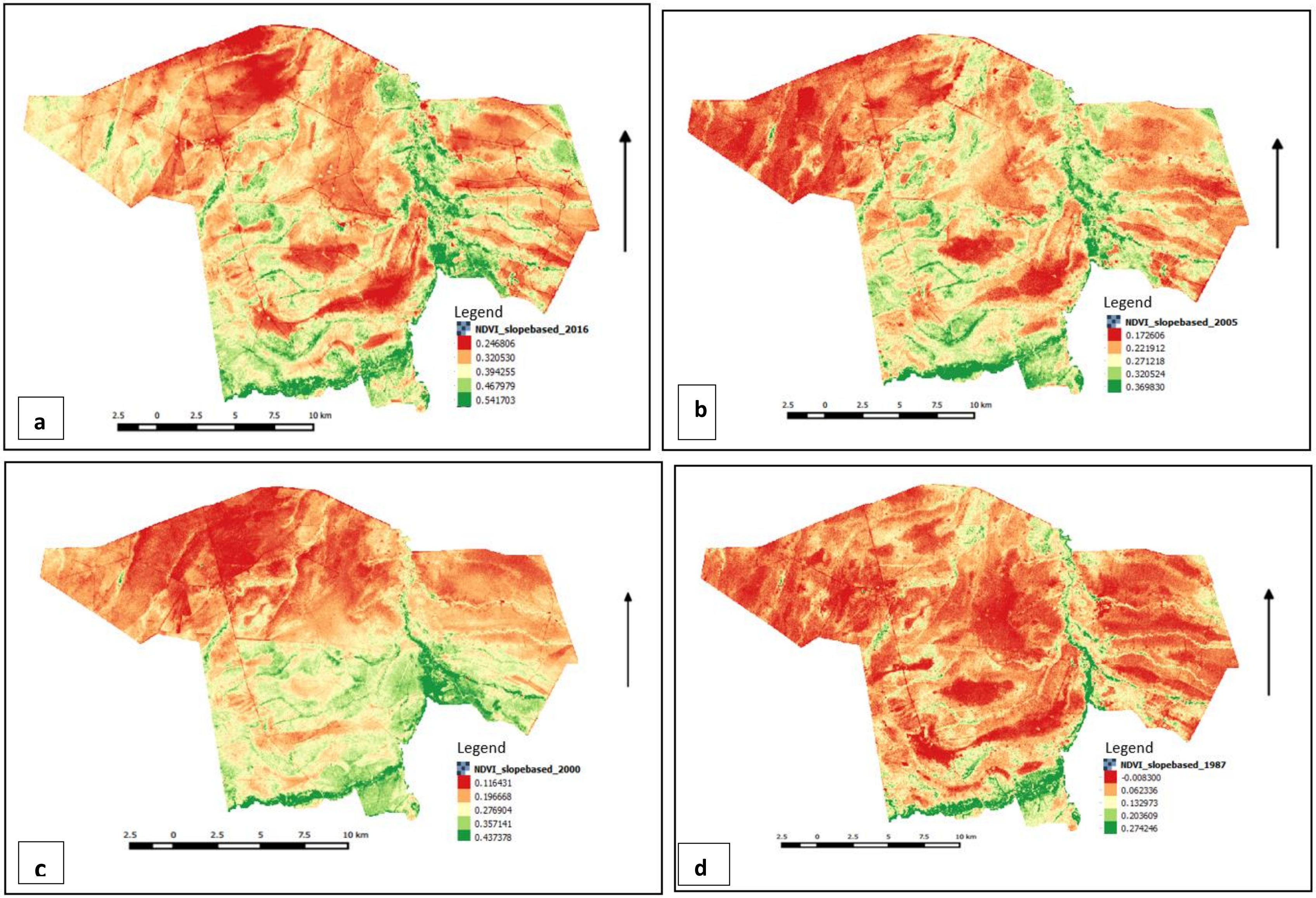


Figure 6: NDVI map (Slope based) for 1987, 2000, 2005 and 2016

4.2.1 Contours and Elevation overlaid on vegetation map

Overlay of both topographic features, which include contours and elevation (observable features) showed that areas below 1800m above sea level (ASL) were covered by *E. divinorum* as in figure 7.a, b, c and d. However, this encroachment shows to be expanding towards areas even at higher altitudes than 1800m ASL.

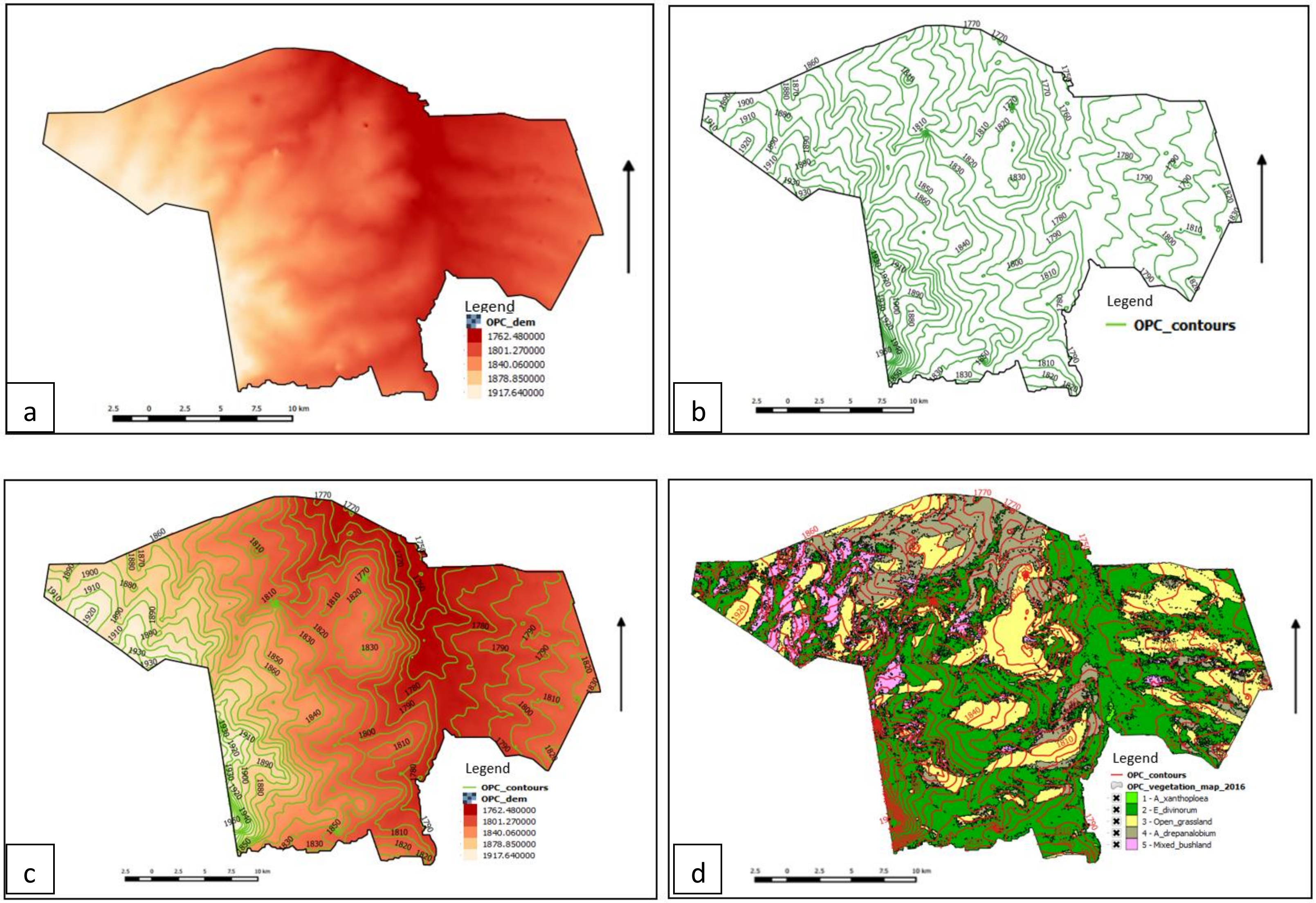


Figure 7: DEM, contours and vegetation overlays for OPC

4.3 Wildlife Survey for Diversity and Richness Assessment

4.3.1 Species richness across the habitat types

In the four habitat types the taxas (S) recorded were as follows; *A. drepanolobium* had higher species richness with 23 animal species followed closely by Open grassland with 21 species, *E. divinorum* 19 species while mixed bushland came at distant with 15 species in total refer species list in the appendix. Figure 8 shows species richness across four habitat types in OPC.

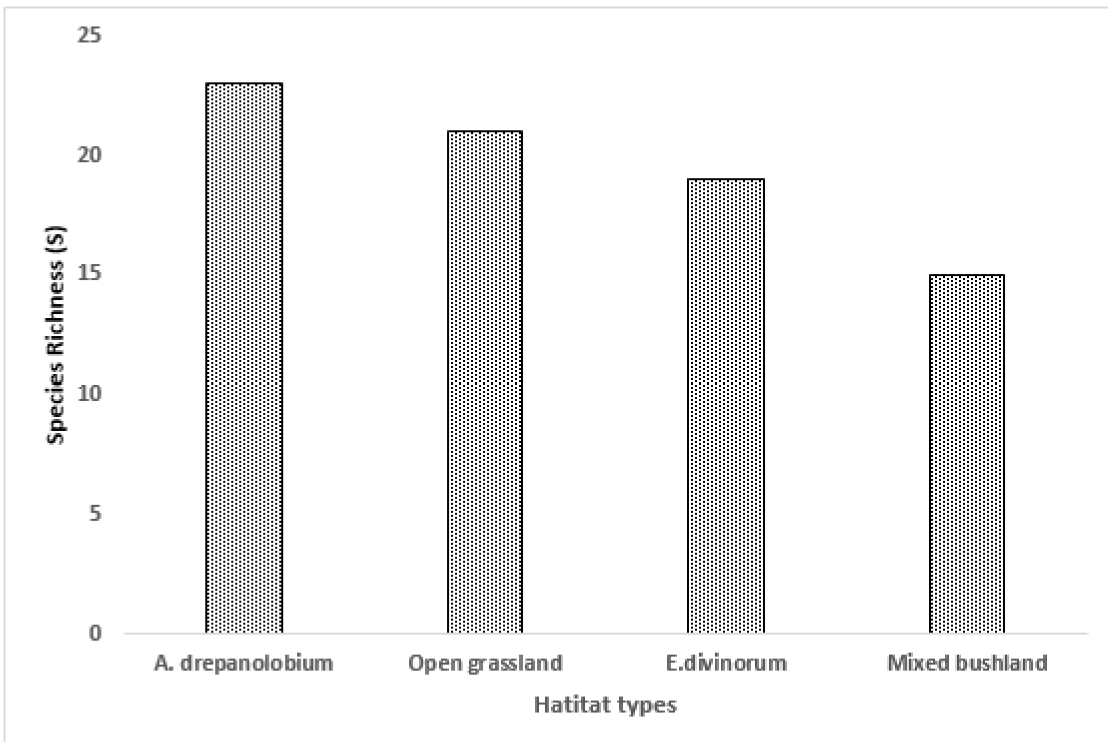


Figure 8: Species richness across four habitats in OPC

4.3.2 Species Dominance (D)

Species dominance, defined as most conspicuous and abundant species, was also compared across the four habitat types. Species dominance (D) was higher in Open grassland (D= 0.334) followed closely by mixed bushland (D= 0.302), followed by *A. drepenolobium* at (D= 0.197) and lastly *E. divinorum* (D= 0.154). Graphically species dominance is shown as in figure 9.

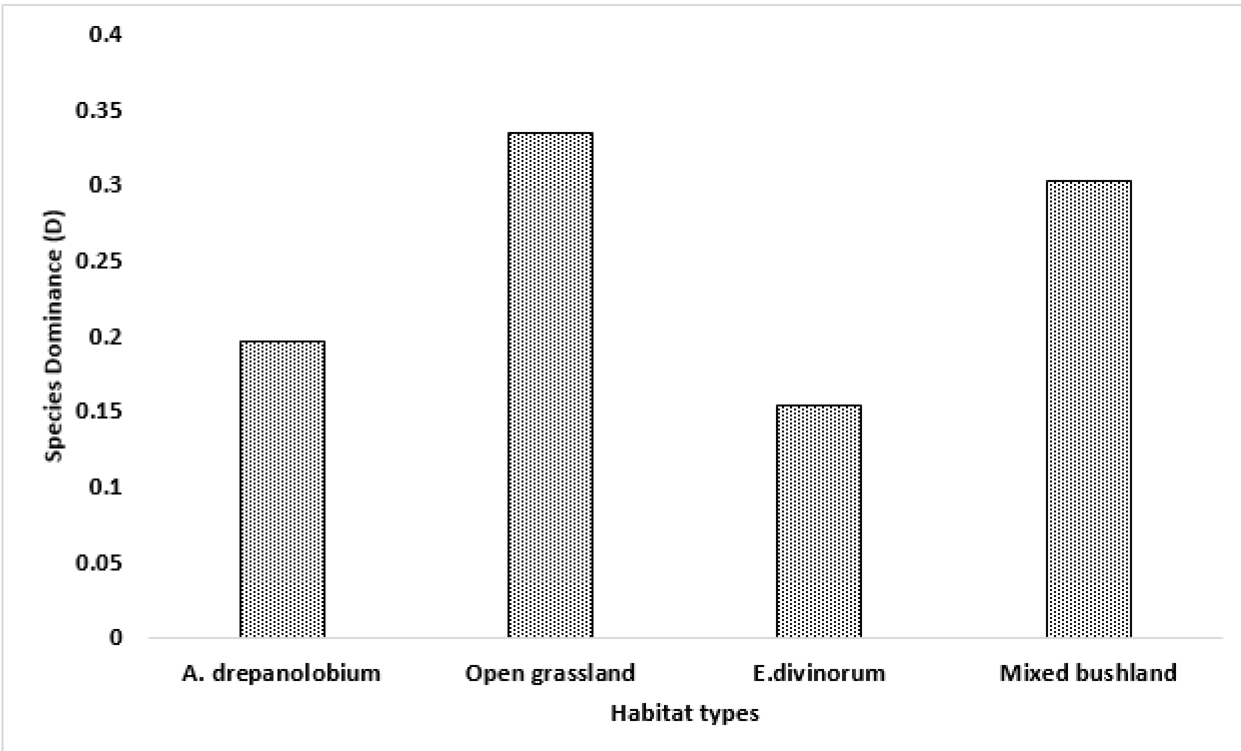


Figure 9: Species dominance across four habitats in OPC

4.3.3 Species diversity and evenness

Species diversity (H) was higher in *E. divinorum* vegetation cover at 2.291, *A. drepanolobium* at 2.058, Mixed bushland at 1.728 and Open grassland with least index value of 1.715 as shown in figure 11. Evenness (H/S) was highest in area under *E. divinorum* at 0.5201, followed by mixed bushland at 0.3751, then closed by *A. drepanolobium* at 0.3404 and finally Open grassland at 0.2647 as shown in figure 10.

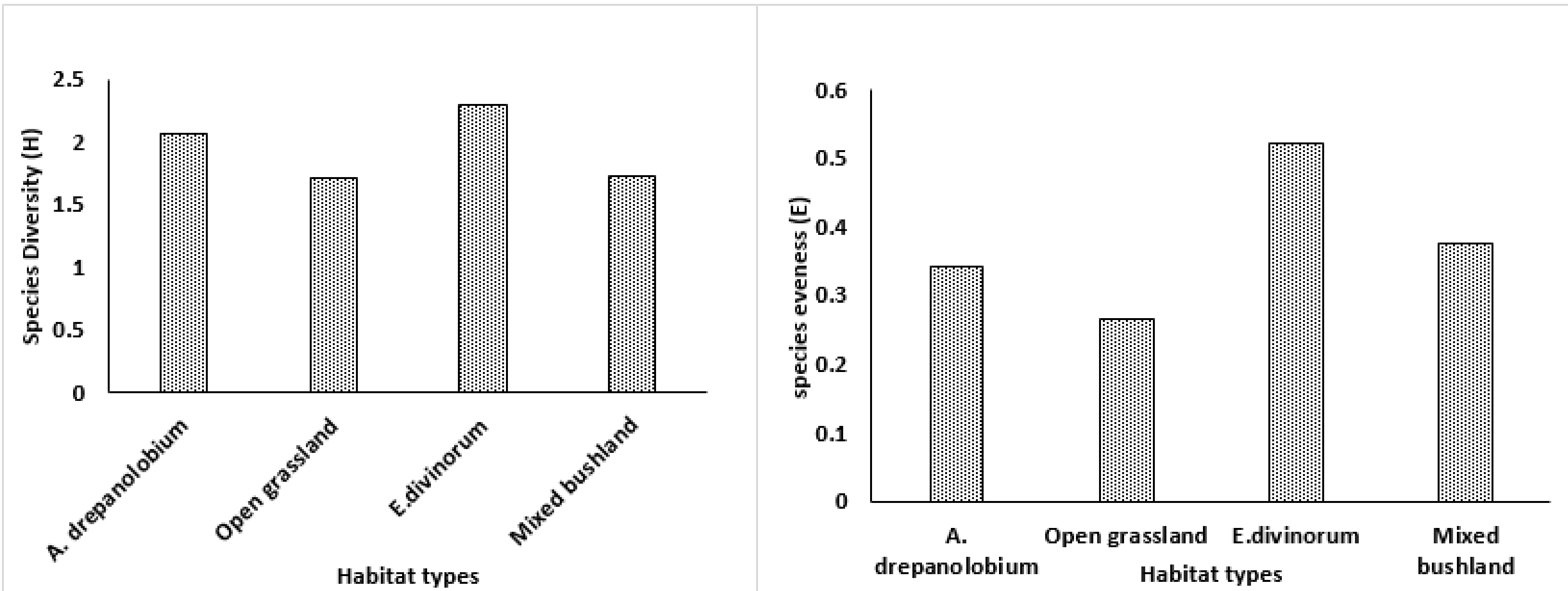


Figure 10: Species diversity (left) and species evenness (Right) across four habitats in OPC

4.3.4 Species Composition

Hierarchical Cluster Analysis (HCA) compared species composition across the four habitat types namely *A. drepanolobium*, *E. divinorum*, Mixed bushland and Open Grassland. *E. divinorum* and mixed bushland habitats shared 45% similarity in species composition. This implies that 45% of species found in both mixed bushland *E. divinorum* habitats were recorded in both habitats. Further, *E. divinorum* habitat and mixed bushland shared 39% similarity in species composition with *A. drepanolobium* dominated habitat. On the other hand, open grassland habitat shared 27% similarity in species composition with three habitat types namely, *E. divinorum, A. drepanolobium* and mixed bushland as shown in the figure 11.

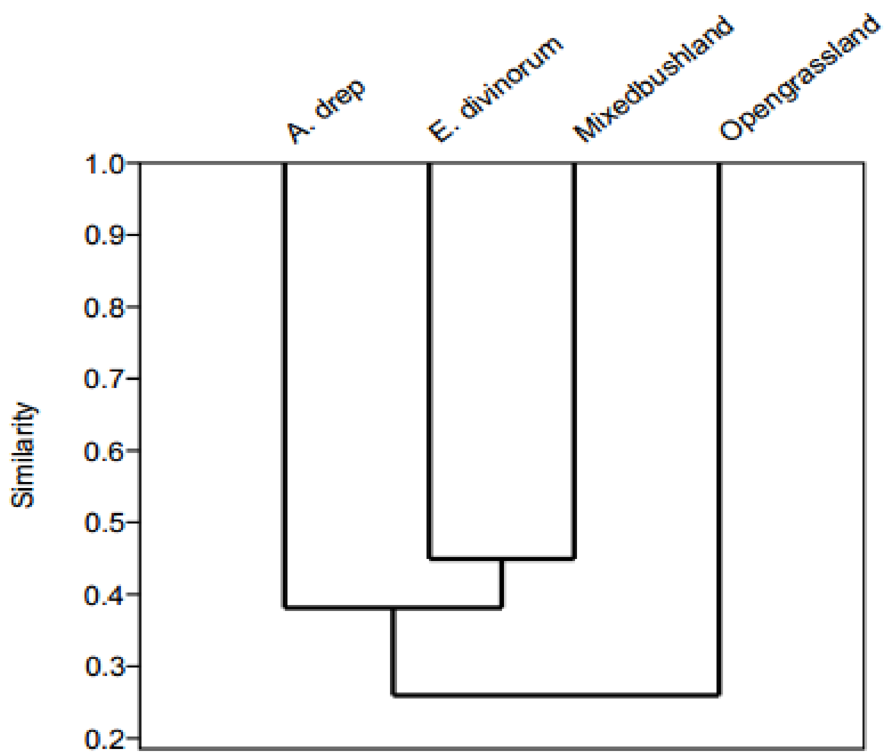


Figure 11: Dendrogram showing species composition

4.4 Habitat preference or avoidance by feeding guilds in OPC

Carnivores showed highest preference for *A. drepanolobium* (D=0.469) followed by Open grassland (D=0.327) whilst they least preferred mixed bushland (D=0.066) habitats. On the other hand, *E. divinorum* was the most avoided habitat by carnivores (D= -0.698). Grazers showed great preference for open grassland s (D=0.773) as well as *A. drepanolobium* (D=0.040). However, *E. divnorum* (D= -0.917) and mixed bushland D= -0.192) habitats were avoided.

Browsers showed preference for *A. drepanolobium* (D= 0.674) and mixed bushland habitat (D=0.175) but avoided both *E. divinorum* (D= -0.673) and Open grasslands (D= -0.116) dominated habitats. Finally, mixed feeders preferred habitats dominated by Open grassland (D=0.688) and *A. drepanolobium* (D=0.523) but avoided *E. divinorum* (D= -0.858) and mixed bushland(D=-0.420) dominated habitats. Figure 12 shows habitat preference or avoidance across the four habitats by all feeding guilds in OPC.

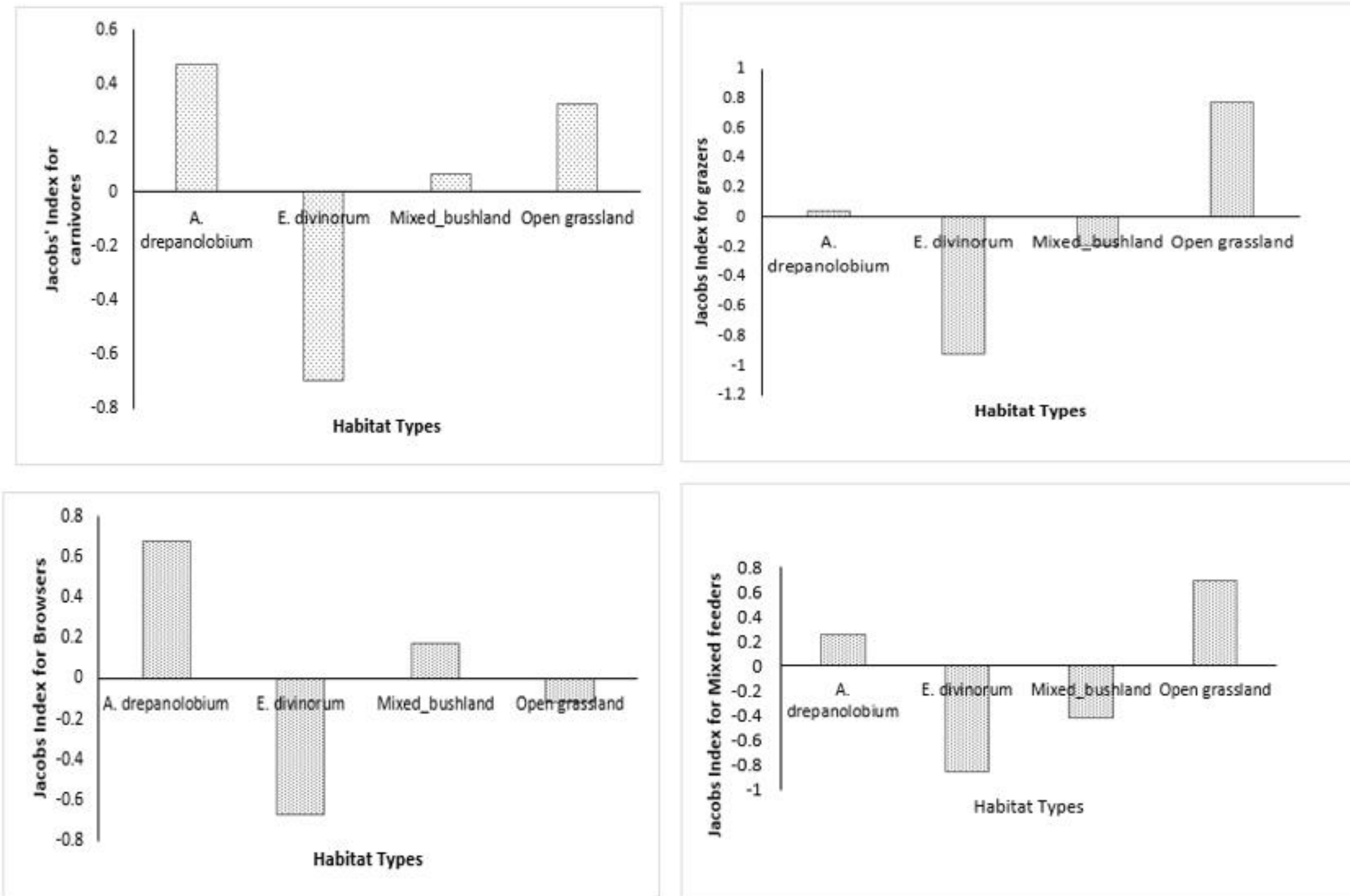


Figure 12: Habitat preference or avoidance (Jacobs' Index) for four feeding guilds in OPC

When a mean preference or avoidance of all habitats by various feeding guilds in OPC was computed, *E. divinorum* and mixed bushland were avoided by all guilds, however *E. divinorum* was significantly avoided (t_1=2.253, *d.f*=3, *p*=<0.001) than mixed bushed land (t_1=2.353, d.f=3, p=0.268). On the other hand, *A. drepanolobium* and Open grassland were both preferred by all guilds, however, *A. drepanolobium* dominated habitats were significantly preferred (t_1=2.353, *d.f*= 3, *p* =0.03) compared to open grasslands (t_1=2.353, *d.f*=3, *p*=0.06) as shown in figure 13.

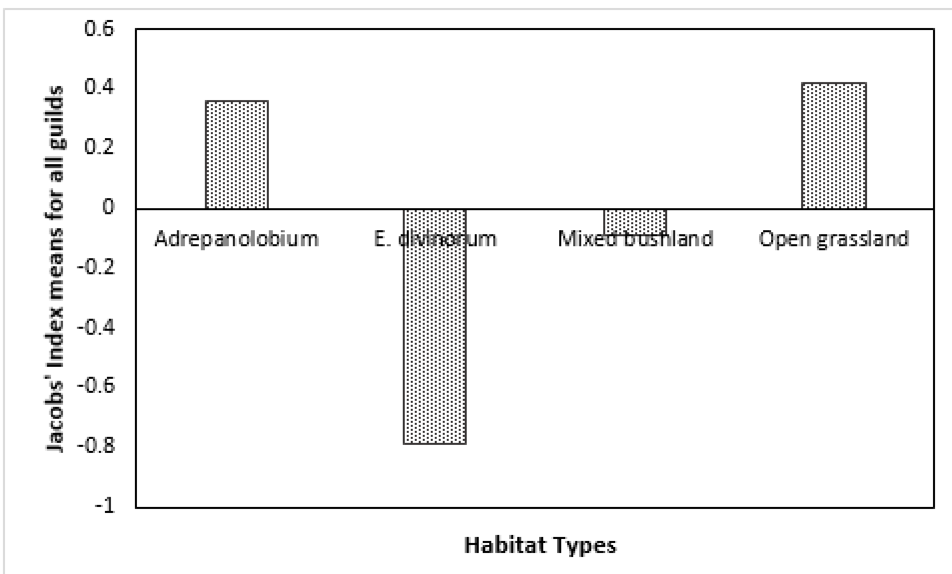


Figure 13: Means for Jacobs index across all four habitat types for all feeding guilds in OPC

When ranked on either preference or avoidance, open grassland habitat was the most prefered followed by *A. drepanolobium* dominated habitat while the most avoided habitat was *E. divinorum* but mixed bushland dominated habitat was randomly selected as shown in the table 3.

Table 3. Ranking of Preference or avoidance of habitats by all feeding guilds based on Jacobs index means

Habitat Type	Jacobs Index(means)	Rank	conclusion	P value for avoidance or preference
A. drepanolobium	0.359183	2	preferred	0.03
E. divinorum	-0.78668	-2	Avoided	0.001
Mixed bushland	-0.09283	-1	Randomly selected	0.268
Open grassland	0.418201	1	Preferred	0.06

Further, analysis revealed that Jacobs index mean when compared for significance avoidance or preference across all the habitat types where, *E. divinorum* habitat was significantly ($F_{(3,12)}$ *15.268, p= <0.01*) avoided by all guilds while *A. drepanolobium* was significantly preferred by all feeding guilds as shown in the figure 14. Further, Tukey Honestly Significance Difference test revealed that *E. divinorum Jacobs index* mean was significantly smaller than all other means of other habitat types as shown in figure 14.

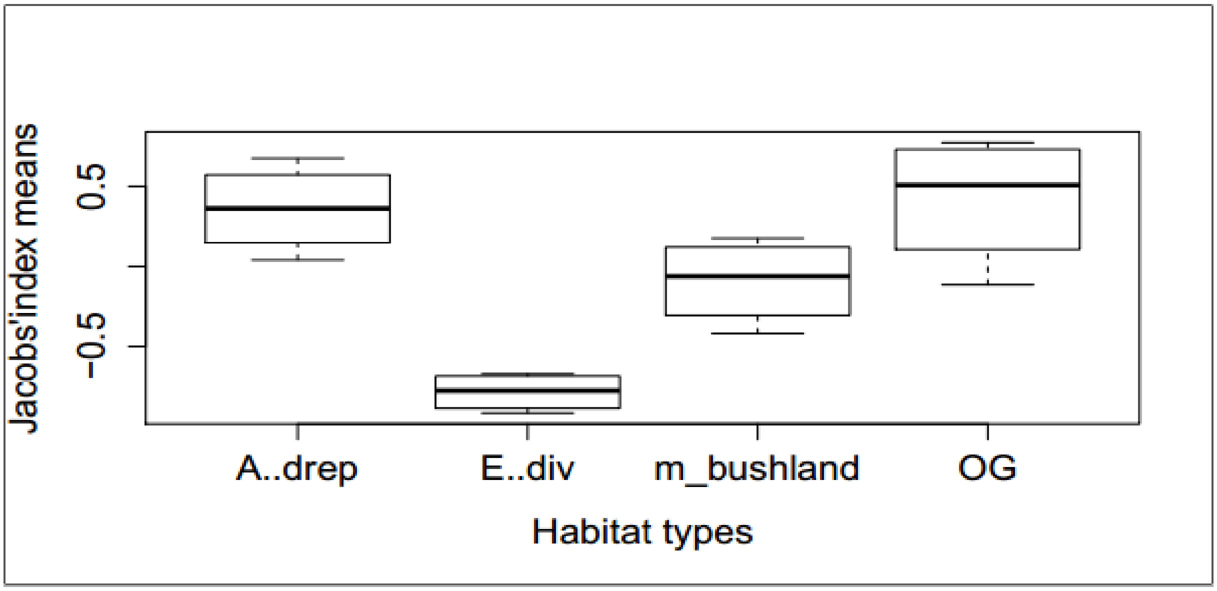


Figure 14: Means of Jacobs' Index across the four habitats in OPC

CHAPTER 5

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

5.1.1 *Euclea divinorum* and other habitat type cover changes

From the findings of this study it was found out that *Euclea divinorum* has over time spread spatially in OPC from 12.35% cover in 1987 to 49.65% cover in 2016. Further, changes in cover by *E. divinorum* is considerably significant over time, which implies that, other habitat cover types in OPC have been reduced due to such increase in coverage by the species under consideration. The increment in cover by *E. divinorum* was gradual from 1987 to 2000, however after 2000 to 2016 the changes in its cover increased sharply. It is also during this period some active management was employed where by 1998 to 2000 there was prescribed burning of *E. divinorum*. Here, the patterns exhibited by spread of *E. divinorum* are consistent with Skellem's (1951) diffusion model for invasive species whereby at the start there is low recruitment rates but over time the recruitment rates increases consequently and cover increases exponentially (encroachment from infested zones to transition zones and finally establishment in the un-infested zone).

Whilst there has been increase in cover by *E. divinorum*, on the other hand *A. xanthophloea* and *A. drepanolobium* have also reduced in coverage notably. As these dynamics in cover changes take place, other habitats have increased and decreased over the entire study period as for the case of mixed bushland majorly composed of other woody species such as *Scutia myrtina, Rhamnus staddo, Euclea divinorum, Acacia* *drepanolobium, Rhus natalensis and Carissa edulis* with no relative abundance. Remarkably, *E. divinorum* has been spreading in to vacant niches in habitat with low densities or areas devoid of the encroaching species (Wahungu *et al*., 2012). The finding of this study is in tandem with other research done in OPC where they reported increase in spatial coverage by *E. divinorum* (wahungu *et al*., 2012) though they reported that there were no significant differences. Given that the woody species under consideration is unpalatable to both wild and domestics animals Smith and Goodman (1987), there is a potential of affecting their resource base indirectly by augmenting loss of resources through replacement (extermination of pasture biomass majorly grass).

Disturbances in savannah ecosystems have been mooted as possible driver for changes in savannah landscapes (Van Langevelde *et al*. 2003). These disturbances can range from human induced land cover changes such as prescribed burning, climatic induced factors such as droughts and rainfall to herbivory and pastoralism (Jeltsch *et al*. 2000, Van Langevelde *et al*. 2003). As such in OPC, where there is an increasing population of elephants, giraffes and black rhinos (personal communication, EMU) their herbivory (with preference towards *A. drepanolobium*) impact is giving *E. divinorum* an advantage over *A. drepanolobium* with regards to their reestablishment.

Earlier research work conducted in the conservancy reported that there was high levels of damage (herbivory) to the *A. drepanolobium* whose net reduction can potentially explain the encroachment by *E. divinorum* (Birkett & Stevens-Woods 2005). Further, ill-grazing management systems/regimes such as over stocking can lead to degradation of the ecosystems functions thus altering grass-woody interactions. To this end, such land management systems can potentially suppress grass biomass thus facilitate encroachment by woody species in arid and savannah ecosystems.

However, herbivory effect especially by mixed feeders has potential to determine heterogeneity of savannah floral composition. This holds true if the woody species in question are palatable. According to past research by Wahungu *et al*., (2012) mega herbivores such as elephants have the ability to open up bushy habitats and regulate woody species density thus minimize net effect of encroachment. In OPC there is low levels *E. divinorum* damage owing to the fact that the species is unpalatable according to Smith and Goodman (1987).

As such, elephant's herbivory net effect on this plant species is insignificant hence may not contribute significantly to opening up of habitats under *E. divinorum*. This observation is consistent with other work done in Seregeti that elephants had no significant effect on *E. divinorum* (Sharam *et al*., 2006). In summary, elephants can suppress or open up closed woody vegetation especially if composed of palatable species whilst on the other hand pure grazers such as cattle can suppress grass hence alter its competitiveness with other plant species. Such interactions coupled with rainfall and other disturbances have potential to augment encroachment by woody species as well as determine dominant plant cover (Accatino *et al*., 2010).

Increasingly, changes in structure of savannah and semi-arid ecosystems from grass to increased bushy or woody species has remained a subject of debate. As such, possible theories and supposition have been postulated to elucidate this phenomenon as observed over time in savannah ecosystems. Climate change, high levels of herbivory, changing fire regimes (fire severity, duration and frequency), changes in competitiveness of grass, seed dispersal by animals and combination of all these factors have been suggested to be responsible for encroachment (Van Auken 2000, Herrmann *et al*.,2005 and Scanlon *et al*., 2005).

Chiefly, introduction of cattle (pure grazers especially in large numbers) in grassland ecosystems has been cited as the major driver of encroachment (Van Auken 2000). However, relatively low herbivory pressure can be tolerated by plants without conspicuous changes in plant productivity, biomass reproduction but higher pressure can affect these factors. In OPC, where there are mixed grazers, browsers and pure grazers, there is a potential that their herbivory effect has benefited spread of *E. divinorum* over time. However, the role of cattle in their indirect facilitation of encroachment in OPC has not been investigated and up to date remains unknown.

5.1.2 Topographic Features Attributable to Encroachment

From this study, it's evident that both natural and anthropogenic factors influence the dynamics of *E. divinorum* in OPC. Here, topographic factors such as slope and elevation examined can potentially determine spatial extent of encroachment. Digital elevation model (DEM) map and contours overlaid on vegetation map of 2016 showed that areas along deep valleys are covered by *E. divinorum*. Further, slope based Normalized Difference Vegetation Index (NDVI) for 1987,2000, 2005 and 2016 map revealed that *E. divinorum* initially infested zones as deep valleys and consequently spreading outward through transition zones to uninfested zones.

Additionally, considerably a large portion under *E. divinorum* cover is below 1800m above sea level as revealed by contour and vegetation map (2016) overlay results. Nevertheless, there are areas outside the recorded altitude infested by *E. divinorum* hence edaphic factors may be responsible for woody species encroachment.

5.1.3 Species Richness, Dominance, Diversity and Evenness

Species richness and dominance was higher in Open grassland compared to other habitat types. On the other hand, species diversity and evenness was highest in *E. divinorum* habitat compared to other habitat types. This implies that several habitat structures can potentially dictate species composition based on needs on animals. According to Sirami *et al.*, (2009) savannah ecosystems are diverse in plant community structure and composition hence they support diverse fauna. As such, abiotic and biotic factors have the ability to dictate species assemblage and space use. Animals have different preference (as revealed later in the study) to certain habitats (Sinclair, Mduma and Brashares 2003) as a function of direct and indirect effects of prey availability, detectability/cover and resource availability (Ripple and Beschta 2004). Such factors can explain reasons for higher diversity in *E. divinorum* dominated landscapes where animals can conceal from predators hence favourable conditions for mixed feeders and browsers in a landscape with both carnivores, herbivores and other mixed feeders. Spatial heterogeneity of ecosystem is important for maintenance of diverse wild animal species and acts as buffer against changes in resources availability for wild animals in era of climate change (Wang *et al.* 2006). On the other hand, woody encroachment, can potentially change this heterogeneity and affect wide range of wild animals.

However, if encroachment exceeds certain threshold there is a possibility of affecting economy of the area indirectly. In this regard, visitor experience may be affected negatively due to reduced visibility (Marshall, Lovett and White 2008) of wild animals potentially affecting number of visitors who are major sources of revenue collected as conservation fees. Grass and herbaceous cover and biomass may be affected negatively thus affect sustainability of subsistence and commercial livestock production as well as wildlife conservation (Archer, 2003; Richter *et al.*, 2001).

5.1.4 Species Composition

Changes in habitat structure can influence species distribution and their space utilisation. Increase in woody cover can affect species herd size, distribution depending on feeding habits and overall behaviour of the species in question. In OPC, species composition is higher in *E. divinorum* dominated habitat suggesting that more animals in the conservancy prefer thick area to conceal themselves and consequently avoid predators. On the other hand, pure grazers are dominant in open landscapes hence loss of significant open grassland and *A. drepanolobium* could negatively hurt those species who prefer such ecosystems in long term. Habitat preference analysis has revealed contrary that *E. divinorum* habitats are avoided by all feeding guilds despite having highest species diversity. As such, high species diversity in this habitat could be due to small fraction utilising such areas as they transverse the entire conservancy. According to Smit & Prins (2015), increase in woody cover in savannah ecosystems will become less grassy, burn less frequently and grazers will be replaced by browsers and mixed feeders especially if the encroacher species is palatable though this may not be the case in OPC since the species in unpalatable. This will consequently exert cascading effects on predator guilds. As such, species composition, feeding behaviour and space use will change greatly in response to changing ecosystems in order to adapt to new vegetation structure. As a function of changing vegetation structure, wild animals will respond through range shifts to other areas with favourable characteristics.

5.1.5 Habitat preference or avoidance by feeding guilds in OPC

It is evident that all feeding guilds in OPC avoid habitats dominated *E. divinorum* significantly while they prefer *A. drepanolobium* and open grassland dominated habitats. Habitat quality determines species distribution and space used hence a primary for conservation efforts (Boyce *et al*.,2016). As such, these qualities in a given habitat determine habitat preference or avoidance by wild animals. Habitat selection theory postulates that animal distributes and colonise habitat patches with highest fitness (Morris 2003) hence this explains why *E. dvinorum* is highly avoided by all feeding guilds. A suggestion that *E. divinorum* habitat is of poor quality in terms resources availability. In case of OPC bush encroachment has degraded ecosystem by reducing vegetation strata into a nearly homogenous cover composed of *E. divinorum* resulting to unfavourable habitat conditions.

These findings are in agreement with other findings which suggest bush encroachment as an indication of ecosystems degradation (Van Auken 200) manifested by its significant avoidance by feeding guilds in OPC.

According to Delle *et al*., (2006) increase in woody cover results to reduction in grassland diversity hence loss of biodiversity, reduction in forage resources and consequently reduction in carrying capacity (artificial shrinkage of carrying capacity). From economic point of view especially in areas where ecotourism is highly relied on as source of revenue, increase in woody cover can potentially affect visitor viewing experience (Wigley *et al*, 2009).

5.2 Conclusions

This work was geared towards examining time series encroachment by woody species, possible topographic features dictating encroachment patterns and implications of such encroachment on species diversity, evenness and habitat selection. The study revealed that *E. divinorum* had increased spatially over time and exterminated other habitat cover types chiefly *A. drepanolobium,* mixed bushland and *A. xanthophloea*. Further, it was revealed that encroachment initially started in deep valleys and over time spread to other areas covering nearly 49% of the entire conservation area. Here, it was concluded that *E. divinorum* had caused other habitat types to reduce in cover, hence potential threat to suitability of these ecosystems for all feeding guilds as revealed by the findings.

Further, this work demonstrated that species diversity and evenness was different across the four vegetation cover types considered, that is, *E. divinorum*, *A. drepanolobium*, Mixed bushland and Open grassland. It was evident that *E. divinorum* dominated landscape had highest species diversity and evenness whilst Open grassland had lowest species diversity and evenness. On the other hand, species richness and dominance was highest in open grassland habitats attributed to high number of pure grazers in OPC, that is, plains Zebra and Buffaloes which spend most of their time in open grassland.

Additionally, species composition was closely similar in *E. divinorum* habitat and mixed bushland attributable to their similar vegetation structure and cover whilst species composition in open grassland had highest dissimilarity from the rest. This is attributable to its uniform landcover type majorly grassland (Key resource) preferentially attracting pure grazers and by extension mixed feeders.

All feeding guilds avoided *E. divinorum* dominated landscapes significantly but preferred *A. drepanolobium* significantly. In general, both open grassland and *A. drepanolobium* habitat types were preferred whilst *E. divinorum* and mixed bushland were avoided by all feeding guilds in the conservancy.

5.3 Recommendations

From the findings of this work several areas have emerged that requires further research to better understand dynamics of woody encroachment and resultant implications on species both fauna and flora composition and assemblage. As such, recommendations are in two-folds as follows:

a) Recommendations for further research;

i. That there is need for a long-term study to understand dynamics of woody tree density per unit area with focus on already infested zone, transition zones and un-infested zones by *E. divinorum*.
ii. That the interactions of both livestock and wildlife are investigated and their influence on establishment of *E. divinorum* needs further research.
iii. Investigate impacts of bushy encroachment by *E. divinorum* on grass production, biomass and diversity on long term basis.

b) Recommendations for management

i. Investigate potential negative effect on visitor experience focusing on regular visitors who may have noticed increase in *E. divinorum.*
ii. That there is need to initiate active management of *E. divinorum* with focus on transition zones to curb further encroachment combining both mechanical and chemical control of encroaching species and further into

already infested zones and harvest mature woody stems of *E. divinorum.* Here, active management should start in trial zones and once effective upscale to other areas.

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APPENDICES

Appendix 1: List of species detected in various habitat types

Species (common Name)	**Scientific Names**	**Habitat Types In OPC**			
		Acacia drepanolobium	***Euclea divinorum***	**mixed bushland**	**Open grassland**
Aardvark	*Orycteropus afer*	1	0	1	1
Baboon	*Olive Baboon*	1	1	1	1
Black Backed Jackal	*Canis mesomelas*	1	1	1	1
Black Rhino	*Diceros bicornis*	1	1	1	1
Buffalo	*Syncerus caffer*	1	1	1	1
Bush Duiker	*Sylvicapra grimmia abyssinicus*	1	1	0	0
Eland	*Taurotragus oryx*	1	1	1	1
Elephant	*Loxodonta africana*	1	1	1	1
Genet (*)	*Genetta tigrina*	1 *(*)*	0	0	0
Giraffe	*Giraffa reticulata*	1	1	1	1
Grants Gazelle	*Nanger granti*	1	0	0	1
Hare	*Lepus victoriae*	1	0	0	1
Hartebeest *(*)*	*Alcelaphus buselaphus*	0	0	0	1*(*)*
Impala	*Aepyceros melampus*	1	1	1	1
Leopard (*)	*Panthera pardus*	0	1 *(*)*	0	0
Lion	*Panthera leo*	1	1	0	1
Dwarf Mongoose (*)	*Helogale parvula*	0	0	0	1 *(*)*
Plains Zebra	*Equus quagga*	1	1	1	1
Serval Cat (*)	*Leptailurus serval*	1 *(*)*	0	0	0
Spotted Hyena	*Crocuta crocuta*	1	1	1	1

Steenbok	*Raphicerus campestris*	1	1	0	0
Striped Hyena	*Hyaena hyaena*	1	1	0	1
Suni	*Neotragus moschatus*	0	0	1	0
Thompsons Gazelle (*)	*Eudorcas thomsonii*	0	0	0	1 *(*)*
Warthog	*Phacochoerus africanus*	1	1	1	1
Waterbuck	*Kobus ellipsiprymnus*	1	1	1	1
White-Rhino	*Ceratotherium simum*	0	1	0	0
White-tailed Mongoose	*Ichneumia albicauda*	1	0	1	1
Wildcat (*)	*Felis silvestris*	0	1 *(*)*	0	0
Zorilla (*)	*Ictonyx striatus*	1 *(*)*	0	0	0

Key: **1** denotes ***detection*** while **0** denotes ***non-detection***

***** Denoted ***detection*** only on one habitat types