THE DISTRIBUTION, ABUNDANCE AND ECOLOGICAL IMPACTS OF INVASIVE PLANT SPECIES AT OL-DONYO SABUK NATIONAL PARK, KENYA

BY

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DECLARATION

I JOSEPHAT K. WAMBUA do hereby declare that this is my original work and has not been submitted to any other University for examination.

Signed..........................

Date....20/05/2010....

Declaration by supervisors.

This thesis has been submitted for examination with our approval as University supervisors.

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Dedication.

This work is dedicated to my children Lawrence Mwendwa and Lydia Kalondu the two of you have been my inspiration and driving force.

Acknowledgement.

This study was made possible through the help of various people. It is however not possible to mention each and everyone's name here, but I sincerely appreciate and thank all of them. First, I would like to express my thanks to Dr. John Mworia and Dr. Nathan Gichuki my supervisors for their invaluable time that they spent in providing guidance during the study. Your availability and time allocation for this work was a pointer that you were dedicated to my academic endeavours. I would also thank Dr. Charles Musyoki of KWS for your moral support and encouragement to pursue the invasive species project. Your availability and guidance during the entire work is appreciated. Mr. Lekishon Kenana of KWS Biodiversity and research department, for your support during field work, The University of Nairobi School of biological sciences for giving me an opportunity to undertake my MSc. at the school.

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List of acronyms.

ASTER -Advanced space-borne thermal emission and reflection radiometer.

NASA- National aeronautics and space administration.

VNIR - Visible Near Infrared.

SWIR -Short Wave Infrared.

TIR - Thermal Infrared.

IFOV - Instantaneous Field Of View

PCA- Principal Component analysis.

SVIs – Spectral vegetation indices.

GPS – Global positioning system.

ANOVA-Analysis of variance.

EOS-Earth Observing System

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ABSTRACT.

Invasive species are a major conservation and management concerns in natural ecosystems and pose a significant threat to many of Africa's conservation areas. The aim of this study was to asses the impacts of invasive plants species on the biodiversity of Ol-Donyo Sabuk National Park. The objectives were to determine the types and distribution of vegetation at the National Park, assess the types, distribution and abundance of invasive plant species, determine the birds and mammal species associated with invasive plant species and examine the factors that were related to the dispersal of invasive plants species. The study area was stratified by analysing an advanced space-borne thermal emission and reflection radiometer (ASTER) imagery and line transect method was used to describe the vegetation in the different strata. Invasive species impact on biodiversity was quantified through random quadrant sampling method while factors related to the dispersal and spread of invasive plant species were determined through point-count and line transects methods. Data was analysed through calculation of density for the different species and Shannon-wiener diversity (**H'**) and evenness (**J'**) indices for each stratum. Student *t* test was used to compare diversity differences between the invaded and un-invaded sites. Chi-square (X^2) test was used to test for trophic differences in mammals and birds associated with disturbed and invaded areas between the wet and dry seasons. Analysis of variance (ANOVA) tests to determine species associations between the different sampling strata within the study and surrounding areas. Results from imagery analysis revealed seven land-cover types with closed canopy forests being the largest and dams the least. *Lantana camara L.* was the most abundant invader species and invaded areas had lower species diversity but higher plant density. There was significant difference in species diversity between invaded and un-invaded sites ($t = 2.41$, $P < 0.05$). In the surrounding areas, invasive species were equally distributed ($F=0.0065$, $P<0.05$). There was significant difference in the trophic status for birds associated with disturbed and invaded areas between the sampling seasons with higher number of insectivore/gramnivores in dry season and higher number of nectivores in the wet season. ($X^2= 83.338$, $P<0.001$, d.f =6). Diversity and density also differed with type of disturbances being highest in places with edge effect. Mammals didn't differ significantly between the dry and wet seasons ($X^2=16.656$, $P < 0.005$, d.f=5). Edge effects were strongly associated with occurrence of invasive species. The study showed that invasive species had negative impact on native species diversity.

Key-Words: Abundance, Spatial distribution, Invasive species, diversity indices, Stratum, Random-sampling, Remote-sensed imagery

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Wildlife is an important resource for Kenya as it generates millions of dollars through tourism and other wildlife based activities. This wildlife is threatened by many factors including human activities, climate change and invasive species.

Global ecosystems that support this important resource are declining in size and biodiversity content at an alarming rate. Thus, wildlife habitats are becoming terrestrial islands in the midst of intensive agriculture, urbanization and other anthropogenic activities. These activities have led to increase in the probability of invasion by invasive species and conservation areas are particularly vulnerable.

Invasive species are particularly a serious threat to biodiversity and are considered second to habitat destruction in driving global biodiversity loss (Baillie *et al.,* 2004, CBD, 2005). However, the impact of invasive species in protected areas (National Parks) is currently poorly understood and the magnitude of the problem is not well appreciated. In this regard biodiversity in protected areas is adversely affected and its long term survival is threatened (CBD, 2005).

Monitoring of environmental processes is becoming an increasingly important management tool whenever there is increasing population and development pressure placed on fragile ecosystems (Sun *et al.*, 2005). Such fragile ecosystems like the Ol-Donyo Sabuk ecosystem are important biodiversity refuge sites and play a critical role in maintaining a stable refuge for endemic species of plant and animal communities. Similarly, the protection of the National Park as a gene-bank for the inherent wild species and as water catchment area is critical for long term benefits to the neighbouring communities.

Monitoring the status of species found in any conservation area is a major aspect of management. However, with increases in invasive species, and their potential threats to biodiversity, there is a need for their monitoring. A species is regarded as invasive if it has been introduced by human action to a location, area, or region where it did not previously occur naturally and it becomes capable of establishing a breeding population in the new location without further intervention by humans (GISP, 2004). Once invasive species become established, their management requires not only the targeting of the population growth with available control measures but also the assessment of where and how populations are spreading in the landscape (Schooler *et al.,* 2005).

1.2 Historical development

The initial inhabitants of the Ol-Donyo Sabuk ecosystem were the Kamba people mainly from Machakos district; they are believed to have occupied the area during the 17^{th} and 18^{th} centuries. They lived by raising cattle and shifting cultivation in the communal fields for grains and pulses. They also traded with the coastal and kikuyu communities (KWS, 1999 b).

This traditional land-use pattern allowed maintenance of natural habitat production potential and was compatible with biodiversity conservation as well as providing minimal impacts to the ecosystem and vegetation. At the onset of independence in early 1960s, the local communities started subdividing the larger communal farms into 5-10 acre plots for individual ownership and this marked the beginning of land-cover destruction, land-cover change, increased disturbance and soil degradation. It's also at this time when the main invader species in the study area - *Lantana camara L.* was introduced in Kenya around Nairobi as an ornamental plant (KWS, 1999 b).

As a result of the combination of population growth, introduction of new farming technologies and in the absence of means and incentives to restore land fertility, this led to increasing land degradation. The net effect of soil degradation on plant growth is that per capita growth rate is decreased at low standing crop (Johan Van de Koppel and Max Rietkerk, 2000).

Thus what used to be large stretches of communal farm-land were actively subdivided, subjected to intensive agriculture and overgrazing. This reduced and still continues to reduce vegetation cover as a result of poor land-use and soil erosion (KWS, 1999b). The management of the national park which is part and parcel to the surrounding ecosystem cannot overlook these issues which are core to long term survival of the conservation area.

1.3 Literature review

1.3.1 Global invasive problem

An invasive species is an expression of non-indigenous species (plants or animals) that adversely affect the habitats they invade economically, environmentally or ecologically. It denotes a species that has been introduced from a different area (native range), becomes established, and spreads without intentional assistance by humans in its new habitat (Schooler *et al.,* 2005). Invasive species are either plant or animal, from another area that over-compete other native species living in an area.

Biological invasions by non-native species constitute one of the leading threats to natural ecosystems and biodiversity and they pose enormous costs to agriculture, forestry, fisheries and other human enterprises as well as human health (GISP, 2001). The ways in which they affect native species and ecosystems are numerous and usually irreversible. Invasive plants affect man directly through social and economic impacts, and indirectly through alteration of biotic communities and ecosystem functions (GISP, 2001).

These species can directly affect agricultural and grazing productivity by displacing desirable species, reducing soil quality (via increased erosion), and reducing water abundance (via evapotranspiration and impeding irrigation systems) (Mooney, 2005). In addition, invasive weeds can indirectly affect ecosystem services by altering biotic diversity.

From an ecological perspective, we can categorize impacts of invasive plants by the ecological level of organization at which we measure the effect. Most often we are concerned with effects on populations, communities, and ecosystems, but genetic impacts and effects on individuals may be important as well (Parker *et al.*, 1999). Plant invasions pose a real and significant threat to many of Africa's conservation areas and affect conservation areas on every continent except Antarctica (Cronk and Fuller, 1995).

Research has shown that plant introductions eventually lead to increased weed problems after a time lag of about fifty years (Hughes, 1995). For example, the introduction of *Prosopis juliflora* by Food and Agricultural Organization for rehabilitation of over-grazed and over-exploited semi-arid woodlands in Baringo District (FAO, 1985) has resulted to more problems than benefits (Mwangi and Swallow, 2005).

Kenya has had several invasions of alien species that have had negative impacts on biodiversity, agriculture and human development. Studies show that Kenya has been invaded by 34 species: 11 arthropods, ten micro-organisms, nine plant species and four vertebrates (Hodges *et al.*, 1983, Muhihu and Kibata, 1985).

Grainger (1999) observed that African rangelands were commonly perceived as undergoing widespread and serious degradation through soil, water, vegetation and biodiversity decline. Biodiversity is generally perceived as declining throughout sub-Saharan African savannas, though this perception is not always well supported (Shackleton, 2000, Homewood and Brockington, 1999, Maddox, 2002). The dominant explanatory model underlying biodiversity conservation policies has been that local land-use practices are detrimental to soil, water, vegetation and habitat conservation. The role of invasive species as key contributors to biodiversity loss is an important aspect that has not keenly be investigated especially in the study area.

Many of the invasive species found in Africa are included on the global list of the one hundred worst IAS (IUCN/SSG/ISSG, 2004). These include the infamous, *Eichhornia crassipes* (water hyacinth); economically important species including the *Lates niloticus* (Nile perch), *Oreochromis mossambicus* (Mozambique tilapia) and *Acacia mearnsi* (black wattle). Species introduced for biological control, such as *Acridotheres tristis* (Indian myna) and *Bufomarinus* (cane toad); and ornamentals such as *Lantana camara*. There are many other invasive species which present serious challenges to regional efforts to conserve the environment, biodiversity and to meet development objectives (IUCN/SSG/ISSG, 2004).

Invasions are important because they impact ecological balance, economies and lifestyles. Invasions start when a niche, space and invader propagules are simultaneously available. Disturbed ecosystems are particularly vulnerable to invasion by non-indigenous species. In Tanzania, for example, *Maesopsis eminii* has become dominant in logged forests (Bingelli *et al.*, 1998). With high levels of environmental change, such as deforestation and growing extraction of timber, Invasive species are likely to become a big problem. Climate change –through its impact on ecosystems may also favour the spread of invasive species.

Invasive species may threaten native species as direct predators or competitors, as vectors of disease, or by modifying the habitat or altering native species dynamics (MA, 2006). The threat posed to biodiversity by invasive species is considered second only to that of habitat loss (CBD, 2005). They have therefore become recognized, as significant conservation concerns (Hobbs and Huenneke, 1992).

On isolated conservation areas (Islands), invasions are now comparable with habitat loss as the lead cause of biodiversity loss (Baillie *et al.*, 2004). Ol-Donyo Sabuk National Park is an "Island" park that is surrounded by settlements thus the inherent biodiversity can adversely be affected by invasive species if their spread is not addressed through research, monitoring and active management.

Among other things, both old and newly established invasive species produce leaf litter which poisons the soil, suppressing the growth of other plants, and in particular that of the under-storey (UNEP, 2004a). They may alter the environment in directions that are more favourable for them but less favourable to native species (MA, 2006). They can also affect the rate of nutrient cycling depending on litter quality (Mworia *et al.*, 2007).

Invasive plants can reduce or displace native species, both plant and animal, and may even alter ecosystem function. Others transform grasslands that support grazing. For example, *Lantana camara L.* poisons cattle and destroys under-storey species (IUCN/SSC/ISSG, 2004). It's also known to have allelopathic qualities that can reduce vigour of plant species nearby and reduce their productivity (Holm *et al.*, 1991)

Wiegand and Florian (2000), observed that vegetation changes generally occur unpredictably in the short term (years) in response to rainfall, and episodically over the long term (several decades) in response to rare events, or due to grazing pressure, climate change, or a combination of these factors. Arid and semi-arid ecosystems exhibit complex non-equilibrium dynamics involving complicated non-linear processes and stochastic event-driven behaviour (Pickup *et al.,* 1998). Brief, unpredictable and episodic events like rainfall in arid regions can be of crucial importance in understanding the ecology of organisms or communities, but these events can best be captured by continuous, long term monitoring (Henschel and Seely, 2000).

Some of the reasons advanced for decline in biodiversity within protected areas have been unsustainable exploitations and conservation incompatible land-uses around these areas. However, invasive species can also play an important role in driving species loss (KWS, 1999b).

Disturbance has often been cited as leading contributor to the problem of invasive plant species. Protected areas close to human settlements such as Ol-Donyo Sabuk National Park and its environs are therefore at risk of being invaded by both native and non-native invasive plants (Ngoru *et al.*, 2007). The focus should therefore be on monitoring these key ecological processes, either through contracting or encouraging needed research (USAID, 2004). This information will be vital both for control as well as management of invasive species especially in insularised conservation areas.

1.3.2 Use of remote sensing techniques in vegetation studies

Kenya's ecosystems are on the edge – unable to continue providing water, plant materials and other basic human needs to its burgeoning population (Forest Conservation News Today, 2002). Kenya as country does not have a systematic and consistent method of monitoring forest resources (KWS, 1999a, IUCN 2002). Aerial photographs and ground surveys have been the main methods used in monitoring forest resources (KWS, 1999a, Lambrechts *et al.,* 2003).

Land-cover mapping (monitoring) using traditional aerial photography is mostly manual in nature, and thus expensive, time consuming, and is not easily translated into a geographical information system (Lambin, 1997). Further, interpretation of aerial photographs becomes even more difficult when the study covers a large area (Mertens and Lambin, 2000). These procedures therefore do not allow for a close monitoring of the rapidly changing ecosystems and at a wider scale. Satellite remote sensing on the other hand, is a less expensive, consistent, and timely method for monitoring land cover changes by providing a synoptic view of the landscape (Lillesand *et al.,* 2004).

Remote sensing has provided an alternative method of land-cover detection with the advantage of capabilities of large regional to global coverage, high temporal and spatial resolution and easy accessibility (Mayuax *et al.,* 2004; Jansen and Gregoria, 2003). Satellite data provide the basis for geographically referenced global land-cover characterization that is consistent, repeatable over time, and potentially more reliable than ground based sources (Defries and Townshend, 1999).

Using these methods to map vegetation types within the Ol-Donyo Sabuk ecosystem, Lubia *et al., (*1993), identified twelve main vegetation types within the park and surrounding areas. These were: forests, woodland thicket, open grassland, open shrubland, grassland, shrubbed woodland, shrubbed bush land, wooded grassland, shrubbed thicket, riverline woodland, plantations, small-scale farms and recent settlements. In a similar study, Rono *et al.*, (1999) used the same technique to map out vegetation change in Nakuru district and were able to quantify changes as a result of farming alone. More recently, Maluki (2007) used remote sensed data and was able to map out vegetation and other land-covers in Mbeere district while Akotsi *et al.*, (2005) in a similar study was able to map-out vegetation changes in Kakamega district using remote sensed data.

Basically there are several land-use and land-cover types of interest in the management of natural resources as availability of these resources varies in space. These are: dense urban residential, grass, agriculture, forest, water, non-forested wetlands, and barren land (Civco *et al.*, 2002). For effective management of conservation areas, information on the distribution of food resources for wildlife is critical and remote sensed data is an important source of this information.

Satellite data have been acquired systematically and regularly since 1972 when the first Landsat satellite was launched. Additional satellites carrying improved sensors have been launched and continue to acquire data. Notable among these sensors are the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) on-board Landsat; SPOT (XS); and the LISS on-board IRS(Lillesand *et al.*, 2004).

Despite this proliferation in satellite data, there has been limited use of the data for mapping in the tropics. Reasons for this are lack of technology in terms of software, hardware and trained analysts, high cost of satellite data and constant cloud cover (Lambin, 1997). Ol-Donyo Sabuk National Park is not an exception and remote sensed data can therefore be used to map-out different vegetation and land-use types in this hilly rangeland.

1.3.3 Vegetation sampling Techniques

Interest in surveys for monitoring plant abundance is increasing, due in part to the need to quantify the rate of loss of biodiversity. Line transect sampling offers an efficient way to monitor many species (Buckland *et al.,2007*). These survey techniques have been used to estimate population density for a variety of species in tropical forests (Plumptre, 2000).

Line transects are commonly established using a stratified random sampling procedure (Plumptre and Reynolds, 1994). A key component in the design of a line transect survey is to ensure an equal coverage probability throughout the region, to reduce any bias that could result from the systematic coverage of areas that present either very high or very low population densities (Marques *et al.*, 2001).

The major advantage of using line transect sampling is that substantially more ground can be covered in a given time than for quadrant sampling, for which all plants within quadrants must be counted if plant abundance is to be estimated without bias. Because plants often have a very patchy distribution, the ability to cover a large area of ground with modest resources is an important advantage (Buckland *et al.,2007*).

To maximise the spatial coverage, transects can be placed at intervals along a grid or established line. In the case of lines placed according to grid, the distance between lines can be made equal to the distance between the transects along the lines, as this allows the short lines to be treated as sampling units which yields more reliable estimate of variance (Marques *et al.*, 2001). Many short transects are preferred over few long ones, because they yield better spatial coverage and more reliable estimates of precision (Krebs, 1999).

1.3.4 Bird and mammal sampling techniques

Counts of birds seen, heard, or captured are commonly used to elucidate avian-habitat relationships, investigate responses of avian populations to management treatments or to environmental disturbances, estimate spatial distribution of species, and monitor population trends (Thompson, 2002).

The point-count method, in which an observer records all birds detected within either a fixed or an unlimited distance from a point during a specified time period (Hutto *et al.,* 1986), is the most widely used counting method in bird population studies (Ralph *et al.,* 1995, Rosenstock *et al.,* 2002). Because not all individual animals associated with the sampling point are observed during the count period, the data provide only an index of animal abundance (Dawson, 1981).

By waiting at each point, there is more time to identify and detect difficult species. In some habitats, there is the advantage of being able to concentrate on birds without noise and distraction and it's easy to allocate sampling points randomly (Glyn, 2002).

1.3.5 Stratification of study area

Stratification is a technique used to analyze/divide a universe of data into homogeneous groups (strata). Often data collected about a problem or event represents multiple sources that need to be treated separately.
Stratification gives a better precision in the estimation of population parameters and confidence intervals can be narrowed appreciably especially if strata are well chosen. Also sampling problems may differ in different strata (Krebs, 1999).

Several methods of stratification are applied in ecological studies. This may include among others geographical area, population density and habitats. Whatever the method is used, the guiding principle is to increase precision of estimates from the samples chosen. As a general rule, the number of strata should not exceed six since a point of diminishing returns is quickly reached by increasing the number beyond this value thus no further precision is achieved (Cochran, 1977). Often fewer strata are desirable (Iachan, 1985).

1.4 Study justification

The nature of the regional dynamics of a species is critical for its survival (Freckleton and Watkinson, 2003). Recognition of the potentially conservation-compatible and positive role of local land-use, alongside a growing understanding of the need to support and develop local livelihoods and welfare, have underpinned the emerging ideology of community-based conservation (IIED, 1994, Roe *et al.,* 2000; Homewood, 2004) and its implementation in a great variety of initiatives in developing regions. The guiding principle being that most Kenyan wildlife is found outside protected areas (Norton–Griffths, 1998).

Rangeland species do better where they can disperse across wider landscapes with conservation-compatible rural land uses, rather than when isolated in protected areas. Privatisation of formerly communal rangelands, and their conversion to commercial monoculture, has resulted in drastic land-cover and wildlife declines in Kenya (Homewood, 2004). Privatisation of communal land restricts mobility and allows landowners to benefit, both from the immediate resource and from any investments they may make. However, it exports resource use problems and concentrates them in communal areas. Exclosure of higher potential areas, often with critical resources like water, leads to pressure on remaining range and adverse environmental trends (Southgate and Hulme, 1996, Prior, 1994). Privatisation of large areas for agribusiness and/or agro-pastoral enterprises (potentially including smallholder titles) has meant migration corridors for livestock and wildlife are squeezed, leading to human wildlife conflicts.

Ol-Donyo Sabuk National Park is an isolated habitat patch which is surrounded by conservation-incompatible land-uses resulting from privatisation of formally large communal land. It's therefore prone to the above problems. Disturbances related to privatization increases the invasibility potential of an area and invasive species interfere with the growth of desirable plants through competition and allelopathy (Wardle *et al.,* 1996).

As a general rule, species numbers present in any protected area is correlated with its size. However, it is not the size of protected area, but the extent of the wider ecosystem within which it sits, that determines the species richness of the protected area (Homehood, 2002). Where the protected area is continuous with a wider rangeland ecosystem with conservation-compatible local land uses like herding and farming, large mammals and other animal and plant species disperse through the wider area (Homehood, 2002, Mworia *et al.*, 2008). If and when the conservation area becomes isolated as an island surrounded by unusable habitat, species are lost (Homehood, 2002). The rate of species loss is particularly high if invasive species are common and no control measures are put in place.

Ol-Donyo Sabuk National park has several types of invasive and potentially invasive indigenous plant species but no proper assessment of their ecological impacts has been undertaken. As species is regarded as potentially invasive if it shows signs of dominating the community under certain conditions and especially after disturbances. Ecological Islands, big or small, have systems which are especially vulnerable to invasions by plants or animals. They often have unique endemic species and these may be eradicated by invasive species (Clout and Veitch, 2002). The study area is an isolated conservation area and thus information on the severity of invasion is a critical management tool that can be used as a case study for control and possible implementation in other protected areas.

1.5 Problem statement

Since its gazettment as a national park in December 1967, the Ol-Donyo Sabuk National Park has had serious decline in species numbers and richness. Chebures (1983) reported the following as the dominant species within the park: Buffaloes (*Syncerus cafer*), Black rhinos (*Diceros bicornis*), Impalas (*Aepyceros melampus*), Leopards (*Panthera pardus*), Spotted hyenas (*Crocuta crocuta*), Crested porcupine (*Hystrix cristata*), Aardvark (*Orycteropus afer*), Warthogs (*Phacochoerus africanus*), Bush pigs (*Potamochoerus Larvatus*), and Olive baboons (*Papio Anubis*). Others recorded then were Bushbucks (*Tragelaphus scriptus*) and Hartebeests (*Alcelaphus buselaphus*). Buffaloes were estimated to number over two hundred. Lubia *et al.,* (1993) reported the following as the most abundant species both within the park and the surrounding areas; Impalas, Warthogs, Bushpigs, Olive baboons, Monkeys a lion (*Panthera leo*) and about 300 buffaloes. Thus 50% of the original species were not in existence in the area after a short period of ten years. Today a population of less than thirty buffaloes comprising of two herds and several individual bulls are estimated to be resident in the park while mammalian population in the surrounding community areas no-longer exist (Ngoru *et al.,* 2007).

Such near catastrophic decline in species numbers and richness within such short period have been attributed to poaching, land-use/land-cover changes, blockage of seasonal dispersal routes, insularization and or inappropriate land-use. However, the ecological role of invasive species in the park and their impact on the inherent biodiversity has not been investigated and information concerning the types and coverage is not yet available.

From the above, it's apparent that proper quantification of the factors that have contributed to the decline of species numbers and diversity within the area of study is necessary. Of importance are the impacts of invasive species and how they have contributed to the dynamics of the protected area.

USAID (2004) identified the following as key problems of protected areas management

- Lack of a fully recognized minimum representative biodiversity system.
- Lack of adaptive biodiversity research, monitoring and evaluation systems

For proper management, information on the diversity, distribution and ecological roles of invasive species is necessary if any sustainable control strategy is to be employed.

Ol-Donyo Sabuk National Park being an isolated conservation area is particularly prone to local species extinctions than other protected areas owing to its small size, species vulnerability to reduced genetic heterogeneity and lack of seasonal dispersal routes to neighbouring areas. It is therefore important to quantify the role played by invasive plant species in influencing species diversity and distribution.

1.6 Hypothesis

The presence of invasive species will significantly alter diversity of native species.

1.7 Objectives

1.7.1 Main Objective

The main objective of this study was to generate data and information on the impacts of invasive plant species on biodiversity in protected areas (National Parks).

1.7.2 Specific objectives

The specific objectives of this study were:

1) To determine the types and distribution of vegetation in Ol-Donyo Sabuk National Park.
2) To assess the types, distribution and abundance of invasive plant species in the park.
3) To determine the birds and mammal species associated with invasive plant species.
4) To determine the factors related to spread of invasive plant species

1.8 Research questions

This study sought to answer the following research questions:

i) What are the major natural vegetation types found in Ol-Donyo Sabuk National park?

ii) What are the different types of invasive plant species and how are they distributed in the Park?

iii) Which bird and mammal communities are associated with the dispersal of invasive plant species?

iv) Which factors are contributing to the spread of invasive plant species in the park?

CHAPTER TWO

STUDY AREA, MATERIALS AND METHODS.

2.1 Study area.

2.1.1 Physical location

The Ol-Donyo Sabuk National park is located on the Eastern side of Nairobi city and is 27 kilometres from Thika Town. It lies between latitudes $10^0 5'$ and $1^0 10'$S, longitudes $37^0 10'$ and $37^0 20'$E and altitude 2145M above sea level at the peak of the hill. The park was gazetted in December 1967, covering an area of 2068 hectares (KWS, 1999b).

Currently, the park is an 'Island' conservation area since it's surrounded by human settlements. The major land-use in the area bordering the park is agriculture. Crops cultivated include; sugar cane, maize, beans, peas, bananas pineapples, and other horticultural crops. Livestock keeping also takes place (Ngoru *et al.*, 2007).

The national setting of Ol-Donyo Sabuk National Park with broad vegetation types is shown in Figure 2.1.

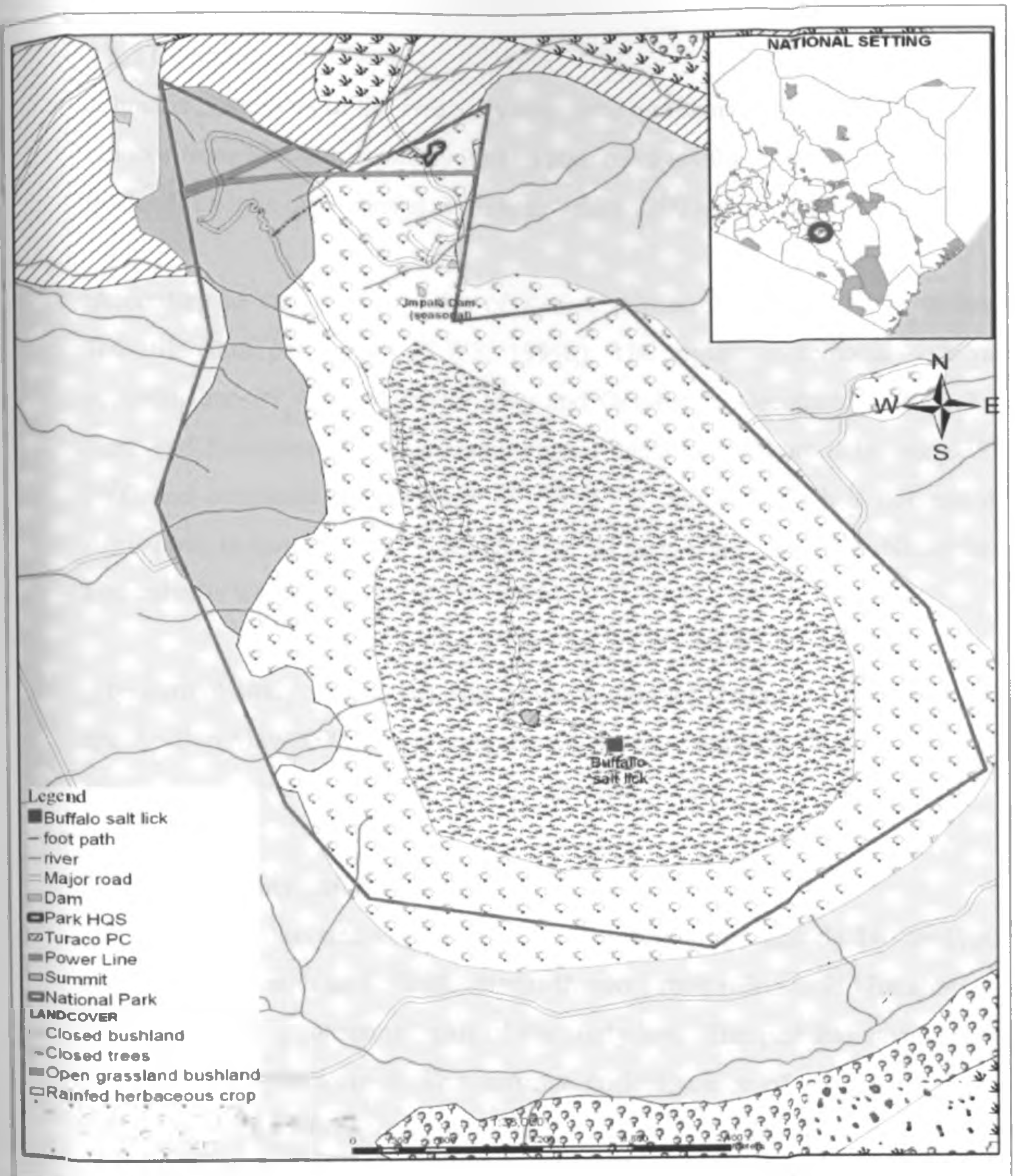

Figure 2.1 National setting of the Ol-Donyo Sabuk National park.

2.1.2 Climate

Climatic conditions of the area vary over time and space. Average annual rainfall reduces from 1200mm at nearly 2000m above sea level to less than 900mm in the lowlands and the dry plains at altitude less than 1200 metres above sea level.

According to the National Atlas of Kenya, rainfall is between 30-40 inches or 760-1015 mm per annum (KWS, 1999b). The regime is bimodal with rains occurring mostly from March to May and October to December with peaks in April and November. The maximum annual mean temperature is between 22^0C-26^0C and minimum annual mean is 10^0C-14^0C. January-March is hot and dry, April-June is hot and wet, July-October is very warm and dry, November - December is warm and wet (KWS 1999b).

The current study was undertaken in the months of October to December 2008 and April to May 2009 representing the wet season sampling while the dry season survey was carried out between January and march 2009.

2.1.3 Topography and drainage.

Topography in the area is characterized by plains at the altitude 1400m-1700m above sea level with an isolated hill- Ol-Donyo Sabuk rising to 2147m above sea level and forms a substantial part of the study area. The park has several water streams originating from it. This forms a critical source of water for the local communities and the inherent wildlife (Ngoru *et al.,* 2007). However, most of these streams have salty water especially during the dry season.

2.1.4 Soils

The hill is surrounded by the expansive lava of the Athi plains with fertile black cotton soils which are well drained. The soils are varied due to such geological formation. They are shallow and stony with rocky outcrops which have been subjected to geological and recent accelerated erosion loosing their original characteristics. They are also deeply weathered, except where eroded on steep slopes or where un-weathered rock outcrops occur (KWS, 1999b).

2.1.5 Plant communities.

The study area vegetation can broadly be characterized into four types, the most dominant is the closed bushland, closed trees, open grassland/bushland, and the herbaceous crop (Ngoru *et al.*, 2007). Part of the middle section of the hill except the summit is covered by the forest consisting of tall trees which include *Croton macrostachus* and *Albizia schimperiana.* Others include *Cassipourea malosana, Cussonia holstii, Albizia gumifera, Tabernaemontana stapfiana, Allophyllus abyssinicus, Teclea simplicifolia and Clausena ansata.* The undergrowth includes *Desmodium subrepanium, Landolfia buchananii, Periplocca linearifolia* and *Aneilema pedunculata.* The forest vegetation serves as water catchment maintaining condition and flow of the several streams that emanate from the hill (KWS, 1999 b).

2.1.6 Wildlife communities

Forests and other vegetated habitats especially Ol-Donyo Sabuk National Park are important wildlife sanctuaries (KWS, 1999b). Twenty species of mammals are documented as resident in the study area. Bovids are the most dominant species and they include antelopes, Buffaloes (*Syncerus cafer*), Bushpig (*Potamochoerus Larvatus*) and giant forest hog (*Hylochoerus meinertzhageni*). The carnivores are the second and comprises Civets (*Viverridae*), genets (*Genetta spp*) and African civets (*Civettictis civetta*), Dwarf mongoose *(Helogale Parvula)* and the Family Hyaenidae comprising of Spotted hyena (*Crocuta crocuta).* Reptiles include the Common python (*Python sabae*), green mamba (*Dendroaspis angusticeps*), Black necked spitting cobra (Naja nigricollis) and Nile monitor lizards(*Veranus niloticus)* (KWS, 1999b).

A total of **72** bird species are recorded as resident in the study area while an extra **53** species are found in the neighbouring area. According to Ngoru *et al.,* (2007), there was much overlap in the bird species occurring on the various sections of the park and this is attributed to their high mobility. However some of the species like the Turaco's, Olive-thrush and Owls only occur in specific areas. This could be due to differences in habitat structure within the different strata. Other species like the Tropical Boubou and Common Bulbul occurs on all the vegetation types and this is due to their general feeding and breeding ecology which the various habitats on the different strata could offer (Ngoru *et al.*, 2007)

2.1.7 Social economic activities

The Ol-Donyo Sabuk National Park is surrounded by agricultural communities, thus creating an island conservation area. These adjacent settlements are mainly involved in intensive smallholder rain-fed agriculture, Irrigation farming (growing horticultural crops e.g. peas and tomatoes) and livestock keeping. Nearby also, are large scale plantation farms which are involved in large-scale commercial horticulture. Communities utilise the park resources for basic subsistence needs including firewood, grass, honey collection, game meat, plant food, medicinal plants and other ecosystem services like carbon sequensation and pollinator services. In some cases, charcoal burning and illegal cultivation and livestock grazing also take place. Encroachment and edge effects resulting from increased population and the associated increase in resource uptake from the park including deliberate bush-burning to stimulate fresh grass growth for livestock are therefore common conservation issues in the study area.

According to the national population census records, there were a total of 2,500 people residing in the surrounding areas of Ol-Donyo Sabuk National Park in 1962, 3,463 in 1969, 6,969 in 1979 and 15,229 in 1990 (Lubia *et al.*, 1993). This gives an average increase of 3.4% per annum. With such increase in population, the pressure for forest resources and the associated disturbances are likely to increase and further drive invasion by non-native species. The problem might further be exacerbated by climate change and its associated effects.

2.2 Materials and methods

2.2.1 Remote sensed data

To determine and quantify the different land-cover types in the study area, an Advanced space-borne thermal emission and reflection radiometer (ASTER) imagery (path 168 row 61) obtained on 26th January 2008 at a resolution of 15-

metres was sourced and analysed using GIS methods. The analysis process entailed image acquisition, pre-processing, image enhancement i.e. improving visual interpretability through increasing the apparent distinction between features in the scene (Lillesand *et al.,* 2004) and image classification which involved sorting out pixels to finite numbers or class themes based on the data file values.

Further ground truthing was done to confirm the validity of the classified themes. The overall objective was to categorize all the pixel values in the image into land cover classes or themes (Lillesand *et al.,* 2004). Using a GPS, waypoints were taken in different land-cover classes at specific areas (training sites) and these actual class land-cover types were compared with the ones from the analysed imagery. The objective of this ground-truthing procedure was to confirm the validity of the digital classification methods.

2.2.2 Analysis of satellite images

This involves manipulation and interpretation of digital images with the aid of a computer (Lillesand *et al.,* 2004).

Acquisition of satellite images and pre-processing

Data for any remote sensing analysis should be obtained from a sensor that acquires data at approximately the same time of day and on anniversary dates. Same date images eliminate diurnal sun angle effects while anniversary dates images minimizes the influence of seasonal sun-angle and plant phenological differences (Jensen, 2005). Satellite data for this work was sourced from an advanced space-borne thermal emission and reflection radiometer (ASTER) and obtained from Regional Centre for Mapping of Resources for Development (RCMRD) Nairobi, Kenya.

ASTER is one of the earth observing systems (EOS) developed by National aeronautics and space administration (NASA). Their focus is to develop an improved scientific understanding of the earth-sun systems and its response to natural or human induced changes (Lillesand *et al.,* 2004). ASTER consists of three separate subsystems each operating in a different spectral region. These sub-systems are the visible near infrared (VNIR), the short wave infrared (SWIR), and thermal infrared (TIR). The VNIR subsystem incorporates three spectral bands that have fifteen metres ground resolution (Lillesand *et al.*, 2004). This imagery was chosen as it had lesser cloud cover and devoid of other atmospheric noise (unwanted disturbances in image data that is due to limitations in the sensing, signal digitization or data recording process).

2.2.3 Geometric correction

Raw digital images usually have some geometric distortions as a result of variations in the altitude, attitude, earth curvature, atmospheric refraction, relief displacement, and nonlinearities in the sweep of a sensor's instantaneous field of few (IFOV). They cannot therefore be used directly as a map base without subsequent geometric correction. The intent of geometric correction is to compensate for distortions introduced by these factors so that the corrected image will have the highest practical geometric integrity and create a more faithful representation of the original scene (Lillesand *et al.*, 2004).

The atmosphere affects the radiance received by the sensor by scattering, absorbing, and refracting light; and correction for these effects, as well as for sensor gains and offsets, solar irradiance, and solar zenith angles are necessary. These must be included in the radiometric corrections procedures that are used to convert satellite recorded digital counts to ground reflectance (Chavez, 1996). The ASTER image used in this work was already geo-rectified and no further geometric correction was necessary. The image was then projected to UTM zone 37 south and subset to the study area using the Park boundary shape file.

2.2.4 Image Enhancement

The main goal of image enhancement is to improve visual interpretability of an image. It involves techniques for increasing visual distinctions between features in the scene. The objective is to create "new" images from the original image data in order to increase the amount of information that can be visually interpreted from the data (Lillesand *et al.*, 2004).

Different techniques are used in image enhancement including point operations and local operations. Point operations modify the value of each pixel in an image dataset independently while local operations modify the value of each pixel based on neighbouring brightness values (Jensen, 2005, Lillesand *et al.,* 2004). Other methods include principal components analysis and vegetation indices (Jensen, 2005; Lillesand *et al.,* 2004). Enhancement operations are normally applied to image data after appropriate restorations procedures have been performed. Noise removal is an important precursor to most enhancements. Without it the process of image interpretation will involve analysing enhanced noise (Lillesand *et al.,* 2004)

Principal Components Analysis (PCA)

This is a technique that transforms the original remotely sensed data into substantially small and easier to interpret set of uncorrelated variables that represent most of the information present in the original data sets (Jensen, 2005). It's therefore a data compression technique which allows redundant data to be compacted into fewer bands.

Spectral Vegetation Indices (SVIs)

These are dimensionless, radiometric measures that indicate relative abundance and activity of green vegetation (Jensen, 2005). SVIs are used to create output images by mathematically combining digital numbers (DN) values of different bands; and usually use the inverse relationship between the red and the near-infrared reflectance associated with the healthy green vegetation. These vegetation indices therefore operate by contrasting intense chlorophyll pigment absorption in the red against the high reflectivity of plant materials in the NIR (Elvidge and Chen, 1995).

2.2.5 Image Classification

The objective of these operations is to replace visual analysis of the image data with quantitative techniques for automating the features in a scene. Multi-spectral image classification involves sorting out pixels to finite numbers or class themes based on the data file values. The overall objective being to automatically categorize all the pixel values in an image into land covers classes or themes (Lillesand *et al.*, 2004).

Image pixel categorization is based on the fact that different features have different reflectance. The classification process involves pattern recognition inherent in the image, with spectral pattern considered the most scientific, though temporal and spatial pattern recognitions can also be used (Jensen, 2005). Supervised and unsupervised classification schemes are the most widely used classification methods. Supervised classification requires *a priori* knowledge of the study area to ensure selection of the training sites.

Unsupervised classification involves algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the image values (Lillesand *et al.*, 2004). The spectral classes from the unsupervised classification are then identified and their information utility defined through comparing the classified image with reference data available. The advantage of unsupervised classification is that it is automated and does not require *a priori* knowledge of the study area (Jensen, 2005).

During this study, supervised classification was carried out as the area was relatively small and there was adequate *a priori* knowledge of the study area. This involved setting up training sites in the different land cover classes where attributes of the different land-cover types were confirmed. Image classification was performed with seven target classes (Forest/Closed canopy thicket, barelands, Shrublands, Wooded grasslands, Open glades, Dams and Degradedlands). The purpose was to provide a framework for stratifying the study area.

Various classifiers are used to identify unknown land-cover pixels based on decision rules that are set by the image analyst. In this work, Gaussian maximum likelihood classifier using Idrisi Kilimanjaro software was used. The Gaussian classifier quantitatively evaluates both the variance and covariance of the category spectral patterns when classifying an unknown pixel. To do this an assumption is made that the distribution of a cloud of points forming the category of training data is Gaussian (Normally distributed) (Lillesand *et al.,* 2004).

Accuracy Assessment

The need for accessing accuracy of spatial data derived from remote sensing techniques and used in Geographic Information System (GIS) analysis is a critical component of any image analysis. According to Congalton (1991), if information derived from remote sensing data is to be used in some decision-making process, then it is critical that some measure of its quality be determined. The most common accuracy assessment elements include overall accuracy, producer's accuracy, user's accuracy and kappa statistic (Lu *et al.,* 2003).

One of the most common methods of expressing classification accuracy is the preparation of a classification error matrix (Lillesand *et al.,* 2004). An error matrix is an array of numbers set in rows and columns that express the number of sample units assigned to a particular category in one classification relative to the number of sample units assigned to a particular category in another classification (Congalton and Green, 1993). The error matrices compare, on a category by category basis, the relationship between known reference data and the corresponding results of the automated classification. The matrix is able to identify both omission and commission errors in the classification as well as the overall, producer's and user's accuracy (Lillesand *et al.,* 2004).

The overall accuracy is computed by dividing the total number of correctly classified pixels by the total number of reference pixels. The producers accuracy results from dividing the number of correctly classified pixels in each category by the number of training set pixels used for that category and gives an indication of how well training set pixels of that given cover type are classified.

The users accuracy are computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category and is a measure of commission error. It indicates the probability that a pixel classified into a given category actually represents that category on the ground.

The Kappa statistic is a measure of the difference between the actual agreement between the reference data and an automated classifier and the agreement between the reference data and a random classifier.

K = observed accuracy – chance agreement /1– chance agreement

The statistic serves as an indicator of the extent to which the percentage correct values of an error matrix are due to “true” versus “chance” agreement (Lillesand *et al.,* 2004).

2.2.6 Determination of sample sizes.

The study area was divided into grids of 500mx500m and all grid-squares of size ¾ and above counted. In total, 78 grid-squares were counted out of which 26 grid squares (33%) were sampled. These grids were proportionately allocated to the different strata as shown in the table 2.1. The calculation for the number of sampling grids was arrived using the following formulae:

Number of grids to be sampled (N)

= Strata area (a) **X** Number of grids selected (C)/ Total area (A)

Table 2.1 Allocation of sampling grids within different stratum.

No.	**Habitat type (Stratum)**	**Size (ha)**	**Total area (ha)**	**Number of grids allocated** **N = a X c/A**
1	Closed canopy forest	1185	2068	15
2	Shrub-land	336	2068	4
3	Wooded grassland	476	2068	6
4	Open glades	35.6	2068	0.4
5	Degraded land	21	2068	0.3

Twelve grids were sampled in the closed canopy forest, while two others were transfered to shrub-land stratum due to similarity in vegetation. The data from the degraded area was pooled together with that from the shrub-land category as the vegetation was of the same type. Eight plots were therefore sampled in the shrub-land stratum. The open glades and degraded areas were small in size but two sampling grids were done in each to ensure replication, while in the wooded grassland, sampling was done in six grids. Dams and bare-land had no vegetation and their sizes were small. Since they did not have vegetation, no data was collected. During the actual sampling two plots in the forest/closed thicket were found to contain more of the shrub-land vegetation hence data from these two transects was reclassified together with the shrub-land category stratum. One sampling grid was in a cliff hence not reachable. In total, thirty grids were sampled.

2.2.7 Determination of sampling grids and placement of transects.

The grids in each vegetation stratum were numbered from the first to the last and random numbers equalling to the allocated sample size picked using Microsoft excel programme as the identity of the sampling sites.

Within each established sampling grid, the lower most left corner on the north south direction was located by the use of a global position system set (GPS). Fifty metres were measured to the right of the established grid-lines intersection and belt-transects of length 100m x 20m located on the North-south direction. All the established sampling areas were marked using a GPS and later plotted on the digital map of the study area to produce a transect map. A total of thirty transects were distributed within different vegetation/land cover strata as shown in Figure 2.2.

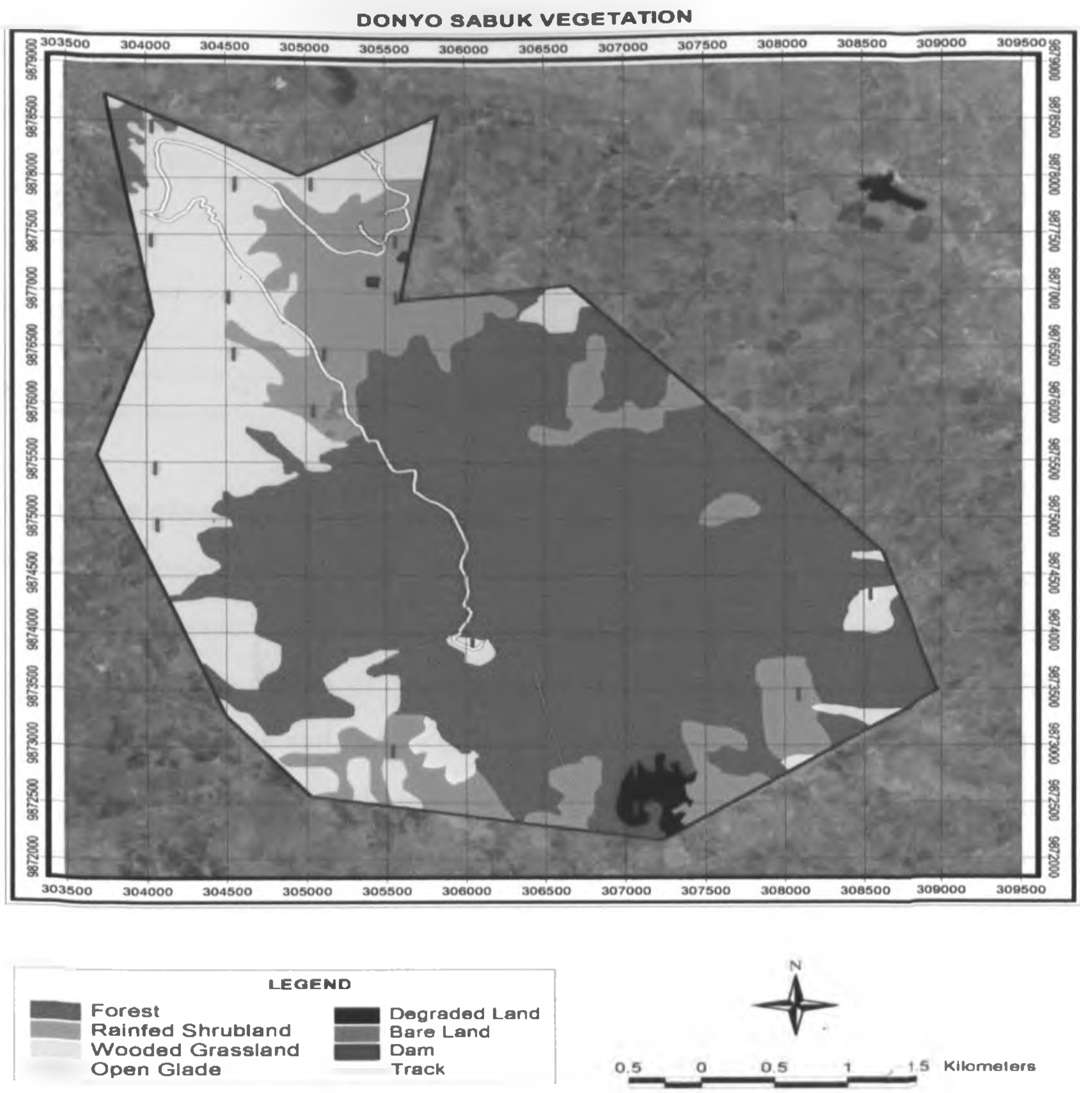

Figure 2.2 Distribution and placement of transects within the study area.

The number of sampling transects allocated in each vegetation/landcover class is shown in Table 2.2. Two transects of the strata earlier classified as degraded were included in the category of shrublands as the area was found to contain the same vegetation and ground truthing in the area showed that the section had been burned when the imagery was taken.

Table 2.2. Number of transects allocated to different sampling strata

Landcover Class(Stratum)	No. of transects
Forest/Closed thicket	12
Shrubland	6
Wooded grassland	8
Open glades	2
Degraded land	2 (Data transfered to shrub land stratum)
Barelands	0
Dams	0
Total	**30**

2.2.8 Invasive plant species and distribution in the park.

Within each transect in the different vegetation strata, the following vegetation data was documented. All trees and shrubs, their growth form and height categorised into three groups of i) 0-5metres ii) 5-10 metres iii) 10 metres and above. Also the species and family names of each tree or shrub located along the transect belt was documented, the elevation and any form of anthropogenic disturbance. Where invasive plant species were found, they were identified and their extent of manifestation categorised into three groups; a) Low i.e. comprising upto 20% of the total ground cover. b) Moderate –comprising between 20%-40%. c) High- comprising more than 40% of the total ground cover.

2.2.9 Assessment of invasive species impact on biodiversity

Ten 10m x 10m random quadrants were established in the areas that didn't have a record of any invasive plant species and similar number of random quadrants in the areas where invasive plant species were recorded. Within each quadrant, both in the invaded and non-invaded areas, all the trees, shrubs, herbs and grasses were identified and documented. The objective of this exercise was to determine if there was any significant difference in species diversity between the invaded and non-invaded areas. The family category of each tree, shrub, herb and or grass species within the quadrant was also documented.

2.3.1 Determination of birds and mammal species associated with Invasive plants.

Four categories of disturbances were documented to be associated with invasive plant species. These were:

i) Dams

ii) Settlements

iii) Roads

iv) Edges (boundaries of the park)

Fixed radius counting technique based on sampling protocol developed by Buckland *et al.* (1993) was used to sample birds and mammal communities associated with invasive plant species. This method involves counting the desired species from a fixed point and is preferable over the transect method as it inflicts minimum disturbance to sensitive bird and mammal species. Fixed radius counts also provide more representative data than transects. (Bibby *et al.,* 1992).

In each disturbance category, all the different birds and mammals were counted between 0700 hours-1100 hours and 1600- 1800hours as birds are active during the early and evening hours of the day thus easy to count. Each point was counted twice i.e. during the wet and dry seasons. In each sampling point, ten minutes were spent before commencement of counting in order for the birds and mammals to habituate. Sampling then proceeded for twenty minutes before moving to the next point which was separated from the previous by a distance of 200metres on the North- South direction.

All the birds and mammals seen or heard were recorded with an average of four to five stations being counted in the morning and evening sessions in each category of disturbance. The species name of each bird and or mammal species within a radius of 30 metres and their trophic status or feeding guild for birds were documented. Each disturbance type was allocated two alternate days of counting and the exercise was carried out during the dry season (January-February 2009) and wet season (April-May 2009).

2.3.2 Factors related to the distribution of invasive species.

To identify factors related to the occurrence of invasive species in the park, the following parameters were recorded while collecting vegetation data along the transects in areas where invasive species were recorded; Elevation, any noted natural or anthropogenic disturbances, birds and primates as well as mammals sighted.

2.3.3 Invasive plant species found on the immediate surroundings of the park.

To determine if there were invasive plant species within the community areas, four transects were established each measuring two Kilometres on the Northern, Southern, Eastern and western parts of the park. Each of these sides had different types of land use and these differences were used as the basis for stratification of the surrounding area. The northern part comprised mainly large-scale commercial farms of pineapples and abandoned coffee plantations. The Southern part was mainly used for subsistence farming and especially on the slopes of the study area.

In the eastern part most of the land use practices entailed subsistence farming and cattle keeping but at lower scale compared to the western side. On the western side, the main land-use included small scale farming and large scale livestock production including migratory pastoral communities. All the invasive plant species found on each of these sections were sampled using belt transect method of two kilometres by twenty metres. Sampling involved counting all the different types invasive plants species found within the belt.

2.4 Data analysis

2.4.1 Remote sensed data.

ArcView 3.2 and ArcGIS 9.1 were used to analyse satellite image into the different vegetation strata based on differences in spectral reflectance's (Lillesand *et al.*, 2004) while Idrisi Kilimanjaro version was used to perform accuracy assessment.

2.4 .2 Vegetation sampling data.

Vegetation data analysis involved both descriptive and statistical analysis stages. Microsoft excel analytical tools were used to calculate total number of each species and densities (number of individuals/area sampled) in each stratum. Statistical analysis involved determination of significance differences in species diversity between the different sampling areas in the surrounding areas and different strata using ANOVA (Zar, 1999).

Species diversity within the different sampling strata was expressed as species richness **S** (the number of species in the community). This is largely a descriptive factor and does not reflect relative contribution or proportion of each species within the community. In order to have an effective measure of diversity and account for richness and the abundance, a proportional abundance index the Shannon-Wiener diversity index (**H'**) and evenness (**J'**) values for the different strata were calculated with the assumptions that randomness in sampling was achieved (Shannon and Wiener, 1963).

The Shannon-Wiener index combines two quantifiable measures, 1) the species richness **S.** 2) Abundance **N** (is the total number of individuals of different species in the sample). The index is termed **H'** with higher values indicating higher diversity. Evenness **J'** is equal to the **H'** divided by maximum possible diversity (**Ln of S**). The values for evenness range from zero to one where a sample of equal numbers of individuals of the same species has a value of one. The formulae for the calculation of the two values of diversity indices used in this study is:

Shannon-Wiener diversity index $H' = -\sum_{i=1}^{s} pi \log pi$

Evenness $J' = H'/\text{Ln } S$

Where: **H'** = Information content of sample, Index of species diversity.

pi = Proportion of total sample belonging to i^{th} species

lnpi = natural logarithm of the proportion

S= Number of species

Information content is a measure of the amount of uncertainty. The larger the value of **H'** the greater the uncertainty. **H'** increases with the number of species in a community and in biological samples it doesn't exceed a value of 5 (Krebs, 1999). This was done within the assumption that all species are represented in the sample (Magurran, 1988, Rosenzweig, 1995, Begon, *et al.,* 1996). Further analysis included calculation of **PiLnpi** which represents the proportion of each species multiplied by natural logarithm of the proportion **and (PiLnpi)2** representing the square transformation of **PiLnPi.**

2.4.3 Birds sampling data.

Birds sampling was done with an objective of determining if they were associated with the dispersal of invasive species in the study area. Indices of point abundance (IPA) were calculated for each disturbance type as well as total richness. Also Shannon-Weiner diversity and evenness indices for each disturbance type were determined. The aim of this was to establish which category of anthropogenic disturbance was associated with high bird species diversity.

2.4.4 Mammal sampling data.

Mammalian data was analysed by calculating the total number of the different species that were documented during the dry and wet season counts. Since the diversity of mammalian species within each disturbance category was relatively low in both counting periods, the data was pooled together into two categories (wet and dry season surveys). This was then analysed by calculating the number of occurrences of different species in order to test if there was any significant difference in species recorded during dry season and wet season counts.

2.4.5 Tests of association

Various inferential statistical tests were performed on the different types of data collected. One way ANOVA was used to test the significance of differences in invasive species diversity within the surrounding areas and diversity differences between sampling strata, Chi-square tests of association to test for differences in bird and mammal species diversity in the dry and wet season counts, while the student t test was used to test for species diversity differences between invaded and un-invaded areas (Zar 1999).

Thus: $t = H'_1 - H'_2 / S_{H'1-H'2}$ and degrees of freedom

$$\mathbf{Df} = (S^2 \mathbf{H'}_1 + S^2 \mathbf{H'}_2)^2 / ({}^{S2}{}_{H'1})^2/N_1 + {}^{S2}{}_{H'2})^2/N_2$$

Where

$\mathbf{H'}_1 - \mathbf{H'}_2$ =Difference between the two diversity indices

${}^{S}{}_{1}\,\mathbf{H'} - \mathbf{H'}_2$ = Standartd deviation of the difference between the two diversity indices

${}^{S2}\,\mathbf{H'}_1$ = Variance of diversity indices $\mathbf{H'}_1$

${}^{S2}\,\mathbf{H'}_2$ = Variance of diversity indices $\mathbf{H'}_2$

$\mathbf{N_1}$ = Number of species in sample 1

$\mathbf{N_2}$ = Number of species in sample 2

CHAPTER THREE

RESULTS

3.1 Landcover stratification using remote sensed image

Land cover classes used in vegetation sampling were obtained through analysis of an advanced space-borne thermal emission and reflection radiometer (ASTER) imagery using Arc View 3.2 and ArcGIS 9.1 softwares.

In the ASTER imagery (Figure 3.1) that was analysed to generate the different land cover types; the study area is represented by (A) while the surrounding cultivated farms are shown as (B). Water in the imagery is shown as (C) while clouds that were on the satellite swath are represented as (D). Clouds contribute to atmospheric noise and prevent accurate generation of data.

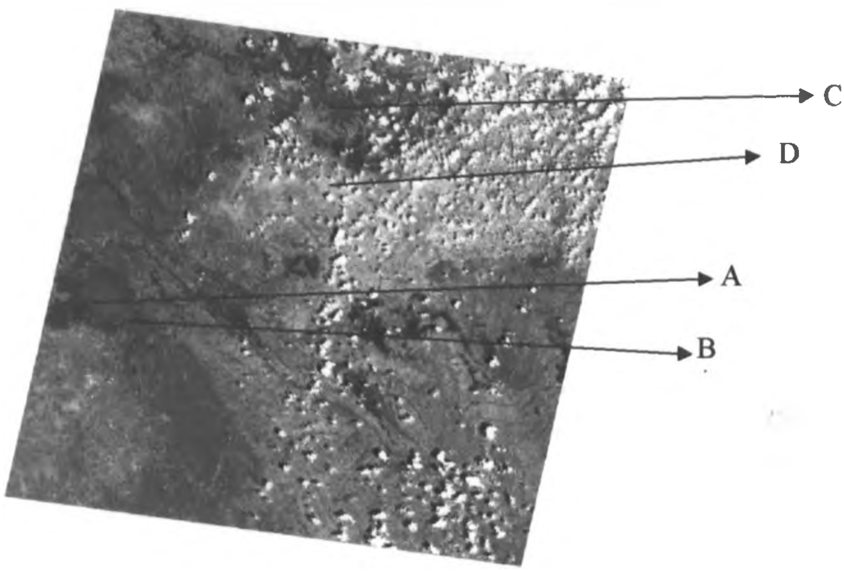

Figure 3.1 Remote sensed image of the study and neighbouring areas

In the next stage, a colour composite of the study area was clipped from the larger imagery and the three primary colours (Red, Green and Blue) (RGB) of the electromagnetic spectrum set at bands 3, 2 and 2 respectively (Figure 3.2). These colour combination portrayed the different vegetation types more accurately.

Key

A- Bare Land
B- Dams
C- Wooded Grassland
D- Closed Canopy Forest
E- Open glade
F- Degraded Land
G- Shrublands

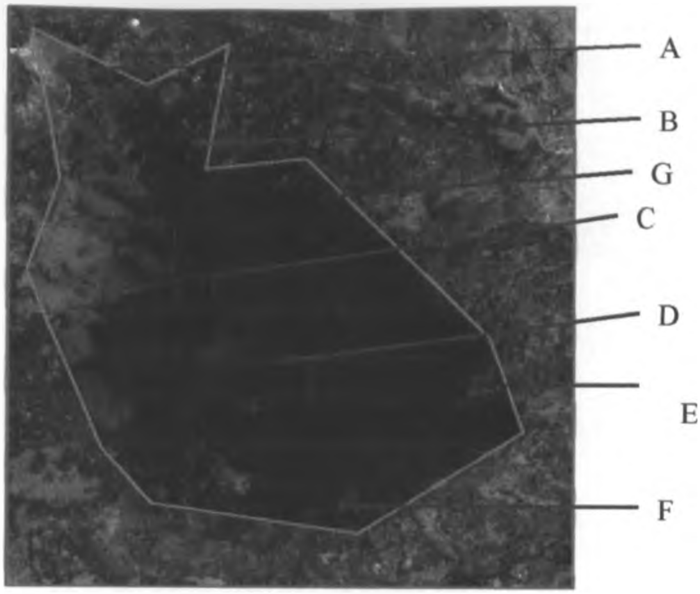

Figure 3.2 Clip colour composite map of the study area

Each of the land-cover classes was assigned a unique colour pattern for easier recognition. This resulted to a vegetation map of the study area (Figure 3.3). The seven different classes that resulted from the above classification before ground truthing were:

i) Closed canopy forests ii) Shrub-lands iii) Wooded grasslands

iv) Dams v) Barelands. vi) Degraded-lands vii) Open glades.

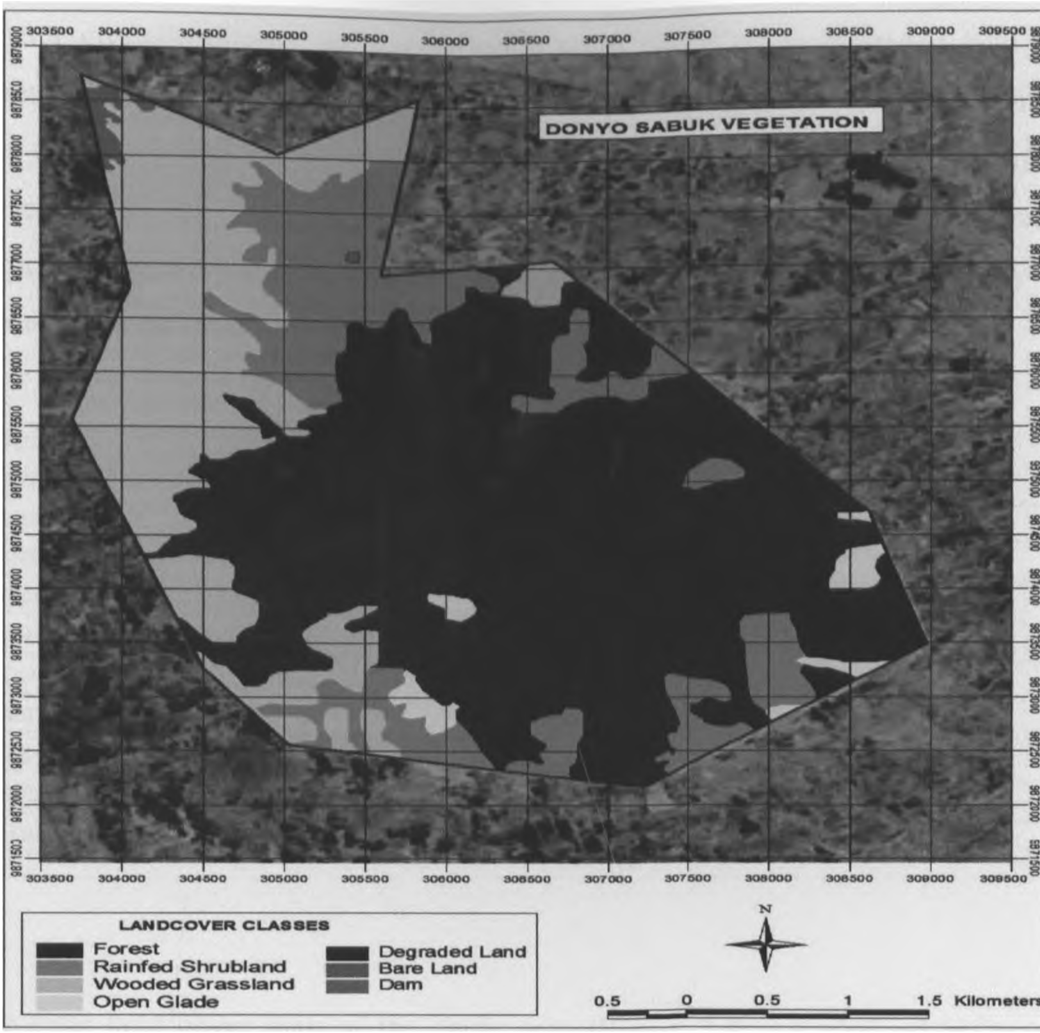

Figure 3.3: Land-cover classes found in the study area as generated from remote sensed imagery before ground truthing.

The sizes of the land-cover types (stratum size) varied widely in their percentage of coverage (Table 3.1)

Table 3.1 Relative sizes of land-cover types before ground truthing.

Land-cover Class (Stratum)	% Coverage	Size in Hectares
Forest/Closed thicket	57	1185
Shrub-land	16	336
Wooded grassland	23	476
Open glades	1.72	35.59
Degraded land	1	20.89
Bareland	0.6	12.503
Dams	0.065	1.348
Total	**100**	**2068**

After ground-truthing, the vegetation stratum classified as degraded land was found to have been burned-up area during the time of sensor data acquisition and the vegetation was the same as that of the shrub-land category. The percentage coverage of the different landcover types after ground truthing (Table3.2) indicates that forests/closed thicket had the highest coverage followed by the shrub-lands the least were the dams.

Table 3.2 Coverage percentage of the different land-cover types after ground truthing.

Land-cover class(stratum	% Coverage	Size in Hectares
Forest/Closed thicket	57.3	1185
Shrub-land	17.27	357.3
Wooded grassland	23	476
Open glades	1.72	35.59
Bare-land	0.6	12.503
Dams	0.065	1.348
Total	**100**	**2068**

The final land cover map of the study area (Figure 3.4) was derived by use of Gaussian maximum likelihood classifier in Idrisi Kilimanjaro software. It shows that most of the areas were correctly classified apart from the degraded-lands which contained shrub-land vegetation hence reclassified as such.

Figure 3.4. Gausian Maximum likelihood classified land-cover map of the study area.

3.1.1 Accuracy assessment results.

The Gausian maximum likelihood classified landcover map of the study area had an overall accuracy of 90% and a Kappa statistic of 0.85 (Appendix 1). The closed canopy forest class had the highest producers and users accuracy (100%). Most other land-cover classes apart from the wooded grasslands had fairly high users and producers accuracies. However, wooded grasslands and dams had low producers and users accuracy. Closed canopy forests were easily distinguishable from the other land cover types and hence exhibited high producer's accuracy. The wooded grasslands had low producers accuracy as some of its pixels were confused with those of shrub-lands, bare-lands and open glades pixels.

3.2 Vegetation sampling data

3.2.1Closed canopy forest

These class covered 1185 hectares or 57% of the study area. It comprised the middle section of the hill apart from the summit which was an open glade. The vegetation had thick canopy with no open ground and most of the sampled trees and shrubs were more than ten metres in height. The Shannon wiener index of diversity (**H'**) in the stratum was **2.89** while the evenness index **(J')** was **0.70.** This was the largest class and had minimal anthropogenic disturbances.

Major tree/shrub species in terms of total number of recorded individuals and density included *Rhus natalensis, Lantana Camara* (an invasive plant species) which had a total of 228 individuals and density of 95 individuals/hectare and *Acacia horkii* (Table 3.3). *Acacia seyal, Acacia melifera* and *cordia ovalis* had the least number of recorded individuals and density (Appendix 4).

At the family level, the family Anacardiaceae had the highest density followed by Verbenaceae and Leguminosae respectively while the families Boranginaceae, Moraceae and Santalaceae had the least density (Appendix 3). Being the largest land-cover in the study area, it provides important ecological functions to the surrounding communities by acting as a water catchment area, carbon sequensation zone, and pollinator services as well as providing cover to wildlife especially the forest dwelling species. It's therefore an important conservation zone that needs to be protected for long-term ecosystem services and species conservation.

A list of ten species that had the highest number of species recorded and density in the stratum (table 3.3) indicates that species with high proportions **(pi),** also had high values of natural logarithm of the proportion **(Lnpi).** This means that they contribute most to the Shannon-wiener index of diversity of the stratum. Detailed table of all the species found in the stratum is shown in Appendix 4.

Table 3.3 Ten most abundant species in the closed canopy forest stratum.

Species name	Number of individual recorded	Density(Ind/Ha)	pi	lnpi
Rhus natalensis	463	192.92	0.27	-1.31
Lantana camara	228	95.00	0.13	-2.02
Acacia hockii	101	42.08	0.06	-2.83
Albizia gummifera	96	40.00	0.06	-2.89
Abutilon longicuspe	92	38.33	0.05	-2.92
Rhus vulgaris	83	34.58	0.05	-3.03
Turraea robusta	71	29.58	0.04	-3.19
Grewia similis	68	28.33	0.04	-3.23
Todalia asiatica	64	26.67	0.04	-3.29
Euclea divinorum	49	20.42	0.04	-3.32

3.2.2 Shrub-lands

This class comprised mainly of shrubs and short trees with few grass species. Covering a total area of 357.3 hectares or 17.2% of the study area, the class covered the southern part of the park mainly on the edges and around the dams. The dominant shrub in this category was *Rhus natalensis* and *Lantana camara* while the tree category consisted of mainly *Acacia hockii.* The Shannon-wiener index of species diversity (**H'**) in the stratum was **2.66** and the evenness index **(J')** was 0.64.

Most of the invasive species were recorded in this stratum and included *Lantana camara*, *Ricinus communis*, *Solanum incanum*, and *Toddalia asiatica.* This is attributable to its close proximity to settlements and increased rate of anthropogenic disturbances.

Within the strata, the invasive species *Lantana camara*, *Rhus natalensis* and *Acacia horkii* had the highest total number of recorded individuals and density respectively while *Fagaropsia hildebraditii*, *Gardenia volkensiii* and *maytenus senegalensis* had the lowest (Appendix 5). *Lantana camara* was the most important invasive species in this stratum with a total of 296 individuals and a density of 185 individuals per hectare while *solanum incanum* had a total of 46 individuals and density of 28.75 individuals per hectare (Table 3.4).

In terms of families, the Anacardiaceae, verbenaceae and leguminosae families had the highest total number of recorded individuals and densities respectively while Agavaceae, Anonaceae, Labiatae, Simaroubiaceae and Rubiaceae had the least (Appendix 6). Woody vegetation especially *Acacia hockii* were extensively exploited for firewood and charcoal burning as indicated by the many stumps and old charcoal kilns encountered during the study. The stratum therefore acted as a buffer zone between the community and the more pristine closed canopy forest.

Table 3.4 Ten most important species in the shrub-land stratum.

Species name	Number of recorded individuals	Density(Ind/Ha)	Pi	Lnpi
Lantana camara	296	185.00	0.21	-1.55
Rhus natalensis	249	155.63	0.18	-1.73
Acacia hockii	126	78.75	0.09	-2.41
Combretum molle	70	43.75	0.05	-2.99
Euclea divinorum	67	41.87	0.05	-3.04
Abutilon longicuspe	55	34.38	0.04	-3.24
Rhus Vulgaris	54	33.75	0.04	-3.26
Solanum incanum	46	28.75	0.03	-3.41
Erythrina abyssinica	41	25.63	0.03	-3.53
Dodonea viscosa	40	25.00	0.03	-3.56

3.2.3 Wooded grasslands.

The stratum was found on the western part of the park and covered an area of 476 hectares or 23% of the study area. It was mainly composed of open grassland with few woody shrubs and trees. The main grass species included the following; *Hyperenia ruffa, Themeda triadra, Hyperenia pilifitura* and *Heteropogon condutus.* Woody vegetation species comprised of *Acacia horkii* and *Dombeya rotundufolia* while the shrub layer was dominated by *Lantana camara* and *Rhus natalensis.* At the species level, the last two species had the highest density (Table 3.5).

The family Leguminosae, Anacardiaceae, Verbenaceae and Sterculiaceae had the highest number of recorded individuals and density while Solanaceae,Tiliaceae and Moraceae had the lowest recorded individuals and density (Appendix 8)

The stratum is an important component of the study area as it's the only grazing area for wildlife and in particular the open grassland species like the bovids. Grasses also provide an important ecosystem service to the surrounding communities through run-off control and enhancement of water catchment properties. Grasslands are critical in providing fodder for livestock especially during the dry season and acting as a source of livestock pests such as ticks and tsetse flies. Shannon-wiener index of species diversity **(H')** in the stratum was **2.93** While evenness index (**J'**) was **0.73.** The tabulation of ten species with the highest number of recorded individuals and density (Table 3.6) shows that *Lantana camara* was an important species in the stratum.

Table 3.5 Ten most abundant species in the wooded-grassland stratum

Species name	Number of recorded individuals	Density(Ind/Ha)	Pi	Lnpi
Acacia horkii	445	278.13	0.29	-1.22
Lantana camara	189	118.13	0.13	-2.08
Rhus natalensis	150	93.75	0.10	-2.31
Dombeya rotundufolia	128	80	0.08	-2.47
combretum molle	107	66.88	0.07	-2.65
Faurea saligna	78	48.75	0.05	-2.96
Rhus vulgaris	46	28.75	0.03	-3.49
Senna singueana	41	25.63	0.03	-3.61
Protea caffra	39	24.38	0.03	-3.66
Dichrostachys cinerea	29	18.13	0.02	-3.95

3.2.4 Open glades.

The class covered the summit area of the hill and several open sections on the south-eastern part of the study area. Open glades covered an area of 35.59 hectares or 1.72% of the study area. These are areas that are open with short grasses and lianas. The main species included the *Sateria incrasata, Pennisetum clandestinum* and *Cynodon dactylon* while the least common species included *Sida schimperiana, Taddalia asiatica* and *Tephrosia holstii* (Table 3.6). In the edges of the glades, and especially in areas that are used as saltlicks by wildlife, *solanum incanum* was recorded and these was attributed to disturbances related to trampling and local nutrient enrichment through faecal-droppings, urine and salts.

Open glades were mainly utilized by wildlife as day-time resting areas. They could therefore be invaded by other invasive and potentially invasive plant species if wildlife species feed and disperse invasive species seeds through faecal droppings. The frequency and density of ten most important species in the stratum (Table 3.6) indicates that species were evenly distributed compared to all the other strata sampled. Shannon-wiener evenness index was therefore highest **(J'= 0.93)** while diversity index **(H')** was **2.79.**

Table 3.6 Number and density (individuals/hectare) of ten main species recorded in the open glades stratum.

Species name	Number of recorded individuals	Density	Pi	LnPi
Pennisetum clandestinum	12	600	0.130	-2.04
Setaria incrasata	12	600	0.130	-2.04
Cynodon dactylon	9	450	0.097	-2.32
Cynoglossum caerulae	7	350	0.076	-2.58
Periploccaineariifolia	6	300	0.066	-2.73
Phytolacca dodecandra	6	300	0.065	-2.73
Sida rhombifolia	5	250	0.054	-2.91
Aspilia pluriseta	4	200	0.043	-3.13
Landolfia buchananii	4	200	0.043	-3.14
Agrocharis nicognito	3	150	0.033	-3.42

3.2.5 Bare-lands

This class was found on the north-western tip of the study area. The class didn't have any vegetation and covered an area of 12.5 hectares or 0.6 % of the study area. Bare-lands in the study area result from intense grazing, and the resultant soil erosion. These are important conservation areas as they require different approaches of management. The control of their expansion through soil erosion as well as grazing regulation is a key management challenge that needs to be addressed both at the local and ecosystem levels. The expansion of bare-land in any conservation area is thus an indication of loss of critical ecosystem services like pollinators and run-off checks. No vegetation data was collected from this stratum.

3.2.6 Dams

Included the two dams found within the Northern edges of the study area and covered an area of 1.4 hectares or 0.065% of the park. The dominant vegetation within the dams included *Ceratophyllum demersum L.* and sedges. Dams are important as they act as watering points for wildlife. They also have inherent species with conservation value like birds, fish and insects. They also control run-off by storing excess rain water thus boosting ground water aquifers.

3.2.7 Species diversity and evenness in the different strata.

Species diversity was highest in the shrub-land stratum followed by the closed canopy forest, open glades and wooded grasslands respectively (Table 3.7). The most evenly distributed class was the open-glades. The second was shrub-lands, closed canopy forest and the least evenly distributed stratum was wooded grassland.

Table 3.7 Shannon-wiener indices of diversity and evenness in the sampling strata.

Stratum	Closed canopy-forest	Wooded grass-land	Shrub Lands	Open Glades
No. of families	31	28	28	14
Total number of individuals.	1720	1511	1401	92
Number of species (N)	63	64	56	20
Mean 0f (PiLnPi)2	0.01	0.01	0.01	0.02
Standard deviation	0.02	0.02	0.20	0.02
Shannon-wiener index of diversity (**H'**)	2.89	2.66	2.93	2.80
Shannon-wiener evenness index (**J'**)	0.70	0.64	0.73	0.93

In all the strata sampled apart from degraded-lands and dams, the family Vebenerceae comprising of the non-native invader *Lantana camara* had high number of recorded individuals and density. This is an indication that a larger percentage of the study area had invasive plants.

3.3 Birds and mammals associated with invasive plant species

A survey of birds and mammal associated with invasive plant species was carried out during the dry and wet seasons.

3.3.1 Dry season counts

During the dry season survey, the most abundant bird species in the invaded areas were; Black Roughwings, Common bulbuls, variable sunbirds and willow warblers (Appendix 10). In the feeding guild/trophic status categorization, the most abundant were the Insectivore/Gramnivores group followed by the insectivores category. The least common category were the raptors, Insectivores/nectivores and Insectivores/frugivores respectively (Figure 3.5).

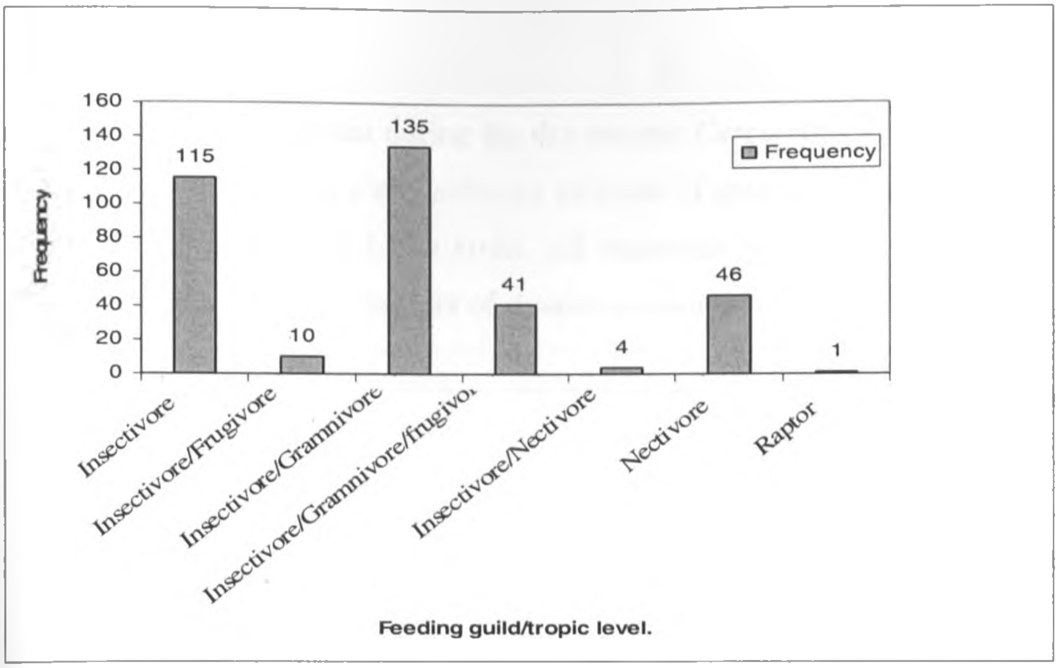

Figure 3.5 Dry season feeding guild/trophic status for birds associated with invaded areas

Several birds were observed feeding on *Lantana camara* ripe seeds. This included mainly the Insectivores/Gramnivores group and this was an indication that ripe *Lantana camara* seeds and insects that are associated with them are an important food resource to this group.

The total number of birds species, Shannon-wiener diversity (**H'**) and evenness (**J'**) index of birds species found on the different types of disturbance (Table 3.8) shows that birds diversity were highest along the edges and lowest on the dams.

Table 3.8 Diversity and evenness indices for birds' recorded during the dry season survey.

Disturbance category	Total number of individuals.	Number of species	Shannon-wiener index of diversity (H')	Evenness index (J')
Edges	166	27	2.87	0.87
Settlements	58	18	2.55	0.88
Dams	68	13	2.03	0.79
Roads	65	24	2.94	0.93

The mammalian groups were dominated by the primates with the following groups being very abundant during the dry season; *Cercopithecus aethiops, Papio cynocephalus anubis* and *Cercopithecus nictitans* (Figure 3.6). The least frequent was *Xerus nutilus* and *madoqua kirkii.* All mammals apart from *Madoqua kirkii* were observed to be active feeders of *Lantana camara* ripe seeds.

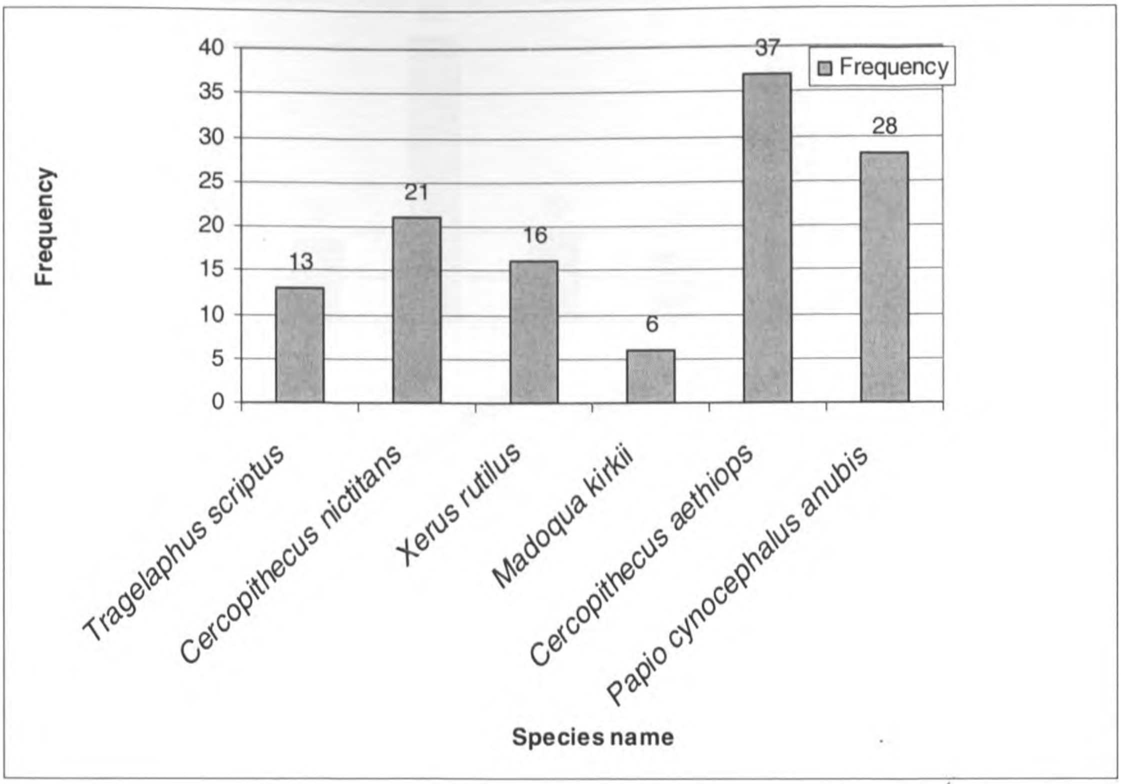

Figure 3.6 Dry season frequency for mammals associated with invaded areas.

3.3.2 Wet season survey

During the wet season count, the most frequent bird species in the invaded areas were the Variable sunbirds, Amethyst sunbird and the Black-and-white minnikins (Appendix 11).

Trophic status classification indicated that the nectivores were the most common followed by the insectivores/gramnivores and insectivores respectively (Figure 3.7). The least frequent were the frugivores. The reduced number of frugivores compared with the dry season survey can be attributed to reduced *Lantana camara* ripe fruits.

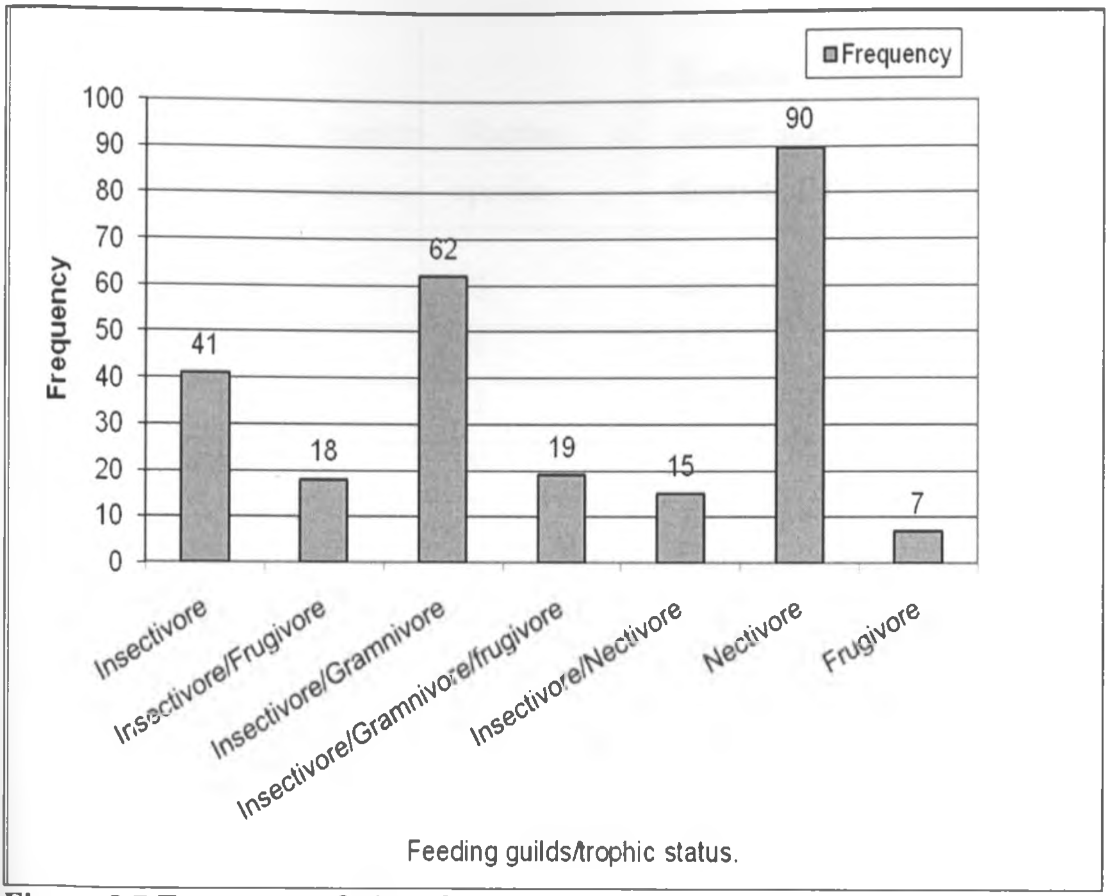

Figure 3.7 Frequency of birds feeding guilds sampled during the wet season in disturbed and invaded areas.

The onset of *Lantana camara* flowering during the early days of the rain season led to the increased number of nectivorous birds while the higher number of insectivore/gramnivores during the early periods of the wet season is closely linked to the high number of insects towards the end of the dry season. Shannon-wiener diversity and evenness indices for birds species recorded during the wet season (Table 3.9) in the different disturbance types indicates that there was more diversity along the edges and roads while low diversities were recorded in the dams.

Table 3.9 Diversity and evenness indices for bird species recorded in the different types of disturbance during the wet season survey.

Disturbance category	Total number of individuals.	Number of species	Shannon-wiener index of diversity (H')	Evenness index (J')
Edges	116	23	2.83	0.91
Settlements	58	16	2.51	0.91
Dams	43	11	2.17	0.90
Roads	46	20	2.83	0.95

The mammalian groups were dominated by Vervet monkeys (*Cercopithecus aethiops*), Sykes Monkey (*cercopithecus nictitans*) and Olive Baboons (*Papio cynocephalus anubis*). However, Ground squirrel (*Xerus nautilus*) was not recorded during the wet season sampling (Figure 3.8).

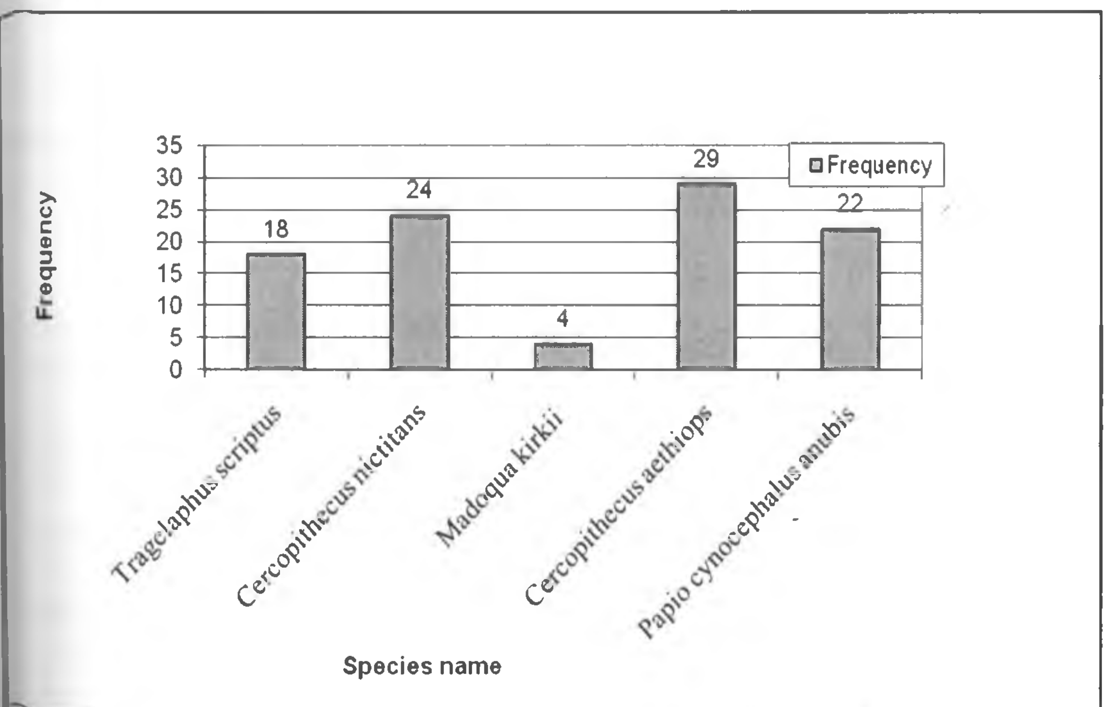

Figure 3.8 Mammalian species frequency during the wet season survey in the disturbed and invaded areas.

3.4 Trophic differences between dry and wet season for bird/ mammal species associated with disturbed and invaded areas

Results from Chi-square tests of association carried out on birds data showed that there was significant difference in trophic status of birds associated with invasive plant species during the dry and wet seasons X^2 =83.338, $P < 0.001$, Degrees of freedom = 6 (Table 3.10).

Table 3.10 Dry and wet season bird surveys.

Trophic/guild level	**Dry season**	**Wet season**	**Total**
Insectivore	115 (91)	41(65)	156
Insectivore/Frugivore	10 (16.3)	18 (11.6)	28
Insectivore/gramnivore	135(114.8)	62 (82)	197
Insectivore/gramnivore/frugivore	41 (34.9)	19 (25)	60
Insectivore/nectivore	4 (11)	15 (7.9)	19
Nectivore	46 (79.2)	90 (56.7)	136
Frugivore	1 (4.66)	7 (3.33)	8
Total	**352**	**252**	**604**

Foot note: The figures in brackets denote the expected frequencies.

In mammalian species categorization, Chi-square tests of association in diversity between the dry and wet seasons showed that there was no significant difference X^2 =16.656, $P < 0.005$, Degrees of freedom =5 (Table 3.11)

Table 3.11 Dry and wet season mammal surveys

Species name	**Frequency-dry season**	**Frequency-wet season**	**Total**
Tragelaphus scriptus	13 (17.2)	18 (13.79)	31
Cercopithecus nictitans	21 (24.97)	24 (20)	45
Xerus rutilus	16 (8.8)	0 (7)	16
Madoqua kirkii	6 (5.5)	4 (4.44)	10
Cercopithecus aethiops	37 (36.6)	29 (29.36)	66
Papio cynocephalus anubis	28 (27.7)	22 (22.24)	50
Total	121	97	218

Foot note: The figures in brackets denote the expected frequencies.

3.5 Effects of invasive plants on indigenous plants Species diversity

Assessment of plants species and family richness and diversity both in the invaded and un-invaded areas showed that there was a 63% decline in richness at the species level in the invaded areas and a further 43% decline at the family level compared to the un-invaded areas (Table 3.12). There was higherspecies density in the invaded compared to the un-invaded areas but Shannon-wiener indices of diversity and evenness were higher in the un-invaded areas. More species were recorded in the un-invaded areas (88) compared to the invaded sections (42) (Table 3.12). The high decline of species diversity is an indication of less food varieties in the invaded areas for wildlife. Consequently wildlife cannot exploit these areas as much as un-invaded habitats.

Student *t* test on differences in Shannon-wiener diversity (**H'**) between invaded and un-invaded areas showed that there was significant difference in species diversity ($t_{0.05(2)}$ 170 = 1.97 $0.05 < P < 0.10$) (table 3.12).

Table 3.12 Diversity and evenness indices in un-invaded and invaded areas.

Category	**Un-invaded areas (1)**	**Invaded areas (2)**	% reduction or increase.
Total number of individuals recorded (N)	161	201	+ 25
Number of families	42	24	- 43
Number of species	88	42	- 63
Shannon-wiener index of diversity **(H')**	1.84	1.09	-
Shannon weiner evenness index **(J')**	0.95	0.67	-
s^2 **H'**	0.0949	0.00266	-

3.6 Factors related to the occurrence of invasive plant species in the study area

The frequencies of the different factors that were recorded as associated with the occurrence of invasive plant species in the study area were:

i) Disturbances ii) Mammals iii) Birds.

In the three categories, anthropogenic disturbances were found to be highly associated with invasive plant species occurrences followed by birds while mammals contributed the least in the study area (Table 3.13).

Table 3.13 Potential factors related to the occurrence of invasive plant species in the study area.

Category	**Frequency** (Number of occurrences recorded)	**Relative frequency**
Disturbance	637	0.530
Mammals	177	0.147
Birds	447	0.372
Total	1201	-

3.6.1 Abiotic factors

Among the abiotic factors, the probability of observing an invasive plant species was highest in areas with disturbances related edge effects such as charcoal burning and grazing of cattle followed by settlements, dams and roads/tracks respectively (Table 3.14). Anthropogenic disturbances are therefore an important related factor in the occurrence of invasive plants in the study area.

Table 3.14 Abiotic factors related to the occurrence of invasive plants.

Factor	**Frequency (Number of occurrences recorded)**
Edge effects (burning, charcoal making, grazing and firewood collection)	457
Settlements(Old & current)	113
Dams	42
Roads/tracks	25

3.6.2 Biotic factors

In this category, primates were the most highly recorded related factor in the mammalian class while squirrels were the least. In the birds class, the insectivores/gramnivores were the most important followed by nectivores, insectivores/gramnivores/frugivores, insectivore/fruigivore, insectivore/nectivore and the frugivores were the least (Table 3.15). Birds therefore play an important role in the occurrence of invasive plant species in Ol-Donyo Sabuk National Park.

Table 3.15 Biotic factors related to the occurrence of invasive plants

Factor	Frequency (Number of occurrences recorded)
Primates	161
Squirrels	16
Insectivore/frugivores	28
Insectivore/Gramnivores	197
Insectivore/Gramnivore/frugivores	60
Insectivore/Nectivores	19
Nectivores	136
Frugivores	7

3.7 Invasive plant species found in the surrounding areas of the Park.

A total of 897 individuals representing 56 individuals per hectare of Invasive and non-indigenous plants species were recorded on the neighbouring areas of the park (Table 3.16). *Lantana camara* had the highest degree of occurrence in all the areas followed by *Dovyalis caffra.*

One way ANOVA tests for significance difference in invasive species diversity in the surrounding areas of the park revealed that there were no significant differences within the different sections ($F= 0.0346$, d.f= 13, $P >0.05$, (Appendix 13). While ANOVA test for significance in species diversity within the study area indicated that there were significant differences ($F = 1.032$, d.f= 199, $P >0.05$ (Appendix 12).

Table 3.16 Invasive and non-indigenous plant species found in the surrounding areas of the park.

Section	Type of invasive species	Number of individuals recorded
Northern	*Lantana camara*	143
	Datura stramonium	34
	Ricinus comunis	4
	Solanum incanum	11
Western	*Lantana camara*	93
	Datura stramonium	14
	Dovyalis caffra	63
	Solanum incanum	26
Southern	*Lantana Camara*	136
	Ricinus comunis	8
	Solanum incanum	37
	Dovyalis caffra	53
Eastern	*Lantana camara*	152
	Solanum incanum	31
	Tegetes minuta	37
	Dovyalis caffra	47
	Datura stramonium	8
Total		**897**

3.8 Distribution and abundance of invasive species

Results from the survey in the study area for invasive plant species indicated that the park is infested by a variety of invasive plants (Table 3.17). *Lantana camara L.* had the highest number of individuals recorded and density in all the strata sampled apart from the open glades. These invasive plant species were found in the edges of the park, around dams, settlements and along the roads.

Other invasive and non-indigenous plant species recorded included *Solanum incanum, Dorvyalis caffra, Ricinus communis, Psidium guajava* and *Toddalia asiatica. Solanum incanum* was distributed along the road to the summit. Pure stands of *solanum incanum* were noted at the summit region near an open glade. Five cases of *Caesalpinia decapelata* were recorded near the main gate. While non-native *Tagetes minuta* was recorded along the main-gate-summit road.

Table 3.17 Invasive plant species found in the study area.

Species name	Life form	Frequency(individuals recorded)	Density (individual s/hectare)	Areas of occurrence.
Lantana camara L.	Shrub	714	119	All parts of the study area. Around settlements, park boundary and the dams.
Datura stramonium L.	Herbaceo-us annual plant.	23	3.83	Along the road to summit
Solanum incanum L.	An annual herb.	234	39	Along the road to summit and near saltlicks
Dovyalis caffra Willd	A shrub or small tree	34	5.67	Impala dam and next to sabuk guest house.
Ricinus cominis L.	An annual herb	28	4.67	southern park boundary. In areas that had been burned.
Tagetes minuta L.	An annual herb	16	2.67	Along the park headquarters-summit road.
Psidium guajava L.	An evergreen shrub 2-10m high.	7	1.17	On the western side of the study area.
Toddalia asiatica(L.)Lam.	Woody liana.	73	12.17	Found on the forest/closed thicket strata.
Caesalpinia decapelata.Alston.	Thorny shrub 2-4m high or a climber up-to 10m.	5	0.17	Near the main gate

3.9 Life-form characteristics of invasive and non-indigenous plant species in the study area.

A) ***Lantana camara L.***

This is a floriferous shrub growing up-to 2metres or higher. Stems are four angled and covered with short stiff hairs. Leaves are dark green, pale yellow, rough and hairy. Flowers pink, red, orange, yellow or white in compact flat-topped heads. Fruits are glossy green turning purple-black. Originally introduced from Central and South America as an ornamental or hedge plant. It invades forests, savannahs and water-courses, roadsides and degraded land (Henderson, 2001). **Plate 3**.

B) ***Datura stramonium L.***

An erect herbaceous annual plant growing up-to 1.5m high. Stems sparsely hairy, green brown or purple. Leaves dark-green or purple ovate and up-to 200mm on long petioles. Leaf margins are coarsely and irregularly toothed or lobed. Flowers white, mauve or purple. Fruits are brown hardened capsules, ovoid up-to 50mm long by 30mm wide, and covered with slender spines measuring 10mm long. Originated from Tropical America. The whole plant is poisonous and irritant (Henderson, 2001).**Plate 2.**

C) ***Ricinus comunis L.***

An annual herb or softly woody shrub up-to 4m high. Leaves shiny, darkgreen or red and large up-to 300mm wide. Palmately five-nine-lobbed, margins which are closely serrated. Flowers are reddish on the upper side and Cream on the lower part and on stalks up-to 150mm long. Fruits are green, brown or red-threelobbed capsules about 10-15mm long and covered with soft spines. Seeds are silvery mottled-brown. Its Cultivated as an ornament and it invades riverbanks, riverbeds and roadsides (Henderson, 2001). **Plate 4**

D) ***Psidium guajava L.***

An evergreen shrub or small tree 2-10m high. Leaves bronze turning light-green, ovate to oblong-elliptic, often broad and rounded at both ends, with a small pointed apex. Flowers are white and in groups of 1-3. Fruits many seeded berries which are green turning yellow when ripe with white, yellow or pinkish flesh which is sweet and edible. Its cultivated for its fruits and invades forest margins, savannah, roadsides and watercourses. Originated from Tropical America and is a declared ecosystem transformer (Henderson, 2001).

E) ***Caesalpinia decapelata.Alston.***

A robust thorny evergreen shrub 2-4m high or a climber up-to 10m or higher forming dense thickets. Stems minutely golden-hairy, Stem thorns straight to hooked, numerous but not in regular rows or confined to nodes. Leaves dark-green, pale beneath and upto300mm long. Fruits brown woody pods, flattened, un-segmented and smooth. Invades forest margins and gaps, plantations, roadsides and water courses. Originated from Asia and is declared as a transformer (Henderson, 2001).

F) ***Toddalia asiatica***

A woody liana growing to a height of 10m in forests as it uses other trees for support. The stems are covered with knobby thorns and are yellow when cut. Leaves are shiny, trifoliate, light to dark green and are extremely aromatic, smelling of lemon when crushed. The twigs are covered with small, recurved thorns. Flowers are small and greenish-yellow. Fruits are 5-7mm in diameter and orange in colour when ripe. Not widely spread in the study area and its impact on other vegetation is currently minimal (Henderson, 2001).

G) ***Tagetes minuta L.***

A weed from America which is an erect annual herb growing up-to 2 metres high. Leaves are slightly glossy green, and are pinnately dissected into 4 to 6 pairs of pinnae. Leaf margins are finely serrate. The under-surface of the leaves bear a number of small, punctate, multicellular glands, orange in colour, which exude a licorice-like aroma when ruptured. Glands may also be found on the stems. It's widely spread between altitudes 760-2210 metres above sea-level (Blundell, 1982).

H) ***Dovyalis caffra***

A shrub or small tree which is usually 3-5 m in height but can sometimes reach 8 metres with a much branched crown. It bears creamy green flowers which are either male of female. Male flowers are 3 mm long and in dense clusters of 5-10 flowers. Female flowers are found in groups of up to three on stalks 4-10 mm long in leaf axils. The fruits are up to 60 mm in diameter and are yellowish orange in colour (Henderson, 2001). **Plate 5.**

I) ***Solanum incanum***

An erect hairy woody herb or shrub. It occasionally trails or scrambles with or without prickles. Leaves are ovate to lanceolate, entire or wavy-edged. Flowers are blue to mauve, 2-4cm in diameter, few in recemes. Petals are webbed with triangular lobes, fruits yellow and up to 4cm in diameter (Blundell, 1982). **Plate 1.**

CHAPTER FOUR

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS.

4.0 Discussion

4.1.1 Vegetation types- stratification.

Satellite remote sensing is an efficient and cost-effective method of acquiring up-to-date and accurate information, which is easily updateable with minimal ground and aerial surveying (Millette *et al.*, 1995). One of the objectives of this study was to stratify the vegetation of the study area into relatively homogenous vegetation strata and this was achieved through supervised classification of a satellite image.

Initial analysis of remote sensed imagery for the study area resulted to seven vegetation types. These were: i) Closed canopy forest ii) Shrub-land. iii) Wooded grassland. iv) Dams. v) Bare land. vi) Degraded land vii) Open glades. However ground truthing confirmed that the vegetation in the class identified as degraded-land was indeed of the shrub-land category and that the area had been burned at the time of sensor data acquisition (26th February 2008). These findings were essential in showing the need for accurate and upto-date remote sensed data and sufficient ground-truthing if any meaningful land-cover mapping (stratification) is to be achieved using this method. Current data will be useful in reducing errors of commission and omission in the final accuracy assessment.

One of the key merits of the remote-sensing methodology for stratifying vegetation types is the ability to provide accurate strata sizes. This is important in determining the sample-weight and statistics with high confidence limits as compared to the other ground based methods. However, ground based methods have an advantage of providing real-time data about an area but they are subjective and prone to human error especially when using grids to determine stratum size. Natural ecosystems are complex, dynamic and interact with each other. For monitoring these ecosystems, decisions about where to measure (Friedel, 1991, Wright *et al.*, 2003) to overcome the difficulty of patchy distribution of vascular plant and soil components are important (Brook *et al.*, 2001, Edwards *et al.*, 2005). Ecosystems/communities do not have discrete boundaries, and they are usually characterized by an ecotone zone whose magnitude depends on ecological factors. The ecosystems can range from intact or natural systems to those heavily modified by human activity, such as high grazing pressure (Bastin *et al.*, 1993, Pickup and Chewings, 1994).

Ideally, the boundaries reflect factors that control landscape distribution at various scales, such that they can be recognized, compared and applied according to the human activities and other natural disturbances. For example, the boundary between the closed canopy forest and the adjacent wooded-grassland stratum may be due to the lack of vegetation caused by changed soil conditions and grazing pressure, particularly in the early stages of regeneration of forest components. Landform pattern with its geologic substrate, surface shape and relief are also important criteria for establishing boundaries (Ghorbani *et al*, n.d.).

The spatial distribution of organisms in ecosystems is of crucial importance in understanding ecosystem functioning (Rosenzweig, 1991, Hayes *et al.*, 1996). Stratification is a way of identifying and classifying heterogeneity of organism's distribution according to the objectives, tools and financial limitations. A number of studies have emphasized that stratification can improve precision and accuracy of spatial sample collection in ground-based and remotely-sensed methods (Bastin *et al.*, 1998, Brook *et al.*, 2001, Wright *et al.*, 2003, Edwards *et al.*, 2005). Stratification ensures that the relative contribution of a particular vegetation community or soil/geomorphology type to a study area is taken into consideration when the total area is sampled. Brook *et al.*, (2001) concluded that stratification is essential for obtaining meaningful results.

In many tropical regions, land-cover maps (strata) have been produced using traditional aerial photography and field surveys. Kammerbauer and Ardon (1999) interpreted aerial photography for three different years for a region in central Honduras and were able to map dense forest, sparse forest and agricultural land while KWS (1999a) carried out an aerial survey of Mt. Kenya forests. The study used visual interpretation of aerial photographs collected to identify areas of the forest that had been destroyed.

Vegetation composition and structure are two important ways for describing plant communities. However, when exploring ecosystem health, ecological processes like succession, nutrient cycling, energy cycling and the products of these processes such as species, nutrients and energy are employed. Many ecological treatments of ecosystem health fall within the category of processes (Rapport *et al.*, 1985; Bertollo, 1998). However, in order to understand a process, it is important to investigate its products. Since ecology is central to assessing ecosystem health (Belaoussoff and Kevan, 1998) norms for describing ecological products must be defined. Hence ecologists need to define which end products of ecosystem processes generate indicators, and subsequently provide adequate tests for degrees of departure from them (Belaoussoff and Kevan, 2003).

It is generally accepted that species diversity is critical to the maintenance of ecosystem functions (May 1975, Hutchinson 1978, Tilman and Downing, 1994). The significance of species diversity for the functioning of ecosystem was proven by the work of Tilman and Downing (1994) on grassland biodiversity. They found that study plots with greater plant species diversity were more resilient to the effects of drought than those with less diversity. Changes in species diversity have often been used by ecologists to determine the effects of disturbance (May 1975, Hutchinson 1978 and Magurran 1988). Based on information theory (Begon, *et al.*, 1996, Magurran 1988, Roth *et al.* 1994 and Rosenzweig 1995) diversity is the measure of order or disorder within a particular system.

Shannon-Wiener indices of diversity (H') and evenness (J') were calculated for each vegetation strata. Values of **H'** fell within the recommended 1.5-3.5 for normal communities (Krebs 1999, Begon, *et al.,* 1996, Magurran 1988, Rosenzweig 1995, Roth *et al.*, 1994). Shrub-lands recorded the highest species diversity while the open glades had the highest evenness (Table 3.7). These results are consistent with the intermediate disturbance hypothesis which suggests that species diversity should be highest at the moderate levels of disturbance (Hobbs and Huenneke, 1992) in which areas that experienced some disturbance had more species compared to the climax vegetation communities.

Where disturbances are rare, very few species occurs as no new micro-habitats are created for colonization by new species. At higher disturbance levels, very few species occurs as there is no species which is adapted to such higher rates of disturbance. Thus both equilibrium and non-equilibrium models of communities predict greatest species richness at intermediate levels of disturbance (Petraitis *et al.,* 1989). High evenness values within the open-glades stratum were also in agreement with the expected results as the species recorded within the stratum had almost equal frequency.

The variation in plants species richness in the strata was influenced by the state of the study sites i.e. whether they were disturbed or undisturbed. The interaction between state of the sampling site and anthropogenic disturbances influenced species richness. Based on this, human activities have an influence on species richness in the study area. The study showed that strata prone to disturbances had higher species richness than the undisturbed ones, but how useful these species are in providing key ecosystem services to the surrounding communities and as browse for wildlife is yet to be investigated and quantified. In view of the above ecologists and conservation area managers need measures to judge the success or failure of management regimes designed to sustain biological diversity.

The relationships between potential indicator species and total biodiversity are not well-established (Lindenmayer *et al.* 2000). Diversity indices can be useful because they provide rapid and easily calculated ecological measures. They can also enhance comparisons between similar studies, which use same indices. Though they are commonly used, they are only useful for comparison between sites, or on sites over time (Krebs 1999).

4.1.2 Distribution and abundance of invasive species.

Survey of the park for invasive plant species results showed that the study area was infested by a variety of invasive plants. *Lantana camara L.* was the most abundant invasive plant species that was spread in all the strata sampled including the surrounding community areas. This invasive plant species was found on the edges of the park, around dams, settlements and along the roads. Other invasive and non-indigineous plants recorded were *Psidium guajava, Caesalpinia decapelata, Toddalia asiatica, Datura stramonium, solanum incanum, Doryalis caffra* and *Ricinus communis.* However, their distribution and frequencies were low compared to *Lantana camara L.* Tests for differences in invasive species diversity showed that there were no significant difference between the various sections that neighbour the park. This is an indication that invasive species are widely spread.

Invasive species have become one of the most serious global environmental problems today (IUCN, 1999). These species often get into the protected areas through several transport vectors and or pathways such as by wildlife, wind, water or humans while some encroach from populations established outside the park boundaries (Ngoru *et al.,* 2007). Africa is home to hundreds of invasive species– both plants and animals, but the magnitude of the problem varies from country to country, and from ecosystem to ecosystem (Chenje and Katerere, 2003). In many parts, freshwater ecosystems are particularly at risk – with invasive species surpassing habitat loss as the number one cause of biodiversity loss.

Invasive species are a problem in diverse ecosystems in Northern, Western, Central, Eastern and Southern Africa and in the Western Indian Ocean (WIO) islands: they affect both savannahs and tropical forests and they are found on land, in freshwater systems, along the coast, and in the ocean (UNEP, 2004b).

Virtually all countries in the region are affected by invasive species. In 2004, the World Conservation Union (IUCN) identified 81 invasive species in South Africa, 49 in Mauritius, 44 in Swaziland, 37 in Algeria and Madagascar, 35 in Kenya, 28 in Egypt, 26 in Ghana and Zimbabwe, and 22 in Ethiopia (IUCN/SSC/ISSG 2004). Although only a small percentage of these species will become invasive, when they do, their impacts are immense, insidious and usually irreversible, and they may be as damaging to native species and ecosystems on a global scale as the loss and degradation of habitats (IUCN/SSC/ISSG 2000). In Africa, some important ecosystems are under threat, consequently undermining development and livelihood opportunities, increasing human vulnerability and threatening human well-being (Chenje and Katerere, 2003).

A high percentage of plant invaders were originally introduced as ornamentals. *Lantana camara L.*, one of the most invasive and widespread tropical weeds in the old world, was spread throughout the tropics in a variety of hybrid forms as garden ornamental (GISP 2001).

Studies have shown that *Lantana camara L.* poisons cattle and destroys understorey species (IUCN/SSC/ISSG 2004). It can form dense mono-specific thickets which are difficult to eradicate once established, making extensive areas unusable and inaccessible, and threatening native plants as well as providing habitat to livestock parasites especially tsetse flies. It's also known to have allelopathic qualities that can reduce vigour of plant species nearby and reduce their productivity (Holm *et al.*, 1991). In all the strata sampled apart from the open glades, *Lantana camara L.* had high number of recorded individuals and density. It's therefore an important invader in the study area. Other invasive species recorded are in minimal densities and their control and management is possible.

Disturbances hereby described as "any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability, or the physical environment' (White and Picket, 1985) are sighted as one of the key drivers of ecosystem invasions. Disturbances can also be described as any process that alters the birth and death rates of individuals present in a particular patch by directly killing individuals or by affecting resource levels, natural enemies, or competitors in ways that alter survival and fecundity (Lockwood *et al.*, 2007).

Deliberate burning to stimulate fresh grass regeneration and illegal grazing along the park boundaries were documented as a major influence to natural vegetation invasion by *Lantana camara L.* Large monocultures of this invasive plant species established in the disturbed areas can continue to spread into other natural areas thus degrading the natural ecosystem to a greater extend if these disturbances are not controlled. Management of invasive species should therefore be a priority issue and need be mainstreamed into all aspects of protected area management.

Disturbance can either facilitate or hinder invasion of non-natives, and is very case and site specific. Often it is not one disturbance, but many working together that create room for invasive species to establish (IUCN/SSC/ISSG 2004). Native species can also respond to changes in circumstances and become invasive, in such a way as to make them deleterious to the objectives of protected area management (Howard and Matindi, 2003). The native species invasiveness is usually due to some other disturbance to the site, for example a change in water level or salinity. Invasiveness by native species is particularly of significance in Africa (Howard and Matindi, 2003) but not limited to the continent. It is not unusual for management issues of native and non-indigenous species to be closely linked.

Eradication of invasive species especially plants that had already been established such as *Eichhornia crassipes* (water hyacinth) or Salvinia can for instance result in the release of invasiveness by a local native species like Typha species, which had been suppressed by the invader. Such situations therefore call for of the need to manage invasive species in the context of an ecosystem (Howard and Matindi, 2003).

Invasive species are a serious impediment to the conservation and sustainable use of global, regional, and local biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems. *Lantana camara L.* is one of the many invasive non-native species that severely affects the health and regeneration of the ecosystems in which it inhabits. In Zambia for example, the Zambia's

National Biodiversity Strategy and Action Plan of 1998 identified *Lantana camara L.* as one of the invasive plants that negatively impacts ecosystems and indigenous plant diversity (Lwando and Russell 2005). The Invasive Specialist Group lists this species as among the world's 100 worst invasive alien species. Other literature has reported that *Lantana camara L.* does affect other biodiversity, such as herbaceous plants but the current study did not consider herbaceous plants alone but also grasses. Results from this study indicated that there was high species diversity in the un-invaded compared to the invaded areas t= 2.4, P>0.05 (Table 3.12). There could also be other compounding effects such as *Lantana camara's* influence on soil fertility.

Lwando and Russell (2005) have shown that the allelopathic effect of *Lantana Camara L.* results in severe reductions in seedling recruitment of nearly all species under its influence. Results from the study are in agreement with this observation as shown by the reduced number of families at the invaded areas. Invasive species may affect native species by introducing pathogens or parasites that cause disease or kill native species. Tsetse flies have been found to take cover under *Lantana camara* bushes (Okoth and Kapaata, 1987). This coupled with the reduced species diversity can result to less suitable habitats for wildlife species leading to reduced mammalian diversity in the study area.

Many invasive species grow faster than native plants and reproduce quickly, and thus replace indigenous plants and completely alter the composition of the area they have colonized. It has been reported that agricultural and grazing land, as well as protected areas, are threatened by rapidly growing species of plants that were introduced during colonialism as garden plants and windbreaks (Hall, 2003). *Lantana camara L.* was introduced in the study area in 1950's as an ornamental plant. It has now completely established itself and out-competed the indigenous species as shown by its high densities in the study area. The out-competing of native species through suppression or exclusion can therefore, fundamentally change the ecosystem. They may indirectly transform the structure and species composition of an ecosystem by changing the way in which nutrients are cycled (McNeely *et al.*, 2001, Mworia *et al.*, 2007).

Given the role biodiversity plays in the maintenance of essential ecosystem functions, invasive species may cause changes in environmental services, such as flood control and water supply, water assimilation, nutrient recycling, conservation and regeneration of soils (GISP, 2004). Among other things, both old and newly established invasive species contribute to land degradation through soil erosion and the drawing of water resources, reducing resources available to people and indigenous plants. Others produce leaf litter which poisons the soil, suppressing the growth of other plants, and in particular that of the understorey (UNEP, 2004b). They may alter the environment in directions that are more favourable for them but less favourable to native species. This could include altering geomorphic processes (soil erosion rates, or sediment accretion), biogeochemical cycling, hydrological cycles, or fire or light regimes (MA, 2006).

As native plants are displaced, animal populations that rely on the plants for food and shelter also decline. Furthermore the invasives often compete with other species directly, alter ecosystem processes and may hybridize with natives thereby degrading the native gene-pools (Chenje and Katerere, 2003).

4.1.3 Factors associated with the dispersal of invasive plant species in the study area

All invasions begin with a set of individuals being taken from a native range and taken to a novel location, and released. This is necessitated through a transport vector and is depended on the pathway (The route between the source and release location). The transport vector is the manner in which species are carried along a pathway. The circumstances surrounding transport and release of invasive species propagules influences dispersal to other area (Lockwood *et al.*, 2007). The more individuals are released, the more likely the incipient population to establish.

Studies on the role played by birds and mammals in seed dispersal have been extensively reviewed (Herrera, 1984, Howe, 1986). A large part of this work focuses on mutualistic relationships, or 'generalized dispersal systems' between broad groups of plants and dispersers (Howe, 1986, Malmborg and Willson, 1988). Highly generalized avian seed dispersal systems involve fruits with small seeds that are produced in large quantities and are consumed by a wide range of frugivorous birds (Howe, 1986). Such dispersal systems may rely on chance relationships with common birds where fruit is a component of a varied diet.

Results from these study indicated that primates and several feeding guilds of birds were active feeders of *Lantana camara L.* ripe seeds and nectar from its flowers. Several species of birds were noted to move from one type of invasive plant species to another. This was more often during the dry season surveys and could be a coping strategy to reduced food but can also play a role in hybridization of closely related species. These coupled with their mobility over large areas is a pointer that they could be playing an important role in the dispersal of *Lantana camara L.* and other invasive species in the study area.

Most relationships between frugivorous birds and invasive plants involve a generalized dispersal system (Noble, 1989., Richardson *et al.*, 2000b., Renne *et al.*, 2002). Mutualisms involving bird-mediated seed dispersal facilitate many plant invasions (Richardson *et al.*, 2000b). Birds benefit from this relationship by having a new food source, and the plant may benefit by having its seeds dispersed. Mutualistic seed-dispersal relationships include when native dispersers shift their foraging patterns to use the fruits of an invasive plant. They also occur when a plant species is re-united in the invaded range with species or genera with which it forms partnerships in its native range (Richardson *et al.*, 2000b). This type of relationships may enhance a plant's invasive potential via increased dispersal effectiveness (Mandon-Dalger *et al.*, 2004).

Chi-square tests of association showed that there was significant differences in the number of birds species associated with invaded areas during the wet and dry seasons (X^2 =83.338, P<0.001) (table 3.10). This is attributed to reduced food (fruits) especially during the onset of the rain season and the migratory nature of most of the recorded species.

Feeding on *Lantana camara L.* fruits and nectar acts as an important facilitator of cross pollination and facilitation through this method can play an important role in maintaining genetic diversity of the invasive plant species through hybridization with the native *Lantana trifolia.* Mammals and especially primates and squirrels were recorded as active feeders of the invasive *Lantana camara L.* and *Dovyalis caffra* fruits. The feeding and eventual dispersal possibly after some germination facilitation by the gut system of these mammals are important dispersion enhancers.

Tests on the difference in mammalian diversity between the two survey seasons showed that there were no significant differences. This results are in agreement with the expected scenario as the mammal species found in Ol-Donyo Sabuk National Park do not disperse owing to the "island" nature of the study area. Very few ungulate species were noted in the invaded areas and this can be attributed to reduced forage as a result of invasion.

A critical step in the invasion process is plant propagule dispersal into locations or microsites that provide conditions conducive to plant establishment (Masters, 2004). Majority of plant invasions often depend on some disturbance such as grazing, fire, human habitation, alteration of resources such as soil nutrients and water. Thus disturbance plays a very important role in facilitating plant invasions (Lodge, 1993) by eliminating/reducing the cover or vigour of competitors or by increasing resource levels (D'Antonio, 1993).

Anthropogenic disturbances such as burning, grazing, roads construction and settlements contributed substantively to the number of recorded occurrences of *Lantana camara* L. in the study area (Table 3.13 and 3.14).

Increase in invasibility following disturbance can be explained by the theory of fluctuating resource availability (Mack *et al.,* 2000); either due to addition of resources in a community or decline in resource uptake by resident vegetation. Species invasions can be accelerated by global environmental changes due to fluctuating resources (Dukes and Mooney, 1999).

Burning by the local communities probably to stimulate fresh growth of grass and charcoal making along the edges were documented as key to the spread of *Lantana camara L.* in the park. Road construction was found to contribute significantly to the spread of *Solanam incanum* and *Datura stramonium* while intentional concentration of wildlife in specific areas through salt licks was found to play a role in the spread of *Solanum incanum.* Dams were also associated with high numbers of invasive plants species especially *Lantana camara L.* However, there could be other confounding factors to the effect of dams especially local concentration of nutrients by wildlife in such areas through urine and faecal droppings.

Studies have shown that disturbances facilitate the establishment of non-native species (Minchinton, 2002, Hobbs and Huenneke 1992, D'Antonio, 2000). Gerhardt and Collige, (2003) found that the history of fire increased non-natives richness in natural pools. Disturbances to plant communities include such events as fires, storms, and floods; but other changes such as altered grazing regimes or nutrient inputs would also be classified as disturbance if they affect resource levels and demographic processes (Hobbs and Huenneke 1992). All these disturbance types occur in the study area and contribute immensely to the problem of invasive species in Ol-Donyo Sabuk National Park.

4.2 Conclusions

Information on the spatial distribution of any species is very important for its management. Similarly invasive species distribution in the study area and how they impact on the inherent diversity of plants is important in developing strategies for management.

Ol-Donyo Sabuk National Park is particularly threatened by *Lantana camara L.* which is quite widespread. This invasive species has already caused negative impacts on the native species and its effects are projected to increase with time. The problem is however aggravated in the disturbed areas where anthropogenic disturbances such as burning and charcoal making take place. The role played by primates and birds in the invasive species dispersal is equally important as shown by their feeding and mobility behaviours.

All the feeding guilds of birds were noted in the invaded areas and this is a pointer that indeed invasive plants especially *Lantana camara L.* and *Dovyalis caffra* are essential food resource for birds in the study area. They should therefore be taken into consideration during the development of any management/control strategy (ies) as they may be key vectors of invasive species propagules into the study area.

Several other non-native invasive species that were recorded during the study such as *Solanum incanum*, *Dovyalis caffra*, *Tagetes minuta*, *Ricinus comunis* and *Caesalpinia decapelatum* are still low in numbers and their impact on biological diversity is small while control and eradication is possible.

One of the key management challenges for control of invasive plant species in the study area is the abnormally high presence of similar species within the surrounding areas. The propagule pressure and seed-bank load are therefore high and not limited to the study area alone. Such a situation means that any control and management strategies put in place in the park should , incorporate the surrounding community areas. This will ensure that propagules are not moved back.

Owing to increased global trade and travel, increased fragmentation of protected areas and synergies with other global phenomena (such as climate change), and the presence of a potentially large number of "sleeper invaders" (Naturalised exotic plant/animal species that are currently present in a small area but have potential to spread widely and have negative impacts on the ecosystem), the threat of invasive species to protected areas will increase in future and further endanger biodiversity. The management of protected areas should therefore pay key emphasis on the dangers posed by these species.

The natural biogeographical barriers like oceans, mountains, rivers and deserts that provided the isolation essential for unique species and ecosystems to evolve have lost their effectiveness or have been overtaken by the high increase in global trade and or tourism. This has resulted in an exponential increase in the movement of organisms from one part of the world to another. While many of the deliberate movements of organisms into new ecosystems where they are non-native are beneficial to people especially in providing food and as ornamentals, nevertheless tremendous ecosystem damage results from those that are detrimental. Invasion by *Lantana camara L.* has contributed immensely to the decline in plant species diversity in Ol-Donyo Sabuk National Park (Table 3.12). Declined food resources for wildlife means less mammalian species and declined value of the conservation area in-terms of species numbers and diversity.

Several methods for control and management of invasive plants are available including among others chemical, biological and mechanical methods. Management aspects entail eradication, containment, control and mitigation strategies. In the study area, the option that is applicable based on the intensity of infestation will be eradication through physical or mechanical removal and minimising the factors that are related to dispersal. This will ensure that the inherent biodiversity is sustained.

4.3 Recommendations

4.3.1 Further research

During the study, several factors were documented as related to the dispersal of invasive species in the study area. Particularly important are anthropogenic disturbances, birds and primates. Further research is therefore required on the following areas;

1) The role played by birds and mammals in the spread of invasive species propagules needs to be investigated and quantified.
2) Quantification of the role of disturbances in the occurrence of invasive plants in the study area.
3) More research is also needed to qualify and quantify the usefulness of some non-native species which are favoured by the birds and primates as food.
4) It's important to further investigate if birds and mammals are coping to reduced food resources through feeding on invasive species fruits or it's a key food item and what could be the likely effect after eradication.
5) Given that invasive species are already established in the park, further research is required to ascertain the best control and management strategy. In particular the effectiveness of mechanical/physical removal *vis avis* chemical methods needs to be quantified.

4.3.2 Conservation and management action

The management and control of well established populations of invasive species is a daunting task when implementing effective strategies for eradication.

Where invasive species are geographically widespread and their numbers are high like the case of Ol-Donyo Sabuk National Park, the resources required may be prohibitive. However, if species diversity is to be ensured within conservation areas, something must be done to control further spread. In this regard, the following recommendations could minimise the spread of invasive species.

1) Anthropogenic disturbances need to be minimised and if possible totally eliminated. Fencing- off the park can be a good way of minimising disturbances.
2) A management and control strategy needs to be instituted. This strategy should however incorporate the community-land as this is a potential source of reverse propagules.
3) Replanting grasses in areas that had been invaded by *Lantana camara L.* after control to stabilise the soil should be prioritised these should however be followed by tree planting in order to boost diversity.

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6.0 Appendices

Appendix 1. Error matrix for Ol-Donyo Sabuk National park derived from Gausian maximum likelihood classifier land-cover map.

	Reference data.								
Classified data	**Closedcanopy forest**	**Shrub-lands**	**Bare-lands**	**Dams**	**Open glades**	**Wooded grasslands**	**Total**	**Producer's accuracy %**	**User's accuracy %**
Closed-canopy forest	**41078**	0	0	0	0	0	41078	100	100
Shrub-lands	0	**27856**	0	0	0	7	27863	98.36	99.9
Bare-lands	0	0	**1685**	0	0	300	1985	99	84.8
Dams	0	0	0	**249**	0	383	632	100	39.3
Open glades	0	0	0	0	**7170**	7045	14215	88	50.4
Wooded grasslands	0	464	17	0	964	**4662**	6107	3.7	76
Totals	41078	28320	1702	249	8134	12397	**91880**		

Overall accuracy = (41078+27856+1685+249+7170+4662)/91880 = 90%
Overall Kappa = 0.8538

Appendix 2. Invasive plant species found in Oldonyo Sabuk National Park and Surrounding area (Plate 1 – 5)

Solanum incanum- **Plate 1**

Datura stramonium - ***Plate2***

Lantana camara –**Plate 3**

Ricinus communis - **Plate 4**

Dovyalis caffra-**plate 5**

Appendix 3. Forest/closed canopy thicket Family frequency and density

Family	No. of individuals	Density
Anacardiaceae	517	215.4167
Apocynaceae	40	16.66667
Araliaceae	3	1.25
Boranginaceae	1	0.416667
canallaceae	3	1.25
Celastraceae	23	9.583333
Combretaceae	12	5
Compositae	8	3.333333
Ebenaceae	49	20.41667
Euphorbiaceae	25	10.41667
Flacourtiaceae	11	4.583333
Labiatae	4	1.666667
Leguminosae	228	95
Lobeliaceae	8	3.333333
Malvaceae	92	38.33333
Meliaceae	80	33.33333
moraceae	1	0.416667
Ochnaceae	40	16.66667
Olacaceae	24	10
Oleaceae	35	14.58333
piperaceae	3	1.25
Rhamnaceae	11	4.583333
Rhyzophoraceae	40	16.66667
Rocaceae	13	5.416667
Rubiaceae	16	6.666667
Rutaceae	177	73.75
Santalaceae	1	0.416667
sapindaceae	24	10
Sterculiaceae	16	6.666667
Tiliaceae	96	40
Verbenaceae	264	110

Appendix 4. Species number and density (Number/hectare)- closed canopy forest stratum

Species name	No.	Density	pi	lnpi	pilnpi
Rhus natalensis Krauss	463	192.9167	0.269186	-1.31235	-0.35327
Lantana camara L.	228	95	0.132558	-2.02073	-0.26786
Acacia hockii De Wild	101	42.08333	0.058721	-2.83496	-0.16647
Albizia gummifera J.F.Gmel	96	40	0.055814	-2.88573	-0.16106
Abutilon longicuspe A.Rich	92	38.33333	0.053488	-2.92829	-0.15663
Rhus vulgaris Meikle	83	34.58333	0.048256	-3.03124	-0.14627
Turraea robusta Gurke	71	29.58333	0.041279	-3.1874	-0.13157
Grewia similis K.Schum.	68	28.33333	0.039535	-3.23057	-0.12772
Toddalia asiatica (L.)Lam.	64	26.66667	0.037209	-3.2912	-0.12246
Euclea divinorum Hiern	49	20.41667	0.028488	-3.55826	-0.10137
Ochna holstii Engl.	39	16.25	0.022674	-3.78652	-0.08586
Tabernaemontana stapfiana Britten	32	13.33333	0.018605	-3.98434	-0.07413
Olea europaea L.	27	11.25	0.015698	-4.15424	-0.06521
Ximenia Americana L.	23	9.583333	0.013372	-4.31459	-0.0577
Allophyllus abyssinicus (Hochst.) Radlk.	20	8.333333	0.011628	-4.45435	-0.05179
Maytenus heterophylla (Eckl.&Zeyh) N. Robson	20	8.333333	0.011628	-4.45435	-0.05179
Clausena anisata (Willd.) Benth.	17	7.083333	0.009884	-4.61687	-0.04563
Grewia bicolar Juss.	16	6.666667	0.009302	-4.67749	-0.04351
Teclea simplicifolia (Engl.)Verd.	15	6.25	0.008721	-4.74203	-0.04135
Vangueria infausta Burch.	15	6.25	0.008721	-4.74203	-0.04135
Cassipourea malosana (Baker) Alston	13	5.416667	0.007558	-4.88513	-0.03692
Croton macrostachus Delile	13	5.416667	0.007558	-4.88513	-0.03692
Combretum molle G. Don	12	5	0.006977	4.96517	-0.03464
prunus Africana (Hook.f.)Kalkman.	12	5	0.006977	4.96517	-0.03464
Dombeya rotundufolia Sauve	11	4.583333	0.006395	5.05218	-0.03231
scutia myrtina(Burm.f.) Kurz.	11	4.583333	0.006395	-5.05218	-0.03231
Carissa edulis (forssk.) Vahl	8	3.333333	0.004651	-5.37064	-0.02498
Olea Africana L.	8	3.333333	0.004651	-5.37064	-0.02498
Lobelia aberdarica R.E.Fr.&T.C.E.Fr.	7	2.916667	0.00407	-5.50417	-0.0224
Pterolobium stellatum (Forssk.) Brenan.	7	2.916667	0.00407	-5.50417	-0.0224
Drypetes gerradii Hutch.	5	2.083333	0.002907	-5.84064	-0.01698
Lepidotrichilia volkensii (Gurke)J.F. Leroy	5	2.083333	0.002907	-5.84064	-0.01698
Clausena anisata (Willd.) Benth.	5	2.083333	0.002907	-5.84064	-0.01698
Albizia schimperiana Oliv.	4	1.666667	0.002326	-6.06379	-0.0141
Bridelia micrantha (Hochst.) Baill.	4	1.666667	0.002326	-6.06379	-0.0141

Dovyalis caffra Wild	4	1.666667	0.002326	-6.06379	-0.0141
Pappea capensis Eckl.&Zeyh	4	1.666667	0.002326	-6.06379	-0.0141
Vernonia auriculifera Hiern	4	1.666667	0.002326	-6.06379	-0.0141
Casearia battiscombei R.E.Fr.	3	1.25	0.001744	-6.35147	-0.01108
Clerodendrum johnstonii Oliv.	3	1.25	0.001744	-6.35147	-0.01108
Ekebergia capensis Sparrm.	3	1.25	0.001744	-6.35147	-0.01108
Erythrococca bongensis Pax	3	1.25	0.001744	-6.35147	-0.01108
Leonitis ocymifolia (Burm.f.)Iwarsson	3	1.25	0.001744	-6.35147	-0.01108
Mystroxylon aethiopicum (Thunb.) Loes.	3	1.25	0.001744	-6.35147	-0.01108
Piper capense L.F.	3	1.25	0.001744	-6.35147	-0.01108
Warburgia ugandensis Sprague	3	1.25	0.001744	-6.35147	-0.01108
Zanthoxylem usambarense (Engl.) Kokwaro	3	1.25	0.001744	-6.35147	-0.01108
Acacia gerrardii Benth.	2	0.833333	0.001163	-6.75693	-0.00786
Acacia melifera(Vahl) Benth.	1	0.416667	0.000581	-7.45008	-0.00433
Acacia seyal Delile	1	0.416667	0.000581	-7.45008	-0.00433
Cordia ovaries Roxb	1	0.416667	0.000581	-7.45008	-0.00433
cussonia holstii Engl.	1	0.416667	0.000581	-7.45008	-0.00433
ia spicata Thunb.	1	0.416667	0.000581	-7.45008	-0.00433
Dovyalis abyssinica (A.Rich.)Warb.	1	0.416667	0.000581	-7.45008	-0.00433
Erythrina abyssinica DC.	1	0.416667	0.000581	-7.45008	-0.00433
Ficus thonnigii Blume	1	0.416667	0.000581	-7.45008	-0.00433
Indigofera swaziensis Bolus	1	0.416667	0.000581	-7.45008	-0.00433
Lantana trifolia L.	1	0.416667	0.000581	-7.45008	-0.00433
Leonotis mollissimma Gurke	1	0.416667	0.000581	-7.45008	-0.00433
Lobelia giberroa Hemsl	1	0.416667	0.000581	-7.45008	-0.00433
Ocimum gratissimum Sauve	1	0.416667	0.000581	-7.45008	-0.00433
Osyris lanceolata Hochst & Steudel	1	0.416667	0.000581	-7.45008	-0.00433
Turraea holstii Gurke	1	0.416667	0.000581	-7.45008	-0.00433
		H'	**J'**		
		2.89	**0.70**		

Appendix 5. Showing the number and density of the different species found in the shrub-land stratum.

SPECIES NAME	No.	DENSITY	pi	Lnpi	pilnpi
Lantana camara L.	296	185	0.211278	-1.55458	-0.32845
Rhus natalensis Krauss	249	155.625	0.17773	-1.72749	-0.30703
Acacia hockii De Wild	126	78.75	0.089936	-2.40866	-0.21662
Combretum molle G.Don	70	43.75	0.049964	-2.99645	-0.14972
Euclea divinorum Hiern	67	41.875	0.047823	-3.04025	-0.14539
Abutilon longicuspe A.Rich	55	34.375	0.039258	-3.23761	-0.1271
Rhus Vulgaris Meikle	54	33.75	0.038544	-3.25596	-0.1255
Solanum incanum L.	46	28.75	0.032834	-3.4163	-0.11217
Erythrina abyssinica DC.	41	25.625	0.029265	-3.53137	-0.10334
Dodonea viscose (L)Jacq.	40	25	0.028551	-3.55606	-0.10153
Protea caffra Meisn	39	24.375	0.027837	-3.58138	-0.0997
Acacia brevispica Harms	31	19.375	0.022127	-3.81095	-0.08433
Acacia gerrardii Benth	28	17.5	0.019986	-3.91274	-0.0782
carissa edulis (forssk.) Vahl	21	13.125	0.014989	-4.2004	-0.06296
scolopia zeyheri (Nees) Harv.	19	11.875	0.013562	-4.3005	-0.05832
Grewia similis K. Schum.	18	11.25	0.012848	-4.3545	-0.05595
Osyris lanceolata Hochst & Steudel	17	10.625	0.012134	-4.4117	-0.05353
Acacia seyal Delile	14	8.75	0.009993	-4.6058	-0.04603
Dombeya rotundifolia Planch.	12	7.5	0.008565	-4.7600	-0.04077
Maytenus heterophylla (Eckl &Zeyh) N. Robson	11	6.875	0.007852	-4.8470	-0.03806
Ochna holstii Engl.	10	6.25	0.007138	-4.9423	-0.03528
Cordia ovalis Roxb	9	5.625	0.006424	-5.0477	-0.03243
Dichrostachys cinerea (L.)Wight & Arn	9	5.625	0.006424	-5.0477	-0.03243
Pappea capensis Eckl.&Zeyh	9	5.625	0.006424	-5.0477	-0.03243
Ormocarpum kirkii S.Moore	8	5	0.00571	-5.1655	-0.0295
Toddalia asiatica (L.) Lam.	8	5	0.00571	-5.1655	-0.0295
Faurea saligna Harv.	7	4.375	0.004996	-5.2990	-0.02648
scutia myrtina (Burm.f.) Kurz	7	4.375	0.004996	-5.2990	-0.02648
Acacia polyacantha Wiild	6	3.75	0.004283	-5.4531	-0.02335
Apodytes dimidiate Arn.	6	3.75	0.004283	-5.4531	-0.02335
Pittosporum mannii Hook.f.	6	3.75	0.004283	-5.4531	-0.02335
Rhus tenuinervis Engl.	6	3.75	0.004283	-5.4531	-0.02335
Albizia amara (Roxb.) Boivin.	4	2.5	0.002855	-5.85865	-0.01673
Clausena anisata (Willd.) Benth.	4	2.5	0.002855	-5.8586	-0.01673
Flueggea virosa (Willd.) Voigt	4	2.5	0.002855	-5.8586	-0.01673
Turraea robusta Gurke	4	2.5	0.002855	-5.8586	-0.01673
Olea Africana(Mill.)P. Green	3	1.875	0.002141	-6.1463	-0.01316
Rapanea melanophloeos (L) Mez	3	1.875	0.002141	-6.1463	-0.01316
Rhus longiscupe Engl.	3	1.875	0.002141	-6.1463	-0.01316
Teclea simplisifolia (Engl.) Verd.	3	1.875	0.002141	-6.1463	-0.01316
Acacia melifera (Vahl) Benth	2	1.25	0.001428	-6.5517	-0.00935
Allophyllus ferruginus Taub.	2	1.25	0.001428	-6.5517	-0.00935
Azanza garckeana (F. Hoffin)Exell & Hillc.	2	1.25	0.001428	-6.55179	-0.00935
Harrisonia abyssinica Oliv.	2	1.25	0.001428	-6.5517	-0.00935
Neoboutonia macrocalyx Pax	2	1.25	0.001428	-6.5517	-0.00935

Ocimum gratissimum Sauve	2	1.25	0.001428	-6.5517	-0.00935
phyllanthus fischeri Pax	2	1.25	0.001428	-6.5517	-0.00935
Pistia aethiopica Kokwaro	2	1.25	0.001428	-6.5517	-0.00935
Ricinus communis L.	2	1.25	0.001428	-6.5517	-0.00935
Senna didymobotrya (Fresen.) Irwin&Barneby	2	1.25	0.001428	-6.5517	-0.00935
Uvaria scheffleri Diels	2	1.25	0.001428	-6.5517	-0.00935
Yucca gloriosa L.	2	1.25	0.001428	-6.5517	-0.00935
Fagaropsis hildebrandtii (Engl.) Milne-Redh.	1	0.625	0.000714	-7.2449	-0.00517
Gardenia volkensii K. Schum.	1	0.625	0.000714	-7.2449	-0.00517
Maytenus senegalensis (Lam.) Exell	1	0.625	0.000714	-7.2449	-0.00517
Trimeria grandifolia (Burkill) Sleumer	1	0.625	0.000714	-7.2449	-0.00517
		H'	**J'**		
		2.93	**0.73**		

Appendix 6.Family totals and density- shrubland Stratum

FAMILY	NUMBER	DENSITY
Agavaceae	2	1.25
Anacardiaceae	314	196.25
Anaonaceae	2	1.25
Apocynaceae	21	13.125
Boraginaceae	9	5.625
celastraceae	12	7.5
Combretaceae	70	43.75
Ebenaceae	67	41.875
Euphorbiaceae	10	6.25
Flacourtiaceae	22	13.75
Icacinaceae	6	3.75
labiatae	2	1.25
Leguminosae	277	173.125
Malvaceae	57	35.625
Myrsinaceae	3	1.875
Ochnaceae	10	6.25
Oleaceae	3	1.875
pittosporaceae	6	3.75
Proteaceae	46	28.75
Rhamnaceae	7	4.375
Rubiaceae	1	0.625
Santalaceae	17	10.625
sapindaceae	52	32.5
simaroubaceae	2	1.25
Solanaceae	46	28.75
Sterculiaceae	12	7.5
Tiliaceae	18	11.25
Verbenaceae	294	183.75

Appendix 7 Total numbers and density of the different species found in the wooded grassland stratum.

Species name	Number	Density	Pi	Lnpi	PiLnpi
Acacia horkii De Willd	445	278.125	0.294507	-1.22245	-0.36002
Lantana camara L.	189	118.125	0.125083	-2.07878	-0.26002
Rhus natalensis Krauss	150	93.75	0.099272	-2.30989	-0.22931
Dombeya rotundufolia Sauve	128	80	0.084712	-2.4685	-0.20911
combretum molle G. Don	107	66.875	0.070814	-2.6477	-0.18749
Faurea saligna Harv.	78	48.75	0.051621	-2.96382	-0.153
Rhus vulgaris Meikle	46	28.75	0.030443	-3.49189	-0.1063
Senna singueana (Fresen.) Irwin&Barneby	41	25.625	0.027134	-3.60695	-0.09787
Protea caffra Meisn.	39	24.375	0.025811	-3.65697	-0.09439
Dichrostachys cinerea (L.)Wight &Arn	29	18.125	0.019193	-3.95323	-0.07587
Osyris lanceolata Hochst & Steudel	28	17.5	0.018531	-3.98832	-0.07391
Euclea divinorum Hiern	23	14.375	0.015222	-4.18503	-0.0637
scolopia zeyheri (Nees) Harv	19	11.875	0.012574	-4.37609	-0.05503
Fluggea virosa (Willd.)Voigt	18	11.25	0.011913	-4.43016	-0.05277
Rapanea melanophloeos (L) Mez	13	8.125	0.008604	-4.75558	-0.04091
Carissa edulis (Forssk.) Vahl	12	7.5	0.007942	-4.83562	-0.0384
Maytenus heterophylla (Eckl. &Zeyh) N. Robson	12	7.5	0.007942	-4.83562	-0.0384
Olea Africana(Mill.)P. Green	10	6.25	0.006618	-5.01794	-0.03321
Ormocarpum kirkii S.Moore	9	5.625	0.005956	-5.1233	-0.03052
Syzygium cordatum Hochst	9	5.625	0.005956	-5.1233	-0.03052
Ziziphus abyssinica A. Rich.	8	5	0.005295	-5.24109	-0.02775
Pistia aethiopicum Kokwaro	7	4.375	0.004633	-5.37462	-0.0249
Acacia drepalonobium Harms ex Sjostedt	6	3.75	0.003971	-5.52877	-0.02195
Acacia seyal Delile	6	3.75	0.003971	-5.52877	-0.02195
Clausena anisata (Willd.) Benth.	6	3.75	0.003971	-5.52877	-0.02195
Dodonea viscose (L.) Jacq.	5	3.125	0.003309	-5.71109	-0.0189
Heteromorpha trifolia (H.L.Wendl.)Eckl&Zeyh	5	3.125	0.003309	-5.71109	-0.0189
Acacia tortilis (Forssk) Hayne.	4	2.5	0.002647	-5.93423	-0.01571
Maytenus senegalensis (Lam) Exel	4	2.5	0.002647	-5.93423	-0.01571
Scutia myrtina (Burm. F.) Kurz	4	2.5	0.002647	-5.93423	-0.01571
Azanza garckeana (F. Hoffin)Exell & Hillc	3	1.875	0.001985	-6.22191	-0.01235
Gnidia subcordata Meisn	3	1.875	0.001985	-6.22191	-0.01235
Ludia mauritiana J.F. Bmel	3	1.875	0.001985	-6.22191	-0.01235
Rhus longiscupe Engl	3	1.875	0.001985	-6.22191	-0.01235
Trichocladus dentatus Hutch.	3	1.875	0.001985	-6.22191	-0.01235
Grewia similis K.Schum.	2	1.25	0.001324	-6.62738	-0.00877
Ozoroa insignis Delile	2	1.25	0.001324	-6.62738	-0.00877
Pappea capensis Eckl &Zeyh.	2	1.25	0.001324	-6.62738	-0.00877
Rhus longipes Engl	2	1.25	0.001324	-6.62738	-0.00877
Trimeria grandifolia (Burkill) Sleumer.	2	1.25	0.001324	-6.62738	-0.00877
zanthoxylum usambarense (Engl.)	2	1.25	0.001324	-6.62738	-0.00877

Kokwaro					
Ziziphus mucronata Willd	2	1.25	0.001324	-6.62738	-0.00877
Fagaropsis hildebrandtii (Engl) Milne-Redh.	1	0.625	0.000662	-7.32053	-0.00484
Acacia brevispica Harms	1	0.625	0.000662	-7.32053	-0.00484
Acacia gerrardii Benth	1	0.625	0.000662	-7.32053	-0.00484
Acacia melifera (Vahl.)Benth	1	0.625	0.000662	-7.32053	-0.00484
Acacia robusta L.	1	0.625	0.000662	-7.32053	-0.00484
Acacia senegalesis L.	1	0.625	0.000662	-7.32053	-0.00484
Albizia shimperiana Oliv.	1	0.625	0.000662	-7.32053	-0.00484
Bridelia micrantha (Hochst.) Baill	1	0.625	0.000662	-7.32053	-0.00484
Combretum collinum Fresen	1	0.625	0.000662	-7.32053	-0.00484
Doryalis abyssinica (A. Rich.) Warb	1	0.625	0.000662	-7.32053	-0.00484
ficus sur Forssk	1	0.625	0.000662	-7.32053	-0.00484
Gardenia goetzei Stapf & Hutch.	1	0.625	0.000662	-7.32053	-0.00484
Gardenia ternifolia Schumach & Thonn.	1	0.625	0.000662	-7.32053	-0.00484
Mystroxylona ethiopicum (Thunb.) Loes	1	0.625	0.000662	-7.32053	-0.00484
Olea capensis l.	1	0.625	0.000662	-7.32053	-0.00484
Piliostigma thonningii (Schumach.) Milne-Redh.	1	0.625	0.000662	-7.32053	-0.00484
Pitosporum viridiflorum Sims	1	0.625	0.000662	-7.32053	-0.00484
Psydrax schimperiana (A.Rich.) Bridson	1	0.625	0.000662	-7.32053	-0.00484
Rytigynia sp. K. Schum	1	0.625	0.000662	-7.32053	-0.00484
sclerocarya birrea (A.Rich.) Hochst	1	0.625	0.000662	-7.32053	-0.00484
Solanum incunum L.	1	0.625	0.000662	-7.32053	-0.00484
Toddalia asiatica (L.) Lam.	1	0.625	0.000662	-7.32053	-0.00484
			H'	**J'**	
			2.66396	**0.64056**	

Appendix 8. Family Totals and density-Wooded grassland.

FAMILY	Number	Density
Anacardiaceae	209	130.625
apocynaceae	12	7.5
Celastraceae	17	10.625
Combretaceae	108	67.5
Ebenaceae	23	14.375
Euphorbiaceae	19	11.875
Flacourtiaceae	27	16.875
Hamamelidaceae	3	1.875
Icacinaceae	9	5.625
Leguminosae	550	343.75
Malvaceae	3	1.875
Moraceae	1	0.625
Myrsinaceae	13	8.125
Myrtaceae	9	5.625
Oleaceae	11	6.875
pittosporaceae	12	7.5
Proteaceae	116	72.5
Rhamnaceae	15	9.375
Rubiaceae	3	1.875
Rutaceae	8	5
santalaceae	31	19.375
sapindaceae	7	4.375
Solanaceae	1	0.625
Sterculiaceae	129	80.625
Thymelaceae	3	1.875
Tiliaceae	1	0.625
Uberiferaceae	6	3.75
Verbenaceae	191	119.375

Appendix 9. Number, density, Shannon-wiener diversity (H') and evenness index (J') in the open glades stratum.

Species name	Number	Density	Pi	LnPi	PiLnpi
Pennisetum clandestinum Hochst ex Chiov	12	600	0.130435	-2.03688	-0.26568
Setaria incrasata (Hochst.) Hack.	12	600	0.130435	-2.03688	-0.26568
Cynodon dactylon (L.) Pers.	9	450	0.097826	-2.32456	-0.2274
Cynoglossum coeruleum A.D.C.	7	350	0.076087	-2.57588	-0.19599
Periplocca linearifolia Quart-Dill & A. Rich.	6	300	0.065217	-2.73003	-0.17805
Phytolacca dodecandra LHer	6	300	0.065217	-2.73003	-0.17805
Sida rhombifolia L.	5	250	0.054348	-2.91235	-0.15828
Aspilia pluriseta Schweinf.ex Engl	4	200	0.043478	-3.13549	-0.13633
Landolphia buchananii (Hallier f.) Stapf	4	200	0.043478	-3.13549	-0.13633
Agrocharis incognito (Norman) Heywood & Jury	3	150	0.032609	-3.42318	-0.11163
Crassocephalum viltellinum (Benth.) S. Moore	3	150	0.032609	-3.42318	-0.11163
Crotaria axillaris Aiton	3	150	0.032609	-3.42318	-0.11163
Cyperus rigidifolius Steud.	3	150	0.032609	-3.42318	-0.11163
Ocimum gratissimum Sauve	3	150	0.032609	-3.42318	-0.11163
Dyschroriste radicans Nees	2	100	0.021739	-3.82864	-0.08323
Indigofera spicata Forssk.	2	100	0.021739	-3.82864	-0.08323
Pterolobium stellata Forssk	2	100	0.021739	-3.82864	-0.08323
Sida schimperiana Hochst & Steyaert	2	100	0.021739	-3.82864	-0.08323
Taddalia asiatica (L.) Lam.	2	100	0.021739	-3.82864	-0.08323
Tephrosia holstii Taub.	2	100	0.021739	-3.82864	-0.08323
			H'	**J'**	
			2.79929	**0.934426**	

Appendix 10. Birds associated with invaded areas- Dry season survey.

Common name	Scientific name	No. Recorded
African citril	*Serinus citrinelloides*	2
common bulbul	*Pycnonotus barbatus*	32
Variable sunbird	*Nectarinia venusta*	29
Black Roughwing	*Psalidoprocne holomelas massaicus*	20
Willow warbler	*Phylloscopus trochilus*	17
Little yellow flyctcher	*Erythrocercus holochlorus*	13
African dusky flycatcher	*Muscicapa adusta interposita*	9
Collared sunbird	*Anthreptes collaris garguensis*	9
Little bee eater	*Merops pusillus cyanostictus*	9
Red eyed dove	*Streptopelia semitorquata*	9
white-browed sparrow-weaver	*Plocepasser mahali*	9
African firefinch	*Lagonosticta rubricata hildebrandti*	8
Amethyst sunbird	*Nectarinia amethystina*	8
Red-cheeked cordon-bleu	*Uraeginthus bangalus*	8
African Golden weaver	*Ploceus subaureus aureoflavus*	7
Speckled mousebird	*Colius striatus kikuyuensis*	7
Yellow bishop	*Euplectes capensis crassirostris*	7
yellow-rumped Tinkerbird	*Merops pusillus cyanostictus*	7
Black-and-white mannikin	*Lonchura bicolor*	12
Upchers warbler	*Hippolais languida*	6
White-headed mousebird	*Colius leucocephalus*	6
African paradise flycatcher	*Terpsiphone viridis*	5
African pied wagtail	*Motacilla aguimp vidua*	5
common fiscal	*Lanius collaris humeralis*	5
Whiteheaded barbet	*Lybius leucocephalus*	5
Grey-backed camaroptera	*Camaroptera brachyura*	4
Olivaceous warbler	*Hippolais pallida elaeica*	4
White-browed scrub-robin	*Cercotrichas leucophrys*	4
chin-spot Batis	*Batis molitor*	3
cinnamon breasted rock bunting	*Emberiza tahapisi tahapisi*	3
singing bush lark	Mirafra cantillans	3
Southern black flycatcher	*Melaenornis pammelaina*	3
Beautiful sunbird	*Nectarinia pulchella*	2
Brown-backed scrub-robin	*Cercotrichas hartlaubi*	2
Emerald-spotted wood-dove	*Turtur chalcospilos*	2
Eurasian roller	*Coracias garrulus garrulus*	2
Lesser striped swallow	*Hirundo abyssinica unitatis*	2
Ring necked dove	*Streptopelia capicola somalica*	2
vitelline masked weaver	*Ploceus velatus uluensis*	2
Augur bazzard	Buteo augur augur	1
Blue mantled crested flycatcher	*Trochocercus cyanomelas*	1

Eastern violet-backed sunbird	*Anthreptes orientalis*	1
Emeraled spotted wood dove	*Turtur chalcospilos*	1
Pearl spotted owlet	*Glaucidium perlatum licua*	1
Rattling cisticola	*Cisticola chiniana*	1
Scaly throated honey guide	*Indicator variegatus*	1
White browned coucal	*Centropus superciliosus*	1
Yellow necked spurfowl	*Francolinus leucoscepus*	1

Appendix 11 Birds associated with invasive plant species Wet-season survey

SPECIES NAME	Scientific name	No. Recorded
African citril	*Serinus citrinelloides*	2
African dusky flycatcher	*Muscicapa adusta interposita*	9
African firefinch	*Lagonosticta rubricata hildebrandti*	8
African Golden weaver	*Ploceus subaureus aureoflavus*	7
African paradise flycatcher	*Terpsiphone viridis*	5
Amethyst sunbird	*Nectarinia amethystina*	8
Beautiful sunbird	*Nectarinia pulchella*	2
Black- and- white mannikin	*Lonchura bicolor*	53
Black Roughwing	*Psalidoprocne holomelas massaicus*	20
Blue mantled crested flycatcher	*Trochocercus cyanomelas*	1
Brown-backed scrub-robin	*Cercotrichas hartlaubi*	2
chin-spot Batis	*Batis molitor*	3
cinnamon breasted rock bunting	*Emberiza tahapisi tahapisi*	3
Collared sunbird	*Anthreptes collaris garguensis*	9
Common bulbul	*Pycnonotus barbatus*	32
Common fiscal	*Lanius collaris humeralis*	5
Eastern violet-backed sunbird	*Anthreptes orientalis*	1
Emerald-spotted wood-dove	*Turtur chalcospilos*	2
Eurasian roller	*Coracias garrulus garrulus*	2
Grey-backed camaroptera	*Camaroptera brachyura*	4
Lesser striped swallow	*Hirundo abyssinica unitatis*	2
Little yellow flyctcher	*Erythrocercus holochlorus*	13
Little bee eater	*Merops pusillus cyanostictus*	9
Olivaceous warbler	*Hippolais pallida elaeica*	4
Pearl spotted owlet	*Glaucidium perlatum licua*	1
African pied wagtail	*Motacilla aguimp vidua*	5
Rattling cisticola	*Cisticola chiniana*	1
Red-cheeked cordon-bleu	*Uraeginthus bangalus*	8
Red eyed dove	*Streptopelia semitorquata*	9
Ring necked dove	*Streptopelia capicola somalica*	2
Scaly throated honey guide	*Indicator variegatus*	1
Singing bush lark	Mirafra cantillans	3

Southern black flycatcher	*Melaenornis pammelaina*	3
Speckled mousebird	*Colius striatus kikuyuensis*	7
Upchers warbler	*Hippolais languida*	6
Variable sunbird	*Nectarinia venusta*	29
Vitelline masked weaver	*Ploceus velatus uluensis*	2
Black-and-white mannikin	*Lonchura bicolor*	6
White-browed scrub-robin	*Cercotrichas leucophrys*	4
White browned coucal	*Centropus superciliosus*	1
White-headed mousebird	*Colius leucocephalus*	6
Whiteheaded barbet	*Lybius leucocephalus*	5
Willow warbler	*Phylloscopus trochilus*	17
Emeraled spotted wood dove	*Turtur chalcospilos*	1
Yellow bishop	*Euplectes capensis crassirostris*	7
Yellow necked spurfowl	*Francolinus leucoscepus*	1
yellow-rumped Tinkerbird	*Merops pusillus cyanostictus*	7

Appendix 12. ANOVA Table 1 (Sampling strata within study area)

SOURCE OF VARIATION.	Sum of squares	Degrees of freedom	Mean squares	F
Total	705151	= (N-1) = 202		
Groups	10806	= (K-1) =3	3602	
Error	694345	=N-K) =199	3489	1.032

$F_{0.05,3,199}$ = 8.54

Appendix 13. ANOVA Table 2 (Sampling sites in surrounding areas)

SOURCE OF VARIATION.	Sum of squares	Degrees of freedom	Mean squares	F
Total	38347.1	= (N-1) =16		
Groups	304.1	= (K-1) =3	101.36	
Error	38034	=N-K) =13	2925.69	0.0346

$F_{0.05,3,13}$ = 3.41