

**THE EFFECT OF INVASIVE PLANTS ON THE ABUNDANCE AND DIVERSITY OF
BLACK RHINOCEROS (*Diceros bicornis* L.) FOOD PLANTS IN NAIROBI NATIONAL
PARK, KENYA**

**OMARI JOYCE KANINI
UNIVERSITY OF NAIROBI**

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FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
SCIENCE IN BIOLOGY OF CONSERVATION**

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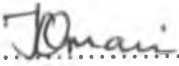


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DECLARATION

I, Joyce Kanini Omari, hereby declare that this thesis is my original work and has not been submitted for a degree in any other university.

Signature..........

Date.....13/2/09.....

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

Dr. E.M. Mwangi

School of Biological Sciences

University of Nairobi

Signature..........

Date.....13/02/2009.....

Dr. J.K. Mworia

School of Biological Sciences

University of Nairobi

Signature..........

Date.....16/02/2009.....

DEDICATION

To my late husband, Omari Gichogo, my source of inspiration and the reason why I must keep the flame of knowledge burning, till we meet again in the heavenly kingdom...To my children: Kemunto, Ong'ombe, Mbeki and Gichogo, for their patience, encouragement and support as I spent long days in college and equally long hours grappling with assignments at home. To my parents, for imparting in me God's wisdom, that can never fail and finally, to all those in pursuit of academic excellence, the sky is the limit...

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ABSTRACT

Invasive plant species pose a significant threat to many of Africa's conservation areas and their management is necessary to maintain both animal and plant species diversity. This study was carried out in the four main vegetation types (forest, grassland, riverine woodland and shrubland) in Nairobi National Park to determine the effect of invasive plants on the abundance and diversity of rhinoceros food plants.

The grassland was the most diverse in terms of invasive plant species (Shannon index = 3.80), while the forest was the most diverse in rhinoceros food plant species (Shannon index = 5.1) but least diverse in invasive plant species (Shannon index = 2.5). There was no significant difference in the density of invasive and rhinoceros food plants among the four vegetation types ($F_{[3, 691]} = 1.79, P = 0.15$). However, there was a significant difference in mean density between invasive and rhino food plants in the forest ($F_{[1, 691]} = 3.1, P = 0.04$). There was also a significant difference in density between invasive and rhinoceros food plants among quadrats at the road edges in the grassland ($F_{[1, 68]} = 4.383, P = 0.040$). Burning did not affect the density of invasive plants as there was no significant difference in density between invasive and rhinoceros food plants in burnt compared to unburnt areas ($F_{[1, 83]} = 1.702, P = 0.196$).

Pearson's coefficients of correlation indicated a weak association between the density of invasive plants and each of the soil chemical characteristics under study (pH, 0.03; nitrogen, -0.05; phosphorus, -0.21; potassium, 0.28). Nutrients and pH played an important role in the distribution of invasive plants, but phosphorus influenced the distribution of most of the invasive plants.

The results of this study suggest that invasive plants could have reduced the density of rhino food plants, especially close to the edge of roads, while phosphorus probably enhanced invasibility.

CHAPTER ONE

GENERAL INTRODUCTION

Government organizations and conservation groups such as the international union of conservation of nature (IUCN) express the phrase “invasive species” in terms of non-indigenous species that adversely affect the habitats they invade economically, environmentally or ecologically. Although the terms non-indigenous, alien, exotic, imported, introduced, non-native, colonizer and naturalized are sometimes used interchangeably in reference to invasive plant species, not all non-indigenous species have an adverse effect on their adopted environment. Moreover, some indigenous species can become invasive in a new environment. A more accurate definition of invasive plant species includes either indigenous or non-indigenous species that heavily colonize a particular habitat and negatively impact on it economically, environmentally or ecologically (Davis & Thomson, 2000). An introduced plant species might become invasive if it can out-compete native species for resources such as nutrients, light, water or food (Tilman, 1997) due to lack of competition and predation in the new environment.

Invasive plant species are considered one of the greatest threats to long-term conservation of biological diversity in both terrestrial and aquatic habitats (Lee & Macdonald, 1996; Wilcove *et al.*, 1998; Mack *et al.*, 2000). According to Cronk & Fuller (1995), invasive plants pose a significant threat to many of Africa’s conservation areas. Some invasive plant species such as *Lantana camara* and *Eichhornia crassipes* are among the world’s worst 100 invasive species (GISP, 2003). *E. crassipes* has been classified as a pest due to its negative economic effects once established, resulting to large economic loses in various sectors (Williamson, 1996; Davis *et al.*, 2000).

Tremendous economic loss has been induced by invasive plant species in agriculture and fisheries activities, forestry, food security and public health (McNeely, 2000; Pimental *et al.*, 2000). Although very little research has been performed to estimate the corresponding economic losses at spatial scales such as regions, states, and watersheds (Eiswerth, 2005), invasive species (both animals and plants) cost an estimated global US\$1.5 trillion per year in environmental and economic damage (Pimental *et al.*, 2000). These costs are low because they are calculated as production costs and management costs, otherwise if monetary values could be assigned to the extinction of species, loss in biodiversity and loss of ecosystem services caused by invasive species would drastically increase (The Nature conservancy, 2007).

There are numerous documented reports on the impact of invasive alien species on biodiversity and ecosystem functioning (D'Antonio & Vitousek, 1992; Richardson, 1998). Consequently, governments and relevant conservation agencies such as world heritage convention (WHC) have increased conservation efforts in an attempt to salvage biodiversity and prevent extinction. Workshops, Conferences and research initiatives have been instituted by different nations and the international community to understand, prevent and manage species invasions (Williamson, 1996; Richardson, 1998) and funds set aside for conservation efforts by state agencies like wild world fund (WWF). International conventions and legal instruments have also been developed to conserve and eliminate threats to biodiversity. These include the 1992 convention on biological diversity (CBD), which calls on its parties to prevent the introduction of, control or eradicate those alien species that threaten ecosystems, habitats or species. The global invasive species programme (GISP) was also established in 1996 to help countries become more aware of invasive species and how to deal with them. All these strategies are indicators of global concern that invasive species are a serious threat to biodiversity.

In some Kenyan and South African rhino habitats such as Nakuru, Mara, Umfolozi and Vaalbos, the unpalatable invader *Tarchonanthus camphoratus* has increased (Adcock *et al.*, 2007). It has been predicted that this invasive species may out-compete and suppress the more palatable rhinoceros food plants, few of which grow beneath its canopies (Adcock *et al.*, 2007). Several Kenyan black rhinoceros habitats such as Sweet waters ranch and Ithala game reserve are showing signs of reduction in palatable rhino food species. The affected rhinoceros food plant species include *Acacia drepanolobium* in sweet waters ranch due to browser pressure (Birkett, 2002), *A. nilotica* and other *Acacias* in Ithala Game Reserve and *Grewias* which have been reduced to dwarf status (Amin *et al.*, 2006). Since species with small population size are highly vulnerable to environmental changes (Barbault & Sastrapradja, 1995), it's important to ensure that any form of change within the rhino habitat is detected and managed appropriately. This is necessary in order to maintain a minimum population size that is required for long-term viability of rare and endangered species (Cunningham & Saigo, 1999).

The black rhinoceros (*Diceros bicornis* L.) is one of the threatened animals globally and is indeed endangered in all its range, despite legislation taken to protect it (Cumming *et al.*, 1990). The global rhinoceros population had declined from approximately 100,000 individuals in 1970 to 3725 in 2005 due to conflict with humans over land use and intense poaching to meet the increased demand for rhino horn (Amin *et al.*, 2006). Thus the black rhinoceros was classified as a critically endangered species in the International Union of Conservation of Nature (IUCN) Red List of Threatened Animals and in Appendix 1 of the Convention on International Trade in Endangered Species of wild fauna and flora (CITES). It is therefore important to improve biological management in order to ensure that population growth becomes enhanced to allow

black rhino recovery and safeguard the long term demographic and genetic viability of the Kenyan black rhinoceros herd (Adcock *et al.*, 2007).

Although Kenya is the stronghold of *Diceros bicornis* L. worldwide and its number is gradually increasing, meta-population growth rates have not reached the internationally accepted minimum target level of 5% per annum (Okita, 2004). Previous efforts to rehabilitate the rhino populations in Kenya focused on increasing their security and the creation of sanctuaries (Brett, 1993). However, food availability and quality are also major determinants of habitat suitability in order to sustain viable rhino populations (Muya & Oguge, 2000). Hrabar & Dutoit, (2005) points out that an understanding of all factors that may affect the productivity of black rhinoceros is crucial in order to achieve maximum productivity and decrease their vulnerability to extinction. Thus, in addition to security and creation of sanctuaries, rapid growth of the national black rhinoceros herds can be achieved if their habitats are managed in such a way as to maximize their breeding performance, minimize death rates and avoid compromising their food resource base (Adcock *et al.*, 2007).

Productivity of the black rhinoceros can be increased by removing all factors that threaten food availability and quality and this includes control of invasive plants. This is important since food availability and quality directly affect productivity of animals including that of the black rhinoceros. Since biological invasion can cause a decrease in biodiversity (Genovesi, 2000), it's important to know the effects of invasive plants on abundance and diversity of rhinoceros food plants in Nairobi National Park. This will ensure that the ecosystem is not altered significantly due to loss of species and genetic resources as pointed out by Foxcroft, (2003).

CHAPTER TWO

2.0 LITERATURE REVIEW

Invasive plant species (IPS) are either indigenous *or* non-indigenous species that colonize a particular habitat resulting to economical, environmental or ecological losses (Davis & Thomson, 2000). Researchers refer to the non-indigenous species as invasive alien species (IAS) as they are more competitive for resources compared to indigenous ones, making it easy for them to spread under certain conditions and thus becoming naturalized (Richardson, 1998).

Several traits have been singled out by researchers as predictors of invasive ability of plants in a new environment (Day *et al.*, 2003). These include, the ability to reproduce both asexually as well as sexually, rapid growth, early sexual maturity, high reproductive output, the ability to disperse young widely, tolerance of a broad range of environmental conditions, high phenotypic plasticity (ability to alter growth form to suit current conditions) and allelopathy (production of chemicals which make the surrounding soil uninhabitable, or inhibitory, to other competing species). However, the single best predictor of invasiveness is whether or not the species has been invasive elsewhere (Williamson, 1996). Besides, invasion is likely if an ecosystem is similar to the one in which the potential invader evolved (Williams & Meffee, 1998).

All plants that are planted in alien environments can become naturalized and spread under certain conditions (Richardson, 1998), thus becoming invasive. Some introduced plant species quickly become naturalized in the new environment, reproducing consistently and sustaining populations over many life cycles without direct human intervention (Richardson *et al.*, 2000). Furthermore, some of these naturalized species become invasive in the new environment, where, without their attendant natural enemies, they are able to survive, reproduce and spread unaided and at alarming

rates across the landscape (Richardson *et al.*, 2000). Invasive alien species (IAS) tend to be more competitive for space, light and nutrients than endemic plant species and therefore colonize any open gap in forests to form monotypic stands; hence can wipe out the indigenous flora and fauna if nothing is done to stop the invasion (Tilman, 1997).

2.1 Impacts of Invasive Plants

Plant invasions pose a real and significant threat to many of Africa's conservation areas and are recognized as one of the major threats to biodiversity and ecosystem stability globally, second only to habitat loss and degradation (Wilcove *et al.*, 1998; Mungoro & Tezoo, 1999; Mack *et al.*, 2000). Invasive alien species (IAS) are also a threat to biodiversity even within protected areas (Lotter & Foxcroft, 2003). These plants are widespread and affect conservation areas on every continent except Antarctica (Cronk & Fuller, 1995). They can negatively affect a wide array of environmental attributes that are important to support recreation, water quality and quantity, plant and animal diversity, and species abundance (Eiswerth, 2005).

The impacts of invasive plants include the extinction of indigenous flora and fauna among others (Cronk & Fuller, 1995). According to Davis *et al.*, (2000), the invasion of habitats by non-native plant and animal species is a worldwide phenomenon, with potentially grave consequences to ecological, economic, and social systems. Biological invasions can have devastating population, community and ecosystem impacts (Parker *et al.*, 1999). Such impacts may include loss of native species, disruption of energy and nutrient webs and unstable production systems (Davis *et al.*, 2000). As a potential threat to native biological diversity (Eiswerth, 2005), invasive plants need to be controlled to ensure that the food plants of all herbivores are in large supply, maximize productivity (Adcock *et al.*, 2007 and hence sustenance of life.

Although the ecological impact of invasions is often difficult to measure (Williamson, 1999), invasions by alien species can have an impact at several levels of ecological complexity from genes to ecosystems (Parker *et al.*, 1999; Mack *et al.*, 2000). Moreover, the impacts of invaders are immense and usually irreversible and often affect more than one aspect on an area's ecology (Foxcroft *et al.*, 2006). They include the replacement of diverse ecological systems with stands of invasive alien plants, the alteration of soil chemistry, geomorphological processes, fire regimes, hydrology and the extinction of indigenous fauna (Cronk & Fuller, 1995). Invasive alien species are also reported to remove or introduce "keystone species" which can lead to the collapse of a system or alter the future dynamics of a particular system completely (Baskin, 2002). Other impacts due to direct competition are species loss, reduced structural diversity, increased biomass production and disruption of the prevailing vegetation dynamics (Van Wilgen & Van Wyk, 1999).

In terms of agriculture, the disadvantages of invasive plants include competition against crop plants for available resources, lowering the quality of agricultural produce and increasing the costs of production (Cousens & Mortimer, 1995; Ngugi *et al.*, (1978) in Njoroge *et al.*, 2004). In regard to conservation of biodiversity, invasive species are perceived to act as "plant pests" (Miller, 1999), especially when they are adapted to fires, lack natural enemies, grow faster than indigenous plant species and produce plenty of seeds (Richardson *et al.*, 1992).

One of the most widely distributed invasive plants is *Lantana camara* which occurs across many continents where it is naturalized in approximately 60 countries or island groups. The plant occurs in diverse habitats and on a variety of soil types in the Asia-Pacific region, Australia, New Zealand, Central and South America, West Indies and Africa (IUCN, 2000). Thus, its diverse and broad geographic distribution is a reflection of its wide ecological tolerance. *Lantana*

camara invades and impacts severely on agriculture as well as on natural ecosystems and has progressively invaded the dry deciduous forest of northern India, threatening the survival of many species (Sharma & Raghubanshi, 2006). Its allelopathic qualities can selectively increase mortality of other plant species (Gentle & Duggin, 1997; Sharma *et al.*, 2005a), resulting in reduction of species diversity as well as decline of species (Sharmer *et al.*, 2005b).

An assessment of all protected areas within Kwazulu-Natal in South Africa in 2001/2002 rated invasive plants as the single greatest threat to biological diversity (Lotter & Clark, 2003). In eastern and central Sudan, exploitation of invading *Prosopis juliflora* by humans at a local scale has not prevented it from becoming a problem (Richardson, 1998). Introduction of *Prosopis juliflora* by Food and Agricultural Organization (FAO) for rehabilitation of over-grazed and over-exploited semi-arid woodlands in Baringo District in Kenya has resulted to more problems than benefits (Mwangi & Swallow, 2005), and its control has proved difficult. In Kajiado district, Kenya, the invasive coloniser *Ipomoea hildebrandtii* has aggravated the problem of inadequate grass forage (Mworia *et al.*, 2008).

2.2 Invasion Success and Susceptibility of a Plant Community to Invasion

A number of researchers have proposed various hypotheses to explain invasion success of plant species such as absence of natural enemies, (Mitchel & Power, 2003), allelopathic effects on native species (Callaway & Aschehoug, 2002), more competitive ability of the invading species (Blossey & Notzold, 1995) and beneficial interactions with soil organisms (Klironomos, 2002). Invasion is also more likely if an ecosystem is similar to the one in which the potential invader evolved (Williams & Meffee, 1998), although invasions also occur in dissimilar environments. However, there has been no consensus on proposed hypotheses since results from field studies have been inconsistent (Lonsdale, 1999; Williamson, 1999).

Invasion of an area is influenced by three factors: the number of propagules entering the new environment, the characteristics of the new species and the susceptibility of the environment to invasion by new species (Lonsdale, 1999). Inconsistencies in the results from various studies demonstrate that the factors that determine the invasion of a community by a given species are yet to be fully understood although some studies have identified specific factors that increase invasion (Lavorel *et al.*, 1999). A combination of disturbance and eutrophication enhances invasion because it involves both a reduction in resource uptake by the resident vegetation and an increase in gross resource supplies (Mack *et al.*, 2000). Global environmental changes can also accelerate species invasions due to fluctuating resource availability (Dukes & Mooney, 1999; Hobbs, 2000).

In addition to disturbance frequency and propagule source, there are three environmental variables that can determine susceptibility to invasion: precipitation, solar insolation and soil nutrients (Huston, 2004). Adding nutrients can increase diversity and invasion, particularly on nutrient-poor soils (Allen *et al.*, 2000), but adding nutrients can also decrease diversity and invasion on soils of intermediate to high fertility (Huston & D'Angelis, 1994). At present there is no clear evidence that nitrogen deposition alone can drive the invasion process on otherwise undisturbed communities (Keeley, 2004). Plant invasions can also alter soil properties and impact on the invasion of ecosystems as well as the invasiveness of species (Ehrenfeld, 2003).

Species diversity can also influence susceptibility of an environment to invasion although experimental and field results are contradictory. Some ecologists (e.g. Stohlgren *et al.*, 1999) found that ecosystems with high species diversity are more susceptible to invasion, while recent experiments on invasion in which species diversity was the treatment variable support the

prediction that highly diverse communities are more resistant to invasion (Tilman, 1993, 1997; Levine, 2000; Kennedy *et al.*, 2002). Other experiments by Lavorel *et al.*, (1999) found no effect of species richness on invasibility. Re-evaluation of the positive experimental results suggests that factors other than variation in species diversity, such as total biomass or plant density, may actually be causing the observed responses (Wardle, 2001; Weltzin *et al.*, 2003).

On the other hand, field surveys of invasive species richness in relation to native species richness found a different pattern compared to that seen in the experiments. A survey of parks and reserves around the world found a positive correlation between the number of native species and the number of exotic species (Lonsdale, 1999). A high-resolution study of vegetation in the Rocky Mountains, western deserts, and Great Plains of North America also found that native and exotic species richness were positively correlated across sample areas at several levels of sampling resolution (Stohlgren *et al.*, 1998; Stohlgren *et al.*, 2001). In riparian systems, the areas with the highest diversity of native plant species also had the greatest number of invasive species, in both California (Levine, 2000) and the southern Appalachians (Brown & Peet, 2003).

2.3 Effect of Disturbance on Abundance and Diversity of Invasive Plants

Many discussions on biodiversity focus on species diversity that can change over time and space, making diversity assessments useful tools in ecological evaluations (Rosenzweig, 1995). Diversity indices have been used widely in studies to indicate threats to biodiversity through determination of species richness over time (Magurran, 1988; Rosenzweig, 1995; Pelz *et al.*, 2001). There are many methods for measuring diversity and most of them consist of two components; species richness and the relative abundance (evenness or unevenness) (Magurran, 1988) where species richness is a count of the number of plant species in a community and is often equated with diversity. Shannon index is one of the popular indices based on the

proportional abundances of species and best suited to describe a plant community as it considers both species abundance and richness. Simpson's index, also commonly used, is heavily weighted towards the most abundant species but less sensitive to species richness (Magurran, 1988).

Many researchers have established that disturbance increases the abundance and diversity of invasive plants. Mack *et al.*, (2000) found that disturbed areas are more easily invaded (by native or exotic species) than undisturbed areas. Most invasive alien species are adapted to highly disturbed, nutrient-rich, low-elevation agricultural or urban environments (D'Antonio *et al.*, 1999; Hobbs, 2000; Sax & Brown, 2000). Disturbances kill part or all of some individual plants, thus affecting both survival and competitive ability, and making various types of resources available to surviving plants (Huston, 1994).

Alteration of resources such as soil nutrients and water brought about by disturbance are responsible for many plant invasions (Lodge, 1993; Hobbs & Humphries, 1995). Disturbance plays a very important role in facilitating plant invasions by increasing resource levels (D'Antonio, 1993). Mack *et al.*, (2000) has explained increase in invasion following a disturbance by the theory of fluctuating resource availability as due to addition of resources in a community or decline in resource uptake by resident vegetation. An increase in the amount of unused resources, mainly phosphorus and nitrogen, can make a plant community more susceptible to invasion (Davis *et al.*, 2000; Mack *et al.*, 2000), since competition intensity is inversely proportional to the amount of unused resources (Davis *et al.*, 1998).

Road construction incurs considerable disturbance on natural communities, baring soil, clearing natural vegetation, admitting light to the ground layer (in forest communities), and altering drainage (Christen & Matlack, 2006). It involves wholesale movement and compaction of soil;

introduction of a new seed bank, often composed of exotic species and pollutant input from traffic on the road (Forman, 2000; Parendes & Jones, 2000). Such habitat invites colonization by invasive species, which are often disturbance adapted (Fox & Fox, 1986; Parendes & Jones, 2000). As conduits for alien plant dispersal roads facilitate invasion by acting as movement corridors, aiding dispersal or channeling population expansion (Christen & Matlack, 2006) and by bringing reproducing plants into close proximity with natural habitat (Gelbard & Belnap, 2003; Watkins *et al.*, 2003). However, the potential conduit function of roads depends on the habitat specificity of the spreading species, its dispersal range relative to the spacing of roads in the landscape, and the relative importance of long- and short-range dispersal (Christen & Matlack, 2006). In extensively disturbed areas of southwest Australia, fire enhanced invasion along roadsides (Milberg & Lamont, 1995).

Disturbance changes the fundamental nature of the ecosystem (Byers, 2002) and may give invasive species which are not otherwise co-evolved with the ecosystem, a chance to establish themselves since there is less competition from more adapted species (Tilman, 2004). On the other hand, large areas of undisturbed habitat are generally resistant to invasion (Fox & Fox, 1986; Kupfer *et al.*, 1997).

2.4 Control of Invasive Plants

Invasive alien plant species have been introduced to enhance economic activities in agriculture, forestry and horticulture and are of extreme importance in certain societies for basic needs such as fodder and energy (Ewel *et al.*, 1999; McNeely, 2000). Research has shown that plant introductions eventually lead to increased invasion problems after a time lag of about 50 years (Hughes, 1995) hence dramatic increases in the populations of various invasive species are expected if appropriate management interventions are not instituted. Non-indigenous organisms

have always provided enormous advantages to human beings economically, as well as culturally, throughout history, despite their deleterious effects (Van Driesche & Van Driesche, 2000). Thus, control programs for invasive species may encounter some opposition from local people benefiting economically from those species. Because of these potential conflicts, choosing the best control program requires an understanding of different community's perceptions of invasive plants particularly where invasions simultaneously bring costs and benefits to local people (Huston, 2004).

According to a report by The Nature Conservancy (2005), the best method of controlling invasive species is to prevent their establishment because they are difficult to control once they are established. However, to control invasive plants successfully if already established, the extent of the problem and the logistics involved need to be known before implementation of the necessary plan of action based on available funds (Foxcroft *et al.*, 2006). The correct planning, based on recognized conservation and invasive plant clearing principles, is necessary to avoid wastage of funds (Lotter & Clark, 2003).

Fire has been proposed as a short-term treatment for restoring natural ecosystems as well as targeting invasive alien species (Keeley, 2004). Some studies indicate that fire restoration may carry with it a cost in terms of increasing alien invasions (Crawford *et al.*, 2001). A viable strategy would be coupling of disturbance such as fire that temporarily diminishes alien species with active restoration of natives as a long term approach (Keeley, 2004) since seeding with natives is a viable means of altering the competitive relationships between native and alien species (Seabloom *et al.*, 2003). Fire is a useful tool for controlling invasive plant species especially prior to mechanical or herbicide control to improve their effectiveness, or as a follow-up to such methods (Tu & Randall, 2001).

However, the best solution to the problem caused by invasive alien plants lies in integrating various control methods such as manual and mechanical, prescribed fire, chemical and biological control (Tu & Randall, 2001). Irrespective of the method chosen, priorities on dealing with invasive plant species should be set according to the following four characteristics (McNeely *et al.*, 2001);

- The current extent of the species in or near the area
- The current and potential impacts of the species
- The value of the habitats that the species has or may invade
- The difficulty in controlling the species

2.5 Justification

Several studies at Nairobi National Park have recorded different numbers of plant species utilized by the black rhinoceros for food: 47 plant species (Waweru, 1985), 52 plant species (Muya, 1993), and 34 plant species (Muya & Oguge, 2000). However no work has been carried out to document and mitigate the increasing threats posed by invasive plants in Nairobi National Park. Yet as pointed out by Adcock *et al.*, (2007), suitable food resources are showing signs of fairly heavy rhinoceros browsing pressure in this park. The aim of my study was to document information on the types, abundance and diversity of invasive plants in the main vegetation types and how they affect the abundance and diversity of rhinoceros food plants at Nairobi National Park. The study will also compare the heights of plants in the main vegetation types and establish if there is a relationship between the density and distribution of invasive plants and soil chemical characteristics (i.e. pH and concentrations of phosphorus, potassium and nitrogen).

The findings of this research will provide a foundation for long term biodiversity and ecosystem monitoring by allowing prompt response to curb the spread of invasive species by indicating

which areas should be given priority in their eradication. This will ensure a healthy habitat for the black rhinoceros and promote its productivity and that of other browsers.

2.6 General Objective

To determine if invasive plants affect the abundance and diversity of black rhinoceros food plants in Nairobi National Park.

2.7 Specific Objectives

1. To identify, determine and compare the density of invasive and black rhinoceros food plants in the four main vegetation types (forest, grassland, riverine and shrubland) and at varying distances from the edge of roads/rivers in burnt and unburnt areas.
2. To determine the diversity of invasive and black rhinoceros food plants in the four vegetation types.
3. To determine and compare the heights of invasive and black rhinoceros food plants in the four vegetation types.
4. To determine if there is a relationship between the density and distribution of invasive plants and soil chemical characteristics i.e. pH and concentrations of phosphorus (P), potassium (K) and nitrogen (N).

2.8 Hypotheses

1. Abundance of black rhinoceros food plants differs between areas with more invasive plants compared to those with few or none
2. Invasive plants affect the diversity of rhino food plants
3. The heights of plants in the main vegetation types differ significantly

4. There is a relationship between the density and distribution of Invasive plants and soil chemical characteristics

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The Nairobi National Park occupies an area of 117 km² and is situated about 8km south of Nairobi city centre between 2° 18' to 2° 20' S and 36° 23' to 36°28' E. The park was gazetted in 1946 and is therefore the oldest legislated conservation area in East Africa, with a variety of mammals, birds and reptiles close to a major city. It is important for conservation of terrestrial and aquatic biodiversity some of which are globally threatened. Correct timing by tourists who wish to see a wide variety of animals is important since most animals migrate from the Park in the dry season due to fluctuation in resource availability. This seasonal migration occurs to and from the adjoining Kitengela conservation area. The rhino and a few other animals do not migrate, thus can be seen throughout the year.

All the boundaries of the park are fenced except for about 20km along Athi River, which forms a natural boundary at the southern far end of the Park. The fence keeps wildlife out of the nearby communities of Karen and Langata to avoid human-wildlife conflicts. Increased human habitation, farming and fencing in the Kitengela area has made dispersal of wildlife difficult and has increased human-wildlife conflict, which is causing a lot of concern to conservationists (Muya & Oguge, 2000). Numerous roads and tracks allow access by vehicles to most areas within the Park, making biodiversity monitoring possible.

There are four major vegetation communities namely forest, grassland, riverine woodland and shrubland which comprise of eight sub- vegetation types as shown in Figure 3.1 below:

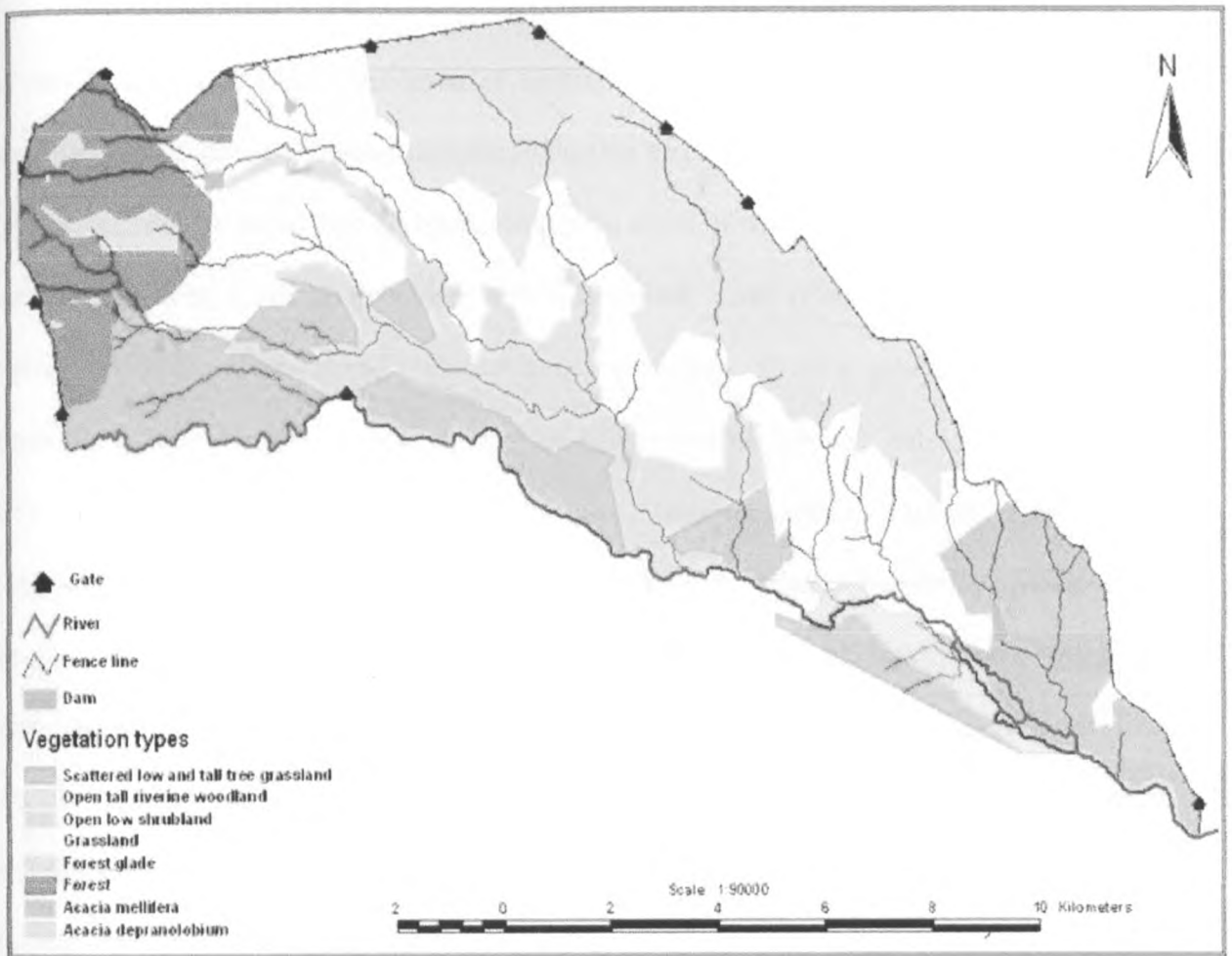


Figure 3.1: Map of Nairobi National Park showing the different sub-vegetation types

Source: Adcock *et al.*, 2007

There are some deep rocky valleys and gorges consisting mainly of scrub and tall grass. Open plains dominate the park with scattered trees and shrubs such as *Acacia drepanolobium*, *Acacia xanthophloea*, *Balanites aegyptica*, *Acacia mellifera*, *Acacia kirkii*, *Acacia gerrardi* and *Acacia senegal*. Other plant species that are food for the black rhinoceros include *Abutilon mauritianum*, *Phyllanthus fischeri*, *Phyllanthus sepialis*, *Justicia whytei*, *Lippia javanica*, *Grewia similis*,

Ocimum gratissimum, *Maytenus senegalensis*, *Aspilia mossambicensis*, *Hibiscus aponeuras*, *Rhus natalensis*, *Achyranthes aspera* and *Acalypha fruticosa*. The invasive plant species commonly seen in the park are *Lantana camara*, *Solanum incanum* and *Opuntia* species.

The park is important for conservation of terrestrial and aquatic biodiversity with a variety of fauna species including the black rhinoceros (*Diceros bicornis*) which is globally threatened. The park is a sanctuary to more than 60 black rhinoceros some of which were translocated to the park from areas in Kenya where poaching was widespread. Lion (*Panthera leo*), spotted hyena (*Crocuta crocuta*), silver-backed jackal (*Canis mesomelas*), Grant's gazelle (*Gazella granti*), Thomson's gazelle (*Gazella thomsonii*), impala (*Aepyceros melampus*), baboon (*Papio anubis*), vervet monkey (*Cercopithecus aethiops*), buffalo (*Syncerus caffer*), warthog (*Phacochoerus aethiopicus*), cheetah (*Acinonyx jubatus*), Burchell's zebra (*Equus burchelli*), Masai giraffe (*Giraffa camelopardalis*), hippopotamus (*Hippopotamus amphibious*) and wildebeest (*Connochaetes taurinus*). There are a number of reptiles such as savanna monitor lizard (*Varanus exanthematicus*), hinged tortoise (*Kinixys belliana*), leopard tortoise (*Geochelone pardalis*) and terrapin (*Malaclemys terrapin*). The birds found in the park include ostrich (*Struthio camelus*), secretary bird (*Sagittarius serpentarius*), yellow necked spur fowl (*Francolinus leucoscepus*), blue bellied bustard (*Lissotis melanogaster*), Hartlaub's bustard (*Lissotis hartlaubii*) and crowned crane (*Grus japonensis*).

The Park consists of a gently undulating slope from higher elevations around woodland areas in the north-west (1790m) to mosaic grasslands of lowland plains in the south-east (1508m) (Muya and Oguge, 2000). There is a permanent river at the southern far end of the park and several seasonal rivers in the north-eastern axis. Several man-made dams are distributed at various parts within the Park to provide drinking water for wildlife. Occasionally, prescribed fire

is used as a way of improving the quality of grass for the grazers as well as to minimize encroachment by bushes. The seasons alternate between long rains that come in March and end in May and short rains from October to December. The mean monthly rainfall is 88.9 mm during short rains and 175.4mm during long rains.

3.2 Sampling and Study Design

Sampling occurred within a period of four months between January and April, 2008. Using a map of Nairobi National Park, the sampling area was divided into squares of 1km². In cases where the squares were incomplete, fractions were added to make complete squares, giving a total of approximately 117 squares. Sampling sites were located within the vegetation types shown in figure 3.1 on page 18 to ensure each was represented. The area occupied by each of the vegetation types was estimated by counting the number of squares occupied by each vegetation type after which they were lumped into the four main vegetation types (forest, grassland, shrubland and riverine woodland). A total of 30 sampling sites were allocated randomly in proportion to the size of each of the four main vegetation types as shown in Table 3.1.

Table 3.1: The four main vegetation types indicating the area, proportion and number of sampling sites.

Vegetation type	Area (km ²)	Proportion	Number of sites sampled
Grassland	88	0.75	13
Shrubland	11	0.10	6
Forest	11	0.09	6
Riverine	7	0.06	5
Total	117	1.00	30

NB: Riverine represents riverine woodland.

In the riverine woodland, five sampling sites were selected; three at different locations along the main river and two along different seasonal rivers. A geographical positioning system (GPS) was used to show the location at the road or river edges where sampling commenced. Figure 3.2 below shows the 30 sampling sites in the different vegetation types as located using GPS.

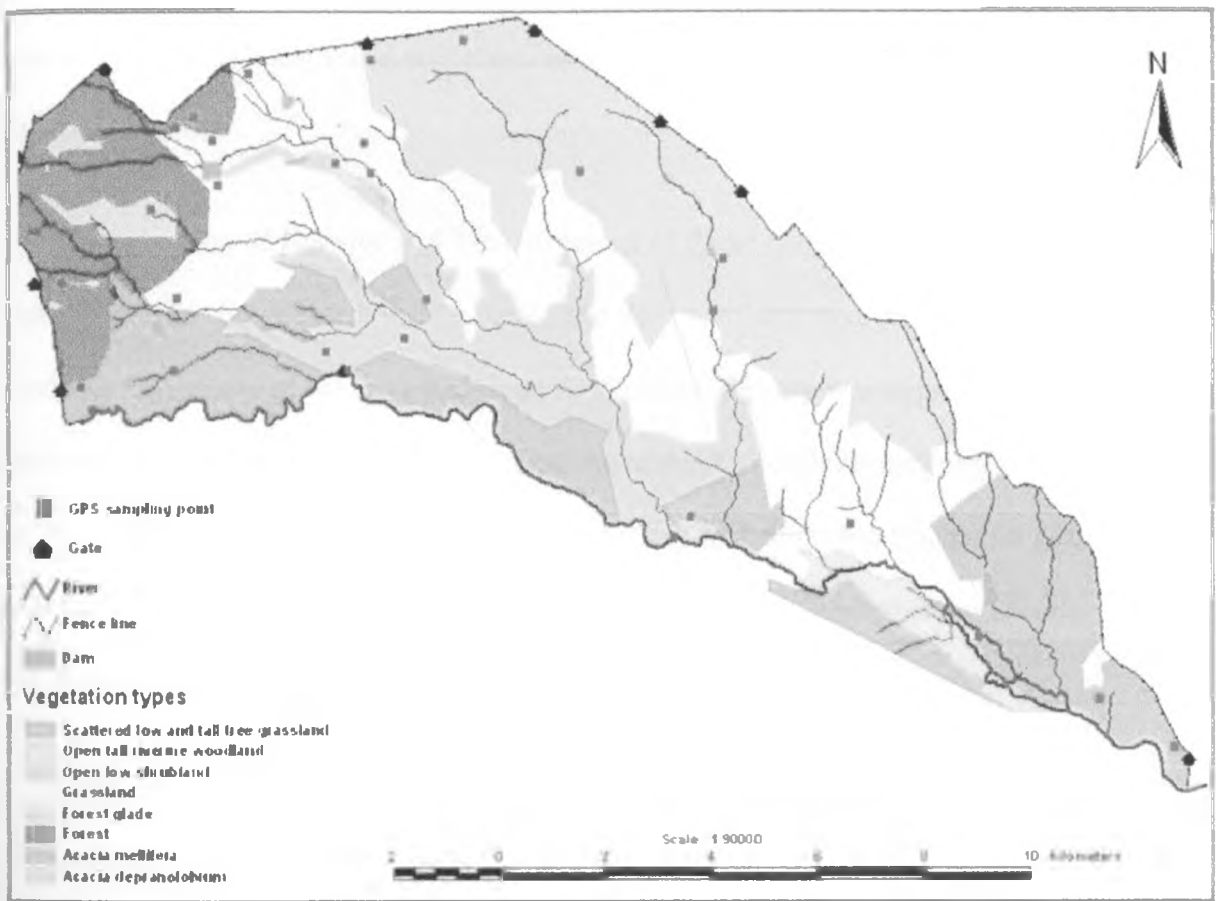


Figure 3.2: Map of Nairobi National Park showing the location of sampling sites in the different sub-vegetation types. The sites were located using a Geographical Positioning system. Source: Adcock *et al.*, 2007

Within each vegetation type, 100m transects were established in burnt and non-burnt areas perpendicular to roads and rivers in the riverine woodland. Geographical Positioning Systems (GPS) coordinates were recorded at the beginning and the end of the transect to ensure repeatability. Along each transect, four quadrats of 5m x 5m were marked out at intervals of 25m along each transect. The four quadrats were marked out starting at the road edges or rivers between 0-5m, 30-35m, 60-65m and 90-95m along the transects. A quadrat of 25m² was considered an appropriate size for sampling all the plant life forms since the variables of interest were density, diversity, height and soil characteristics which would not have been affected much by the size of quadrat.

3.3 Determination of Density and Measurement of Plant Heights

All plant species in each quadrat were counted and their numbers recorded in order to determine and compare the density of invasive and rhino food plants. Density was expressed as the number of plants per square meter, obtained by dividing the number of each species of plants by the area of the quadrat which was 25m². The heights of invasive and rhino food plants in each quadrat were measured using a steel measuring tape and recorded in meters. Secondary data (e.g. Agnew, 1974 & Beentje, 1994) was used in life form categorization of plant specimens.

3.4 Soil Sampling and Analysis

A soil augur was used to collect approximately 300g of soil up to a depth of 6 inches at the center of each of the four quadrats along each transect and transferred separately into labeled plastic bags. Collecting the soils from the center of quadrats was done in order to ensure uniformity of sampling points along all the transects. A total of 120 soil samples were collected along the 30 transects (within 120 quadrats) and taken to Mines and Geology Department, Ministry of Environment and Mineral Resources for analysis. The soil samples were first dried at

110 degrees Centigrade to expel moisture then pulverized into a fine powder to increase their surface area before digestion and analysis.

Potassium was digested using nitric acid and hydrochloric acid in the ratio 1: 3 (aqua-regia) and its concentration determined using a calibrated atomic absorption spectrophotometer at an analytical wavelength of 760 nm. Phosphorus was digested using nitric acid and sulphuric acid in the ratio 5: 1 then adding molybdivanadate solution to generate a phospho-molybdivanadate complex. The percent transmittance was measured using a calibrated visible spectrophotometer at an analytical wavelength of 430 nm. Reagent blank was used as the reference solution while a standard solution was used for calibration. The transmittance was then converted to absorbance using a conversion table and the concentration of phosphorus calculated using the formula below:

$$\text{Concentration of phosphorus in sample} = \frac{\text{Absorbance of sample} \times 25 \times 100 \times 1000}{\text{Absorbance of standard} \times 10 \times 50} \text{ mg/l}$$

Nitrogen was digested using distilled water since all nitrates are soluble in water. The mixture was filtered and a nitrate buffer added to the resulting filtrate. The reading was taken using a nitrate meter calibrated with the help of a selective nitrate electrode. The pH was determined by mixing the soil sample with distilled water, leaving the mixture to stand overnight before using a pH meter. Details of digestion and analysis of the soil samples are presented in Appendix 4.

3.5 Identification of Plant Specimens

The indirect approach of identifying rhinoceros food plants as used by Muya and Oguge (2000) was applied in the field. Feeding by rhino involves cutting plants in such a way that the stumps left appear like they have been cut with a sharp knife, a distinct cut compared to one made by

other browsers. All the plant specimens were identified with the help of a Taxonomist either in the field or at the University of Nairobi herbarium. Photographs of the invasive plants were taken using a digital camera to assist in their identification and for documentation purposes.

3.6 Data Analyses

Statistical package for social science (SPSS) software was used for chi square test and to test for differences in means of density and heights of plants using one way Analysis of variance (ANOVA). PC-ORD software was used to analyze the invasive plant species density alongside the soil chemical characteristics using canonical correspondence analysis (CCA) and also to determine the diversity of plants in the four main vegetation types using Shannon index.

The density of invasive and rhino food plants in the four main vegetation communities was determined and compared using analysis of variance (ANOVA). The density of invasive plants at different distances from the edge of roads or rivers and among the different vegetation types were compared using ANOVA. This was done by testing for differences in means of density and heights of plants. Student-Newman-Keul's post ANOVA test was performed in cases where there were significant differences so as to establish which means actually differed from each other..

Rhinoceros food plants were categorized into those whose height was equal to or less than 2m and those whose height was above 2m. This was done in order to estimate the frequency of rhino food plants that were within the reach of the black rhino since they browse at a maximum height of 2m (Oloo *et al.*, 1994). Chi squared test was used to establish if the observed frequencies of each category of rhino food plants in the four vegetation types deviated from the expected frequencies using the formula below:

$\chi^2 = \sum (O - E)^2 / E$ where O is the observed frequency and E the expected frequency (Kothari, 2004).

PC-ORD program that performs multivariate analysis of environmental data was used to determine Shannon Wiener diversity indices of invasive and rhino food plants in the four vegetation types. This gave an indication of species diversity for invasive and rhinoceros food plants in the different vegetation types.

$$H = - \sum [P_i \times \ln (P_i)]$$

Where:

H is Shannon's diversity index

$P_i = N_i/N$ and is the proportion of species relative to the total number of species (P) while ln is the natural logarithm (Magurran, 1988).

To assess the relationship between invasive plants and soil chemical characteristics, correlation coefficients were used to measure the intensity of association between the two variables (Kent & Coker, 1992). To determine the variation in habitat preference (distribution) of invasive plant species as influenced by soil chemical characteristic, Canonical Correspondence Analysis (CCA) was applied (Kent & Coker, 1992) to analyze the soil data alongside the invasive plant species data. Canonical correspondence analysis is a direct ordination technique that simultaneously uses two data sets; environmental data set and species data set to relate community variation (abundance and composition) to environmental variables (soil chemical characteristics in this case). The main outputs of CCA include correlations of environmental variables to ordination axes which indicate the variables that were most influential in structuring the ordination. In the invasive plant species – soil characteristics biplot (ordination diagram), the points represent individual species and arrows represent soil chemical characteristics plotted in the direction of

maximum change. A species near or beyond the tip of an arrow when a perpendicular line is drawn to it shows that it was positively correlated and influenced by the soil chemical characteristic. An alternative approach would have been to use separate regression analysis for each species; however, CCA models are more readily implemented for many species simultaneously.

Thus, of the 120 quadrats sampled, only 62 quadrats had invasive plants species and these were considered against their soil characteristics for purposes of analysis using CCA. The soil data consisted of potassium, phosphorus, nitrogen and pH whereas the invasive plant species data consisted of *Datura stramonium*, *Lantana camara*, *Opuntia exaltata*, *Opuntia vulgaris*, *Solanum incanum*, *Tagetes minuta*, *Caesalpinia decapetala*, *Ricinus communis*, *Opuntia ficus-indica* and *Argemone mexicana*.

CHAPTER FOUR

4.0 RESULTS

4.1 Density of Invasive and Rhino Food Plants

In this section, results on the densities of invasive plant species in the four main vegetation types (forest, grassland, riverine woodland, shrubland) are presented. The mean densities (m^2) and standard errors (\pm SE) of invasive plants (IP) and black rhinoceros food plants (RFP) are also compared using ANOVA among the four vegetation types and at varying distances from the edge of roads/rivers.

A total of 76 plant species were identified; 68 rhinoceros food plant species and 10 invasive plant species, two (*Lantana camara* & *Solanum incanum*) of which doubled up as rhinoceros food plant species. The two invasive plants were also found in all the vegetation types. *Lantana camara* was the most abundant shrub with the highest density in the forest. On the other hand, *Solanum incanum* was the most abundant herb with the highest density in the grassland. *Argemone mexicana*, *Caesalpinia decapetala*, *Opuntia exaltata*, and *Ricinus communis* were found at low densities in the grassland vegetation only whereas *Opuntia ficus-indica* was found in the riverine vegetation only. The density of invasive plant species in the different vegetation types and their mean density in the four vegetation types were as shown in Table 4.1.

Table 4.1: Density of invasive plant species per vegetation type and their mean density in the four vegetation types.

Vegetation types	Invasive plant species									
	Arm	Cad	Dst	Lac	Oex	Ofi	Ovul	Ric	Sin	Tam
Forest	0.0	0.0	0.7	1.8	0.0	0.0	1.4	0.0	1.4	1.7
Grassland	0.2	0.1	2.5	1.7	1.0	0.0	0.6	0.1	11.0	1.2
Riverine	0.0	0.0	0.1	0.1	0.0	0.2	1.4	0.0	5.4	0.1
Shrubland	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	1.1	0.2
Mean density	0.05	0.03	0.83	1.08	0.25	0.05	0.85	0.03	4.73	0.80

NB: Riverine represents riverine woodland on this table and elsewhere

Key

Dst- *Datura stramonium*

Lac- *Lantana camara*

Oex- *Opuntia exaltata*

Ovul- *Opuntia vulgaris*

Sin -*Solanum incanum*

Tam- *Tagetes minuta*

Cad- *Caesalpinia decapetala*

Ric- *Ricinus communis*

Ofi- *Opuntia ficus-indica*

Arm- *Argemone mexicana*

There were no significant differences in the mean density of invasive and rhino food plants among the four vegetation types ($F_{[3, 691]} = 1.79$, $P = 0.150$). However, there was a significant difference in mean density between invasive and rhino food plants in the forest ($F_{[1, 691]} = 3.1$, $P = 0.04$). The mean densities of the two types of plants in the four vegetation types were as shown in Figure 4.1.

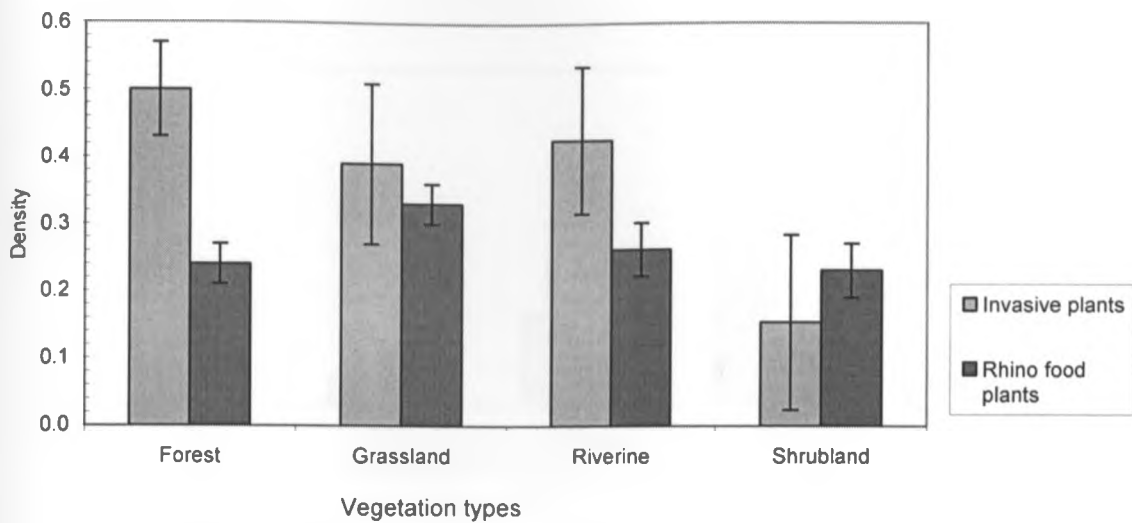


Figure 4.1: Mean densities and standard errors of invasive and rhinoceros food plants in the four vegetation types.

There was no significant difference in the mean density of invasive plants in the quadrats marked out at varying distances from the edge of the roads in the forest ($F_{[3, 10]} = 1.003, P = 0.431$), the same case applied to rhinoceros food plants ($F_{[3, 175]} = 0.295, P = 0.829$). There were also no significant differences in mean densities between invasive and rhino food plants among the quadrats marked out at varying distances along the transects starting from the edge of the road; 0m ($F_{[1, 54]} = 2.394, P = 0.128$), 30m ($F_{[1, 45]} = 0.413, P = 0.524$), 60m ($F_{[1, 42]} = 0.719, P = 0.401$) and 90m ($F_{[1, 44]} = 2.977, P = 0.091$). Figure 4.2 below shows the mean densities of invasive and rhinoceros food plants at varying distances from the edge of roads in the forest:

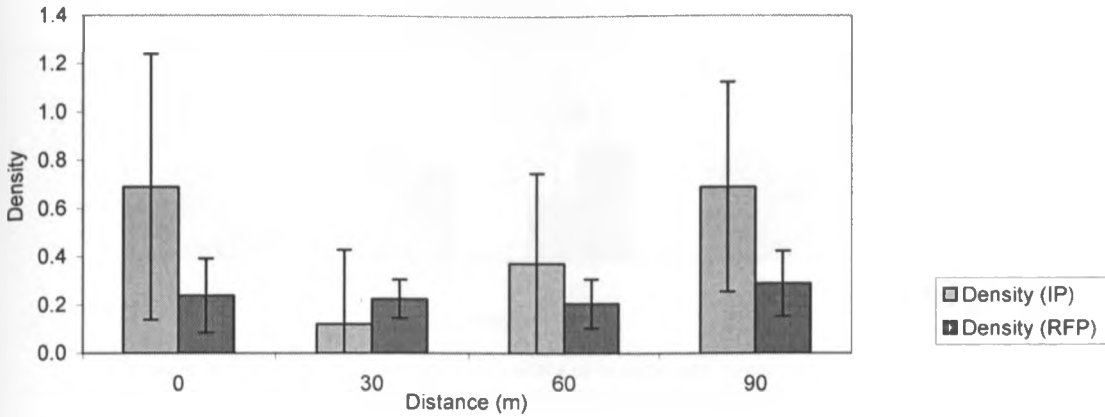


Figure 4.2: Mean densities and standard errors of invasive and rhinoceros food plants at varying distances from the edge of roads in the forest

There was no significant difference in the mean density of invasive plants among quadrats marked out at varying distances from the edge of roads in the grassland ($F_{[3, 43]} = 0.227$, $P = 0.877$, the same case applied to rhino food plants ($F_{[3, 179]} = 1.831$, $P = 0.143$). However, there was a significant difference in the mean density between invasive and rhino food plants among the quadrats marked out at the edge of roads 0m ($F_{[1, 68]} = 4.383$, $P = 0.040$), but not among the other quadrats marked out further away from the edge of roads; 30m ($F_{[1, 66]} = 0.210$, $P = 0.648$), 60m ($F_{[1, 44]} = 0.594$, $P = 0.445$) and 90m ($F_{[1, 44]} = 0.088$, $P = 0.769$). The mean densities of invasive and rhinoceros food plants at varying distances from the edge of roads in the grassland were as shown in Figure 4.3.

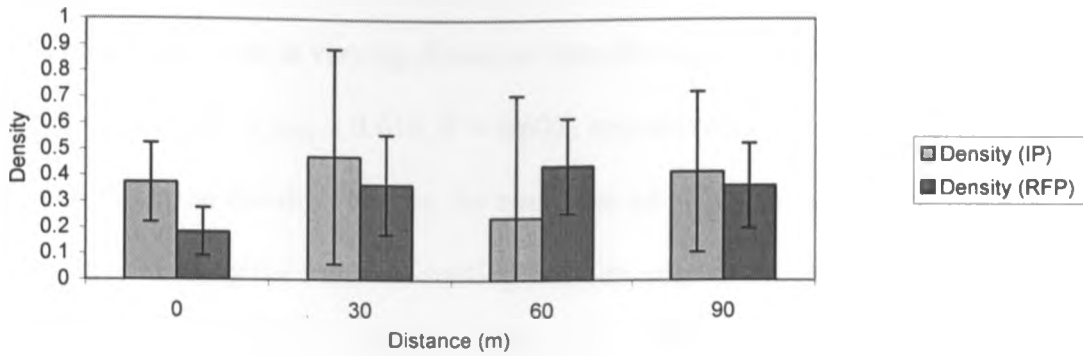


Figure 4.3: Mean densities and standard errors of invasive and rhinoceros food plants at varying distances from the edge of roads in the grassland

There was no significant difference in the mean density of invasive plants among quadrats marked out at varying distances from the edge of rivers in the riverine ($F_{[3, 13]} = 1.203$, $P = 0.348$, the same case applied to rhino food plants ($F_{[3, 111]} = 0.455$, $P = 0.715$). There was a significant difference in the mean density of invasive and rhino food plants among quadrats marked out at 30m from the edge of rivers ($F_{[1, 30]} = 8.388$, $P = 0.007$), but not among the other quadrats: 0m ($F_{[1, 36]} = 0.149$, $P = 0.702$), 60m ($F_{[1, 33]} = 1.568$, $P = 0.219$) and 90m ($F_{[1, 25]} = 1.229$, $P = 0.278$). The mean densities of invasive and rhinoceros food plants in the quadrats marked out at varying distances from the edge of rivers were as shown below in Figure 4.4.

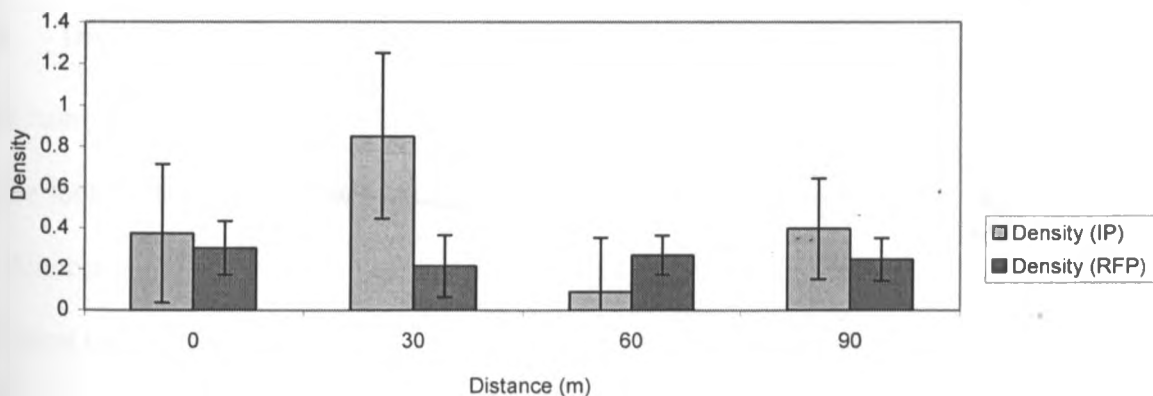


Figure 4.4: Mean densities and standard errors of invasive and rhinoceros food plants at varying distances from the edge of rivers in the riverine

There was no significant difference in the mean density of invasive nor in rhinoceros food plants among quadrats marked out at varying distances from the edge of roads in the shrubland ($F_{[3, 9]} = 0.809, P = 0.520$) and ($F_{[3, 127]} = 0.618, P = 0.605$) respectively. There were also no significant differences in the mean density between the two types of plants among the quadrats marked out at varying distances along the transects starting from the edge of the roads: 0m ($F_{[1, 48]} = 0.001, P = 0.981$), 30m ($F_{[1, 32]} = 0.124, P = 0.727$), 60m ($F_{[1, 30]} = 0.162, P = 0.690$) and 90m ($F_{[1, 26]} = 0.189, P = 0.668$). The mean densities of invasive and rhino food plants in the shrubland at varying distances from the edge of roads were as shown in Figure 4.5.

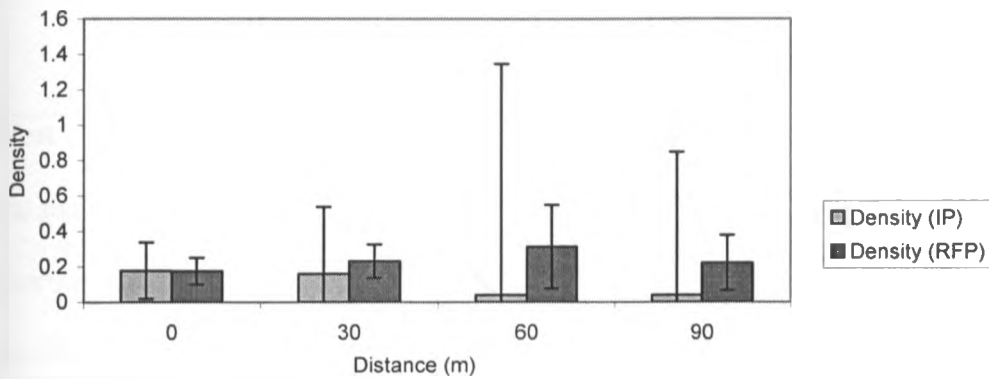


Figure 4.5: Mean densities and standard errors of invasive and rhinoceros food plants at varying distances from the edge of roads in the shrubland

4.2 Diversity of Invasive and Rhino Food Plants

The number of plant species was determined and the diversity of invasive and rhino food plants in the four vegetation types determined and compared using Shannon index. The Shannon index of rhinoceros food plants was highest in the forest, but that of invasive plants lowest. The overall Shannon index was highest in the grassland, which was also the most diverse vegetation in terms of invasive plant species (Tables 4.2 and 4.3).

Table 4.2: Shannon indices of plant species diversity in the four vegetation types

Vegetation type	Shannon index of Rhino food plants	Shannon index of Invasive plants	Overall Shannon index
Forest	5.05	2.54	5.13
Grassland	4.97	3.79	5.22
Riverine	4.44	2.68	4.59
Shrubland	4.71	2.55	4.82

Table 4.3: Number of plant species in the four vegetation types

Vegetation type	Number of rhino food plant species	Number of invasive plant species	Overall number of species
Forest	45	5	50
Grassland	32	9	41
Riverine	30	6	36
Shrubland	36	3	39

4.3 Height of Invasive and Rhino Food Plants

The heights of invasive and rhino food plants in the four vegetation types were compared using ANOVA. There were highly significant differences in the mean heights of invasive and rhino food plants among the four vegetation types ($F_{[3, 3293]} = 22.66, P < 0.01$). The mean heights of invasive and rhinoceros food plants in the different vegetation types were as shown in Figure 4.6, whereas Table 4.4 shows the vegetation types in which mean heights differ significantly.

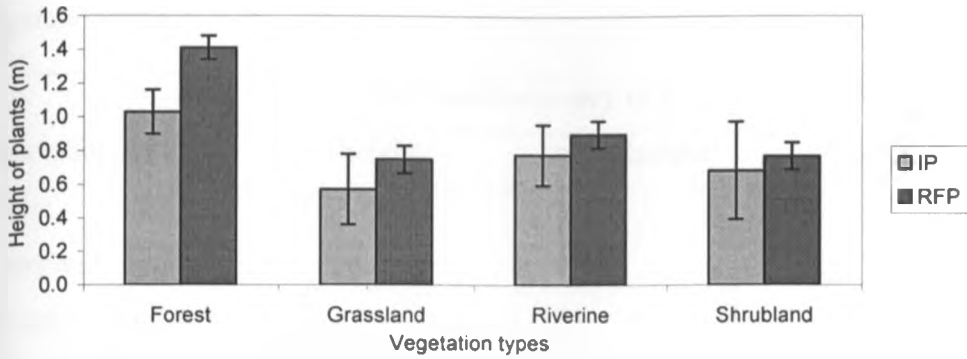


Figure 4.6: Mean heights and standard errors of invasive and rhinoceros food plants per vegetation type

Table 4.4: SNK test results for mean heights of plants in the different vegetation types. The means with different superscripts are significantly different ($P < 0.05$).

Vegetation type	Mean height (m)
Forest	1.36 ^a
Grassland	0.71 ^b
Riverine	0.88 ^c
Shrubland	0.77 ^b

The observed frequencies of rhinoceros food plants whose height was less than or equal to 2m and those whose height was above 2m in the four vegetation types are presented on Table 4.5 and compared with the expected frequencies using chi square.

Table 4.5: The observed frequency of rhino food plants with heights $\leq 2\text{m}$ and $> 2\text{m}$ in the four vegetation types:

Vegetation type	Observed frequency of RFP		Total
	$\leq 2\text{m}$ height	$> 2\text{m}$ height	
Forest	495	104	599
Grassland	907	17	924
Riverine	616	35	651
Shrubland	593	11	604

Chi squared test revealed highly significant differences in frequency between the two categories of rhino food plants in all the vegetation types: Forest $\chi^2_{(1)} = 255.227$, $P < 0.01$; Grassland $\chi^2_{(1)} = 857.251$, $P < 0.01$; Riverine woodland $\chi^2_{(1)} = 518.527$, $P < 0.01$ and Shrubland $\chi^2_{(1)} = 560.801$, $P < 0.01$.

4.4 Effect of Roads and Burning on the Density of Invasive Plants

Roads and burning were the two forms of disturbance considered. The effect of roads on the density of invasive plants was compared in burnt and unburnt areas in the grassland and the riverine woodland. There were no significant differences in the density of invasive plants among the quadrats marked out along transects at different distances from the edge of the roads/river ($F_{[3, 83]} = 1.177$, $P = 0.324$) nor between burnt and unburnt areas ($F_{[1, 83]} = 1.702$, $P = 0.196$). The mean densities of invasive plants at varying distances along transects starting at the road edge in burnt and unburnt areas were as shown in Figure 4.7.

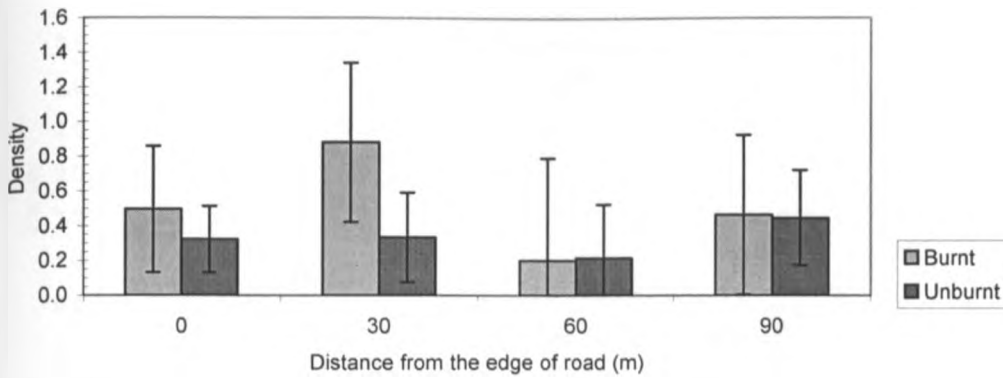


Figure 4.7: Mean densities and standard errors of invasive plants at varying distances from the edge of roads in burnt and unburnt areas

4.5 Soil Chemical Characteristics and Density of Invasive Plants

The density of invasive plants in quadrats at varying distances from the edge of roads/rivers was correlated with pH and the concentration in parts per million (ppm) of nitrogen, phosphorus and potassium.

Pearson's coefficient of correlation (r) for the association between the density of invasive plants and pH was 0.03, whereas the coefficients of correlation for the association between density of invasive plants and concentrations of potassium, phosphorus and nitrogen were 0.28, - 0.21 and - 0.05 respectively. The results of the correlations indicated a weak association between density of invasive plants and the four soil chemical characteristics as shown on Figures 4.8, 4.9, 4.10 and 4.11.

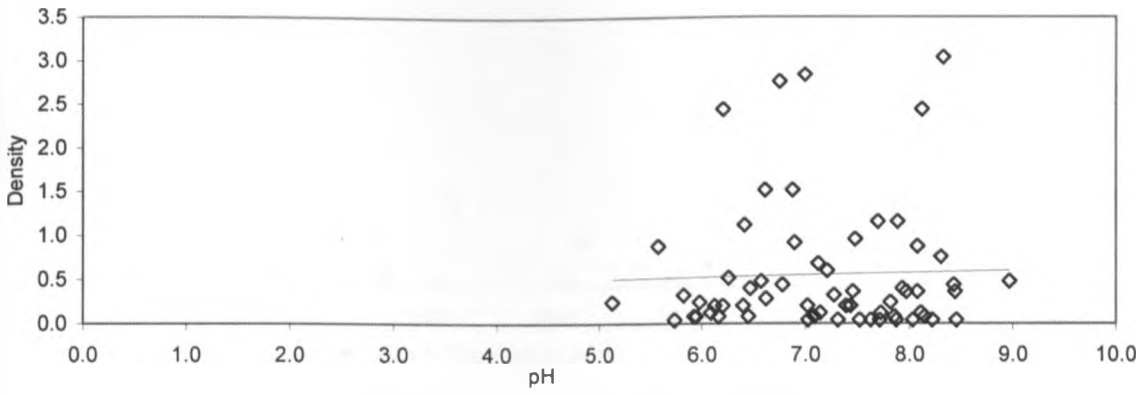


Figure 4.8: Correlation between the mean density of invasive plants and soil pH

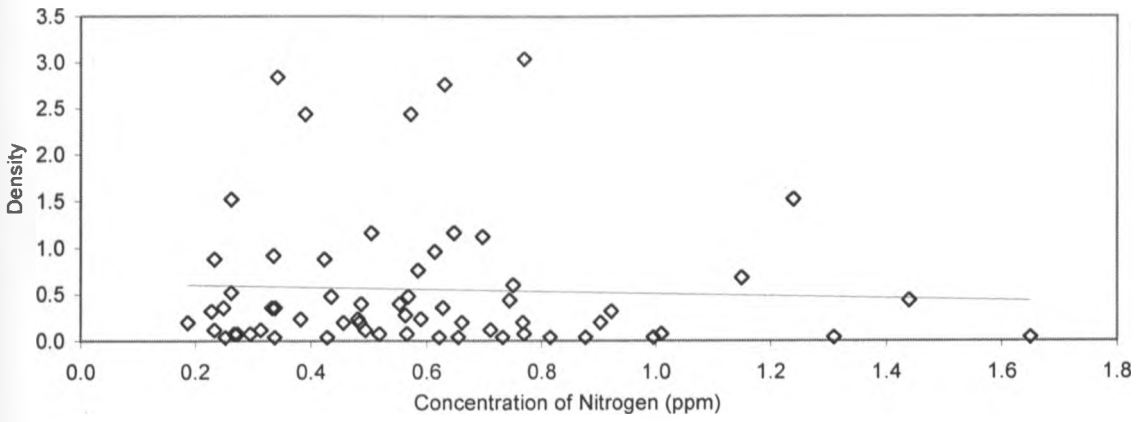


Figure 4.9: Correlation between the mean density of invasive plants and concentration of soil nitrogen

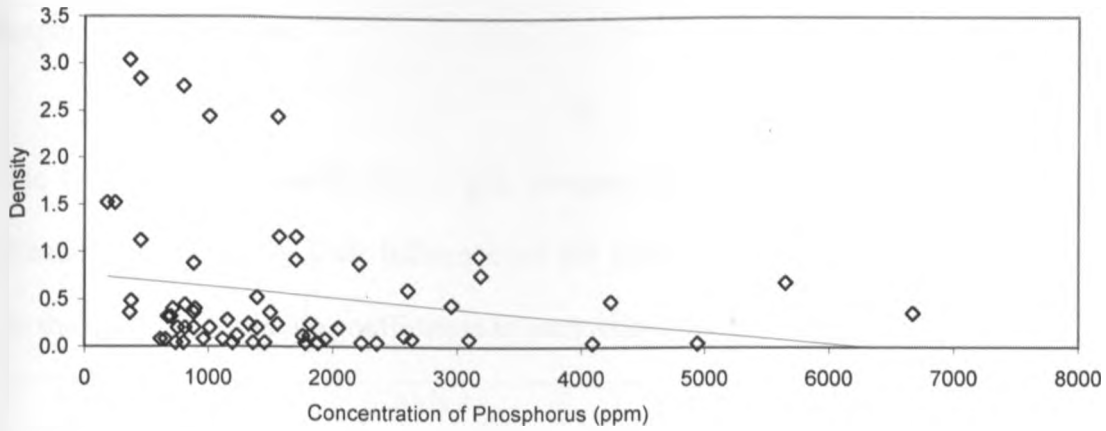


Figure 4.10: Correlation between the mean density of invasive plants and concentration of soil phosphorus

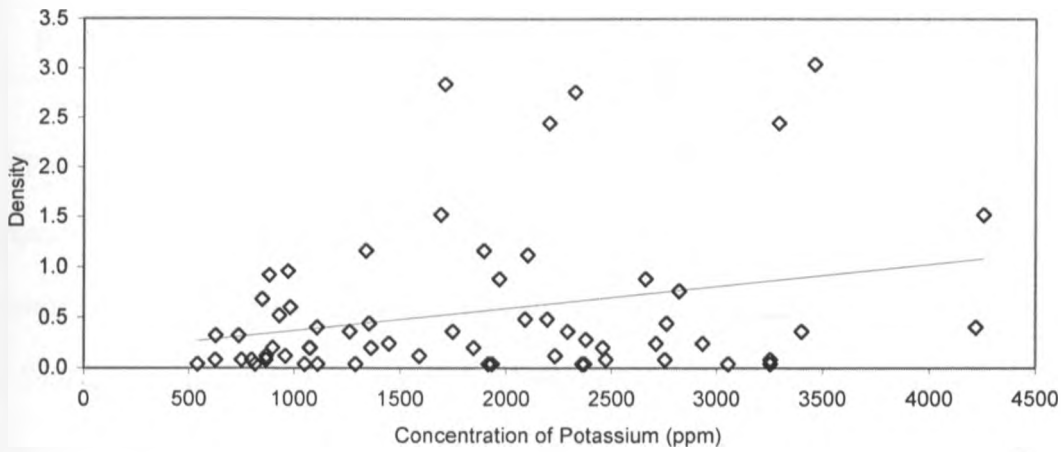


Figure 4.11: Correlation between the mean density of invasive plants and concentration of soil potassium

4.6 Soil Chemical Characteristics and Distribution of Invasive Plant Species

In this section, the species and the environmental variables (soil chemical characteristics) were correlated using CCA to show how well the extracted variation in community (invasive plant species) composition was explained by the soil chemical characteristics. Phosphorus and nitrogen were correlated with the first axis but varied in opposite directions whereas pH and potassium were correlated with the second axis and varied in the same direction (Table 4.6). This

implies that pH and concentration of potassium are not influenced by the concentrations of phosphorus and nitrogen.

Table 4.6: Correlation coefficients of pH, nitrogen, phosphorus and potassium with the first two ordination axes showing their influence on the distribution of invasive plant species. Factors with the highest correlation coefficients to each axis are shown in bold.

Variable	Axis 1	Axis 2
pH	0.23	-0.61
Nitrogen	-0.51	0.05
Phosphorus	0.50	0.04
Potassium	-0.20	-0.54

Phosphorus had a greater influence on the distribution of most of the invasive plant species compared to potassium, nitrogen and pH. Thus, most of the species (*Caesalpinia decapetala*, *Opuntia ficus-indica*, *Tagetes minuta*, *Opuntia exaltata*, *Ricinus communis*, *Argemone mexicana* and *Solanum incanum*) fall near or beyond the tip of the arrow representing phosphorus when a perpendicular line is drawn to it, implying that they are positively correlated and influenced most by this factor (Figure, 4.12). The same point on the ordination diagram represented *Ricinus communis* and *Argemone mexicana* both of which occurred in areas with high phosphorus content but low nitrogen content. The distribution of *Solanum incanum* was influenced by phosphorus more than pH, whereas *Lantana camara* occurred in acidic (low pH) soils. *Datura stramonium* occurred in areas with high potassium content while *Opuntia ficus-indica* occurred in areas with low potassium content. Nitrogen highly influenced the distribution of *Opuntia vulgaris*.

The distribution of the ten invasive plant species as influenced by pH, concentrations of phosphorus, nitrogen and potassium were as shown in figure 4.13 below.

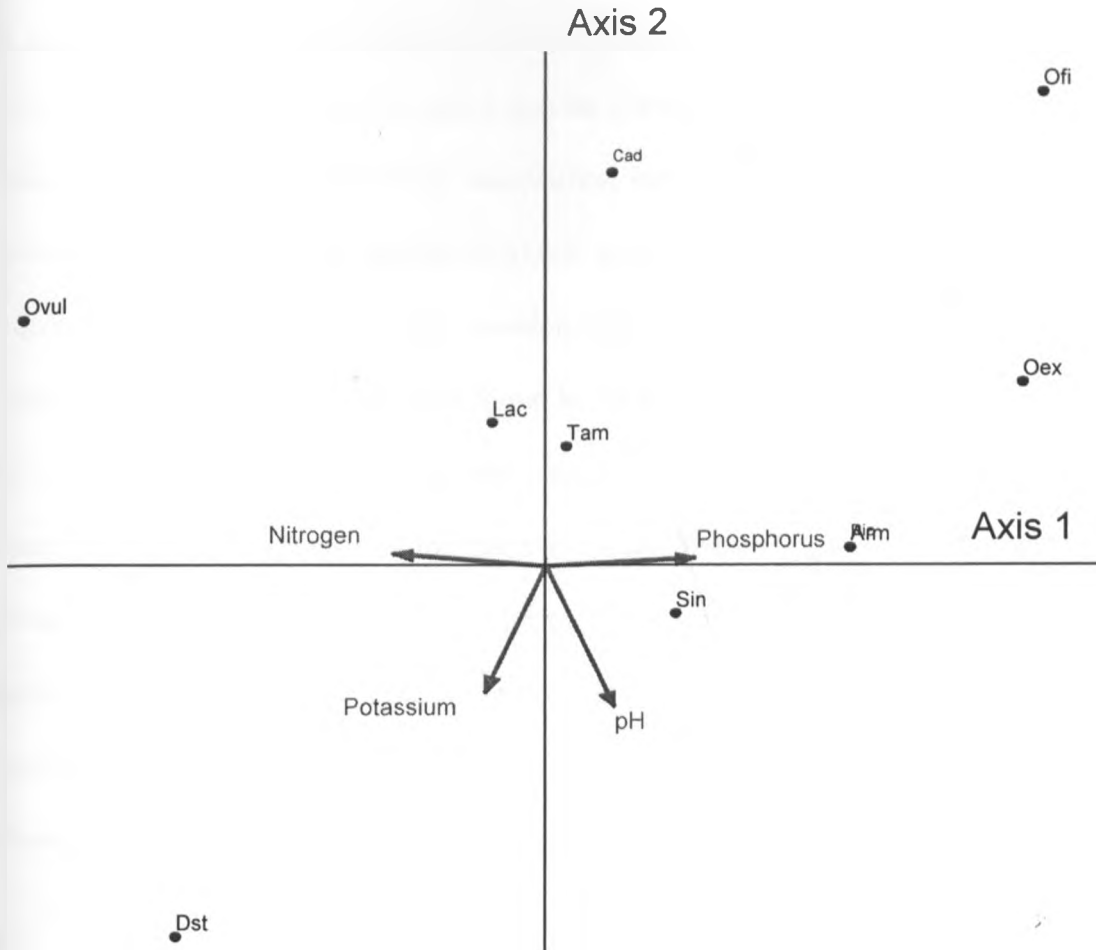


Fig. 4.12: Ordination diagram showing distribution of invasive plant species as influenced by pH, phosphorus, potassium and nitrogen

Key

Dst- *Datura stramonium*

Oex- *Opuntia exaltata*

Sin -*Solanum incanum*

Cad- *Caesalpinia decapetala*

Ofi- *Opuntia ficus-indica*

Lac- *Lantana camara*

Ovul- *Opuntia vulgaris*

Tam- *Tagetes minuta*

Ric- *Ricinus communis*

Arm- *Argemone mexicana*

CHAPTER FIVE

5.0 DISCUSSION

The grassland supported most of the invasive plant species. Probably there was more disturbance as some invasive plants can take advantage of vegetation disturbance and exploit an available niche that is not well utilized by native species (Morgan, 2001). A disturbance that damages the resident vegetation and reduces its competition intensity may free up some resources that an invading species can take advantage of (Davis & Pelsor, 2001). Davis et al. (2000) also proposed a quantitative relationship between invasion and fluctuations in resource availability. *Lantana camara* and *Solanum incanum* were found in all the vegetation types implying that they could thrive in different conditions. *Lantana camara* was the most abundant shrub in the forest, whereas *Solanum incanum* was the most abundant herb in the grassland. Although these two invasive plants were found to double up as rhinoceros food plants, recent studies at Nairobi National Park by Adcock *et al.*, (2007) rated them relatively low as preferred rhinoceros browse. *Lantana camara* was not among the top ten preferred rhino browse in any of the vegetation types whereas *Solanum incanum* was among the top ten preferred rhino browse in the grassland only.

Although there were no significant differences in mean density between invasive and rhinoceros food plants among the four vegetation types, the mean density of invasive plants was significantly higher than that of rhino food plants at 0m i.e. at the edge of roads in the grassland. Roads are highly disturbed areas and such areas are known to be more easily invaded (by native or alien species) than undisturbed areas (Mack *et al.*, 2000). The invasive plants could have reduced the abundance of rhino food plants at the edge of roads by occupying the space which would otherwise have been occupied by rhino food plants. This finding concurs with that of Gelbard & Belnap, 2003 who found that roads could act as conduits for alien invasive plant

dispersal, conducting them further inside into undisturbed areas. The fact that there were no significant differences in mean density between the two types of plants in most of the quadrats does not rule out the potential danger of invasive plants, which are known to be more competitive for resources compared to indigenous plants (Tilman, 1997).

The mean density of invasive plants was also significantly higher than that of rhino food plants at 30m from the edge of rivers in the riverine woodland. The rivers could also have acted as conduits for plant invasion, although if this was the case it was not clear why the mean density of invasive plants was relatively low at the edge of rivers. Probably other environmental variables such as soil texture that were not the focus of this study were responsible for this finding. The high mean density of invasive plants in the quadrats close to the road edges and at 30m from the river edges could have been responsible for the relatively low density of rhinoceros food plants in the same quadrats. This is due to the fact that invasive plants have been known to reduce the abundance and diversity of rhino food plants (Mack *et al.*, 2000; Eiswerth, 2005), probably due to competition for resources such as water, light and nutrients (Tilman, 1997; Davis *et al.*, 2000; Mack *et al.*, 2000).

There was also no significant difference in density of invasive plants between burnt and unburnt areas, implying that burning did not affect the density of invasive plants. This finding contradicts that of Milberg & Lamont (1995) who found that fire enhanced plant invasion along roadsides, and resulted in an overall decrease in the abundance of native species in extensively disturbed areas of southwest Australia.

Although the forest was the most diverse in terms of rhino food plant species, it was the least diverse in terms of invasive plant species. The forest also had the highest mean density of

invasive plants, with *Lantana camara* being the most abundant. These results appear to contradict the findings of a number of ecologists (Tilman, 1993, 1997; Levine, 2000; Kennedy *et al.*, 2002), who found that ecosystems with high species diversity were less prone to invasion because of fewer available niches. However, the results suggest that specific invasive plants could invade ecosystems with high species diversity. This could be possible if such invasive plants are capable of out-competing the plants already established in the said ecosystem. *Lantana camara* has been known to reduce species diversity as well as abundance of species (Sharma *et al.*, 2005b). Although this was not the case in the forest where the diversity of rhino food plants was highest and *Lantana camara* the most abundant invasive plant, one cannot rule out the possibility of reduction of species diversity in years to come.

The grassland had a relatively low diversity of black rhinoceros food plants compared to the forest, but was the most diverse in terms of invasive plant species. It is probable that the high diversity of invasive plants reduced the diversity of rhinoceros food plants in the grassland compared to the forest and resulted to a higher overall diversity of plants in the former. The mean densities of invasive and rhinoceros food plants in the grassland were also relatively high. Although experimental results by Lavorel *et al.*, (1999), indicated no effect of species richness on invasibility, this study seems to concur with that of Stohlgren *et al.*, (1999), who found that ecosystems with high species diversity were more susceptible to invasion. Areas with the highest diversity of native plant species were also found to have the greatest number of invasive alien species in riparian systems of both California and the southern Appalachians respectively (Levine, 2000; Brown & Peet, 2003). A survey of parks and reserves around the world found a positive correlation between the number of native species and the number of exotic species, a number of which were invasive (Lonsdale, 1999). Higher-resolution study of vegetation in the

Rocky Mountains, western deserts, and Great Plains of North America also found that native and invasive alien species richness were positively correlated across sample areas at several levels of sampling resolution (Stohlgren *et al.*, 1998; Stohlgren *et al.*, 2001).

The highly significant differences in the mean height among the four vegetation types was probably due to variation in resources required for plant growth, since there were no significant differences between invasive and rhino food plants among the four vegetation types.

The density of invasive plants slightly increased as the pH and concentration of Potassium increased, but slightly decreased as the concentration of phosphorus and that of nitrogen increased. This means that there was a weak association between the density of invasive plants and the soil chemical characteristics. These results seem to contradict the findings of some researchers like Davies *et al.*, 2000 & Mack *et al.*, 2000, who found that phosphorus and nitrogen affected the growth of invasive plants positively. A study by Owens *et al.*, (2007), found that the abundance of Eurasian watermilfoil (*Myriophyllum spicatum* L.) increased due to phosphorus loading caused by senescence of Curly-leaf pondweed (*Potamogeton crispus* L.) in Lake Shiwano, Wisconsin. A study carried out by Marcia & Anderson (2004) in the United States on effects of nitrogen addition on the invasive grass *Phragmites australis* and a native competitor *Spartina pectinata* indicated that increased nitrogen favored the growth of the invasive grass over its competitor. However, the results of this study indicated a general trend involving all the invasive plants and thus do not indicate the response of an individual invasive plant to variation in concentration of soil nutrients and pH.

Analysis using canonical correspondence indicated that the soil chemical characteristics, especially phosphorus were important in determining the distribution of invasive plants. These soil variables influenced the distribution of individual invasive plants differently, which preferred different levels of pH and concentrations of the soil nutrients. It was not clear whether the concentration of nutrients and pH levels were as a result of the presence of the invasive plants or whether the prevailing levels had influenced the establishment of the plants. This is because it has been established that nutrient dynamics could also be altered as a result of changes in physical and chemical properties of the soil caused by introduction of new species (Cronk & Fuller, 1995; Ehrenfeld, 2001). However, since plant invasions can alter soil properties and impact on the invasibility of ecosystems as well as the invasiveness of species (Ehrenfeld & Scott, 2001), they are a serious threat to biodiversity. It is therefore important to control invasive plant species even if the impacts are not yet obvious so that biodiversity is not driven to extinction.

5.1 Conclusion

A number of invasive plants were identified which potentially threaten the abundance and diversity of rhino food plants. The density of rhino food plants differed between areas with invasive plants compared to those without or with few invasive plants. The significant differences in mean density between invasive and rhino food plants in some quadrats are an indication that the density of invasive plants may be on the increase, especially at the edge of roads. Rivers could also have enhanced invasiveness, although this was not clear since significant differences in mean density of invasive and rhino food plants occurred in quadrats at 30m from the edge of rivers. These findings emphasize the need to eradicate invasive plants as they occupy the habitat that would otherwise have been occupied by rhinoceros food plants and

other indigenous plants. Invasive plants need to be controlled so that they don't reduce the density of rhino food plants due to possible competition for resources. As pointed out by other researchers (Cronk & Fuller 1995; Tilman, 1997), invasive plants can reduce and eventually cause extinction of indigenous flora and fauna.

It was not clear if invasive plants affected the diversity of black rhinoceros food plants in most of the vegetation types. The low diversity of invasive plant species in the forest could have been responsible for the high diversity of rhinoceros food plants in this vegetation. However, since the density of invasive plants was also highest in the forest, the conditions probably favored growth of rhinoceros food plants and specific types of invasive plants. The high diversity of invasive plant species could have been responsible for the relatively low diversity of rhinoceros food plant species in the grassland.

The hypothesis that heights of plants in the four vegetation types differ significantly was proved correct. However, this difference was not due to presence of invasive plants since the differences in mean density of invasive and rhinoceros food plants among the different vegetations were insignificant.

There was no significant difference in the density of invasive plants in burnt areas compared to unburnt areas, implying that burning did not affect the density of invasive plants.

Soil chemical characteristics (pH, phosphorus, potassium and nitrogen) did not affect the density of invasive plants since there was a very weak association between the mean density of invasive

plants and each of the named variables. However, the same variables, especially phosphorus, were found to affect the distribution of invasive plants.

5.2 Recommendations

In order to avoid crisis management that is costly and less promising in terms of expected outcome, experimental work needs to be carried out to respond to the following questions:

1. Do factors such as soil texture, moisture levels and herbivory affect the density of invasive and/or rhino food plants in the park?
2. How does the density of individual invasive species vary with pH and concentrations of phosphorus, nitrogen and potassium?
3. Do invasive plants have any effect on the diversity of rhinoceros food plants?
4. Does the difference in the pH level and concentrations of phosphorus, potassium and nitrogen affect the distribution of invasive plants similarly in the different vegetation types?

The Park management should consider controlling the spread of invasive using mechanical, chemical or biological control methods depending on the type of invasive plant and the extent of invasion. Follow up is critical irrespective of the method employed to avoid wastage of funds and a no-win situation as suggested by Lotter & Clark (2003). As a potential threat to native biological diversity, invasive plants in Nairobi National Park need to be controlled in order to maximize productivity of the black rhinoceros and other browsers.

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APPENDICES

Appendix 1: GPS Coordinates at the start and end of Transects

Vegetation type	X	Y	X1	Y1
Grassland	266817	9845002	266857	9844910
Grassland	254809	9851354	254907	9851338
<i>A. drepanolobium</i> Grassland	261724	9850834	261624	9850830
Grassland	255419	9852718	255428	9852618
Grassland	254139	9848740	254203	9848814
<i>A. Mellifera</i> Grassland	271478	9842080	271464	9841982
<i>A. Mellifera</i> Grassland	272901	9841274	272814	9841222
Forest	254459	9851752	254548	9851712
Shrubland	252330	9847294	252354	9847198
Forest	251945	9847654	251851	9847660
Forest glades	253637	9850210	253625	9850312
Grassland	252536	9846894	252501	9846990
Riverine woodland	257341	9847548	257256	9847594
Forest	251965	9848992	251884	9849030
Forest	254911	9850622	251375	9851140
<i>A. drepanolobium</i> Grassland	264434	9849390	264533	9849406
Forest	254126	9851570	254066	9851504
Riverine woodland	263505	9844772	263480	9844862
Grassland	257669	9851304	257770	9851296
<i>A. drepanolobium</i> Grassland	257710	9853068	257738	9852972
Riverine woodland	269210	9843104	269296	9843178
Shrubland	258412	9848066	258450	9848160
Shrubland	263793	9845104	263694	9845126
Shrubland	258847	9848710	258941	9848746
Shrubland	257135	9850986	257104	9850894
<i>A. drepanolobium</i> Grassland	264238	9848514	264225	9848614
<i>A. drepanolobium</i> Grassland	259470	9853356	259488	9853258
Shrubland	256925	9847854	256948	9847756
Riverine woodland	254075	9847536	254091	9847436
Riverine woodland	257798	9850808	257724	9850734

Where XY is the GPS coordinate at the start of a given transect and X1Y1 is GPS coordinate at the end of the transect.

Appendix 2: Table Showing the family, genus, species and life form of rhino food plants in Nairobi National Park

Family	Plant species	Life Form
Acanthaceae	<i>Justicia whytei</i> S. Moor	Herb
Amaranthaceae	<i>Achyranthes aspera</i> L.	Herb
Anacardiaceae	<i>Rhus natalensis</i> Krauss	Shrub
Apocynaceae	<i>Carissa spinarum</i> (Forssk)	Shrub
Asclepiadaceae	<i>Gomphocarpus semilunatus</i> A. Rich.	Shrub
Asparagaceae	<i>Asparagus africana</i> Lam.	Liana
Balanitaceae	<i>Balanites aegyptica</i> (L.) Delile	Tree
Burseraceae	<i>Commiphora africana</i> (A. Rich.) Engl.	Shrub
Celastraceae	<i>Maytenus senegalensis</i> (Lam.) Exell	Shrub
Compositae	<i>Aspilia mossambicensis</i> (Oliv.) Wild	Shrub
Compositae	<i>Brachylaena huillensis</i> O. Hoffm	Tree
Compositae	<i>Gutenbergia cordifolia</i> Benth.ex Oliv.	Herb
Compositae	<i>Psiadia punctulata</i> (Dc.) Vatke	Shrub
Compositae	<i>Vernonia lasiopus</i> O. Hoffm.	Shrub
Compositae	<i>Microglossa pyrifolia</i> (Lam.) O. Ktze	Shrub
Ebenaceae	<i>Euclea divinarum</i> Hiern.	Tree
Euphorbiaceae	<i>Acalypha fruticosa</i> Forssk.	Shrub
Euphorbiaceae	<i>Croton dichogamus</i> Pax	Shrub
Euphorbiaceae	<i>Croton macrostachyus</i> Delile	Tree
Euphorbiaceae	<i>Croton megalocarpus</i> Hutch	Tree
Euphorbiaceae	<i>Erythrococca bongensis</i> Pax	Shrub
Euphorbiaceae	<i>Euphorbia crotonoides</i> Boiss.	Herb
Euphorbiaceae	<i>Phyllanthus fischeri</i> Pax	Shrub

Euphorbiaceae	<i>Phyllanthus sepialis</i> Mull.Arg.	Shrub
Flacourtiaceae	<i>Dovyalis caffra</i> Warb	Shrub
Flacourtiaceae	<i>Trimeria grandifolia</i> (Burkill.) Sleumer	Shrub
Labiatae	<i>Leonotis nepetifolia</i> (L.) R. Br.	Herb
Labiatae	<i>Leucas grandis</i> Gurke	Herb
Labiatae	<i>Ocimum gratissimum</i> Suave	Herb
Labiatae	<i>Tinnea aethiopica</i> Kotschy ex Hook.f.	Shrub
Leguminosae	<i>Acacia brevispica</i> Harms	Shrub
Leguminosae	<i>Acacia drepanolobium</i> Harms ex Sjostedt	Shrub
Leguminosae	<i>Acacia gerrardi</i> Benth	Tree
Leguminosae	<i>Acacia kirkii</i> Oliv.	Tree
Leguminosae	<i>Acacia mellifera</i> (Vahl) Benth.	Tree
Leguminosae	<i>Acacia senegal</i> (L.) Wild	Tree
Leguminosae	<i>Acacia xanthophloea</i> Benth	Tree
Leguminosae	<i>Aeschynomene schimperi</i> A.Rich.	Herb
Leguminosae	<i>Crotalaria brevidens</i> Benth.	Herb
Leguminosae	<i>Indigofera arrecta</i> A. Rich.	Herb
Leguminosae	<i>Ormocarpum trichocarpum</i> (Taub.) Engl.	Shrub
Leguminosae	<i>Tephrosia hildabrandtii</i> Vatke	Herb
Lythraceae	<i>Nesaea kilimandscharica</i> Koehne	Herb
Malvaceae	<i>Abutilon mauritanum</i> (Jacq.) Sweet	Shrub
Malvaceae	<i>Hibiscus aponeuras</i> Sprague & Hutch	Herb
Malvaceae	<i>Hibiscus calyphyllus</i> Cav.	Shrub
Malvaceae	<i>Hibiscus flavifolius</i> Ulbr.	Herb
Malvaceae	<i>Hibiscus fuscus</i> Garcke	Herb
Malvaceae	<i>Hibiscus micranthus</i> L.f.	Shrub
Malvaceae	<i>Sida tenuicarpa</i> Vollesen	Herb
Malvaceae	<i>Sida ovata</i> Forssk.	Herb

Malvaceae	<i>Sida rhombifolia</i> L.	Herb
Oleaceae	<i>Olea europaea</i> L.	Tree
Papilionaceae	<i>Indigofera schimperi</i> Jaub. & Spach	Herb
Rubiaceae	<i>Pentas parvifolia</i> Hiern.	Shrub
Rutaceae	<i>Clausena anisata</i> (Willd.) Benth	Shrub
Rutaceae	<i>Teclea simplicifolia</i> (Engl.) Verd.	Tree
Solanaceae	<i>Solanum incanum</i> L.	Herb
Sterculiaceae	<i>Dombeya burgessiae</i> Gerr. ex Harv. & Sond.	Shrub
Sterculiaceae	<i>Melhania ovata</i> (Cav.) Spreng.	Herb
Tiliaceae	<i>Grewia bicolor</i> Juss.	Shrub
Tiliaceae	<i>Grewia similis</i> K. Schum.	Shrub
Tiliaceae	<i>Triumfetta brachyceras</i> K. Schum.	Herb
Tiliaceae	<i>Triumfetta rhomboidea</i> Jacq	Shrub
Verbenaceae	<i>Lantana camara</i> L.	Shrub
Verbenaceae	<i>Lantana trifolia</i> L.	Herb
Verbenaceae	<i>Lippia javanica</i> (Burm.f.) Spreng	Shrub
Vitaceae	<i>Cyphostemma lentianum</i> (Volk. & Gilg) Descoigns	Climber

Appendix 3: Table Showing the family, genus, species and life form of invasive plant species in Nairobi National Park

Family	Plant species	Life form
Cactaceae	<i>Opuntia exaltata</i> A. Berger	Shrub
Cactaceae	<i>Opuntia ficus-indica</i> (L.) Mill.	Shrub
Cactaceae	<i>Opuntia vulgaris</i> (L.) Mill.	Shrub
Caesalpinaceae	<i>Caesalpinia decapetala</i> (Roth) Alston	Shrub
Compositae	<i>Tagetes minuta</i> L.	Herb
Euphorbiaceae	<i>Ricinus communis</i> L.	Shrub
Papaveraceae	<i>Argemone mexicana</i> L.	Herb
Solanaceae	<i>Datura stramonium</i> L.	Herb
Solanaceae	<i>Solanum incanum</i> L.	Herb
Verbenaceae	<i>Lantana camara</i> L.	Shrub

Appendix 4: Digestion and Analysis of Soil Samples

Digestion of soil powder and Analysis of Potassium (K)

A soil sample of 2.5g was weighed accurately, placed into a 150ml beaker and 50ml of distilled water added followed by 20ml of Aquaregia (HNO_3 : HCl in the ratio 1:3). The contents of the beaker were digested on a hot plate until reduced to approximately 10ml and allowed to cool. The digested contents were filtered into a separate beaker and the filtrate transferred into a 50ml volumetric flask. Distilled water was added to the mark and the reading taken from the Atomic Absorption Spectrophotometer (AAS) at an analytical wavelength of 760nm for dilute solutions. Since the optimum working range of the machine was 0 – 10ppm, any solution overshooting 10ppm was diluted to fall within the machine working range. The AAS was calibrated using 1ppm and 10ppm potassium solutions.

Digestion of Soil Powder and Analysis of Phosphorus (P)

A soil sample of 1g was weighed accurately, transferred into a 150ml beaker followed by addition of 50ml of distilled water, 5ml of HNO_3 and 1ml of H_2SO_4 . Digestion was allowed to take place on a hot plate until the contents of the beaker were reduced to 2ml. The contents of the beaker were allowed to cool after which 20ml of distilled water was added. The pH was then regulated to 6.5- 7.5 with 1M NaOH using a pH meter. If the pH exceeded the range it was reduced with HCl and H_2O in the ratio 1:1 (pH was regulated to allow maximum formation and maintenance of constant Phospho-molybdivanadate complex which absorbed the radiation at 430nm). The resultant more or less neutral mixture with digested soil sample was then transferred into a 100ml volumetric flask and topped up to the mark with distilled water. Digested samples (10ml), blank and standard solutions were pipetted separately into 100ml

beakers. Molybdivanadate solution (10ml) was added into each beaker followed by 25ml of distilled water after which the contents of the three beakers were mixed and allowed to stand for at least 10 minutes. The % transmittance was measured using the visible Spectrophotometer for each solution at 430nm, using reagent blank as the reference blank solution. The transmittance of the blank was 100% while that of the standard ranged between 50% and 60%.

Transmittance was converted to absorbance using a conversion table then the concentration of the phosphorus in the soil sample was calculated in mg per liter using the formula below:

$$\text{Concentration of phosphorus in sample} = \frac{\text{Absorbance of sample} \times 25 \times 100 \times 1000}{\text{Absorbance of standard} \times 10 \times 50} \text{ mg/l}$$

Where 25 = Concentration of the standard in mg/l (parts per million or ppm)

10 = Amount of standard pipetted

$\frac{100}{50}$ = Dilution factor

Digestion of Soil Powder and Analysis of Nitrogen (N)

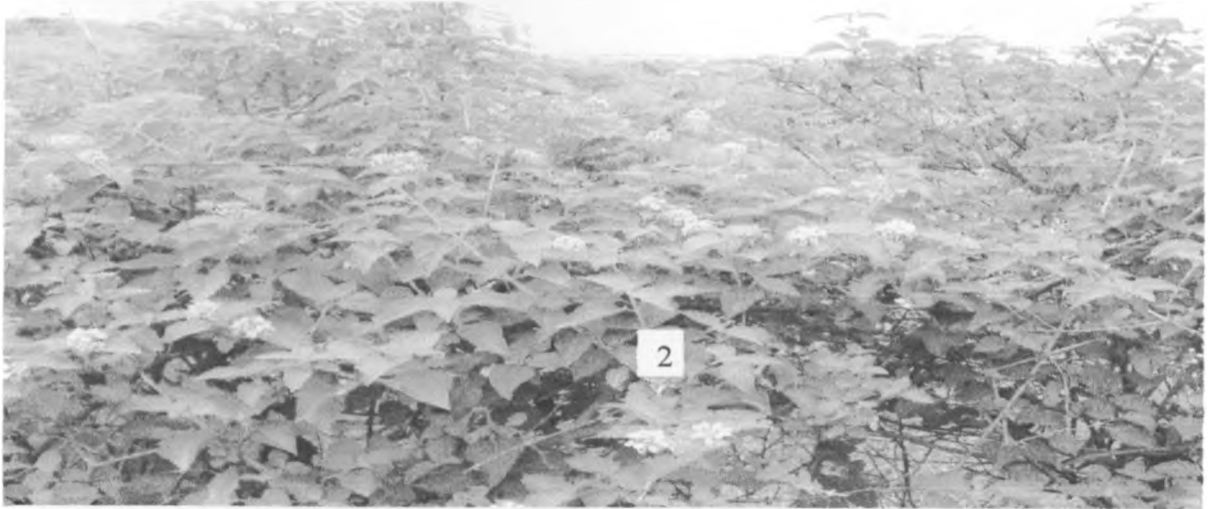
A soil sample of 2g was weighed accurately, placed in 150ml beaker followed by addition of 100ml of distilled water. The contents were mixed thoroughly and the mixture filtered to obtain a 50ml filtrate. A Nitrate buffer amounting to 10ml was added to arrest any chemical activity and maintain a constant atmosphere. Standards of 1ppm and 10ppm were prepared from stock standard solutions and used to calibrate the Nitrate meter with the help of selective NO_3^- electrode. A volume of 50ml of the 1ppm and 10ppm were measured separately and placed into 150ml beakers after which 10ml of Nitrate buffer was added into each to calibrate the Nitrate meter. The soil sample reading was then taken using the calibrated meter.

Determination of pH

A soil sample of 10g was weighed accurately and transferred into a 100ml beaker. Distilled water amounting to 25ml was added and the mixture stirred for 5 minutes. The contents of the beaker were covered with a cover glass and allowed to stand overnight. The pH was then determined using a pH meter.

Appendix 5: Photos of Invasive Plant Species Identified at Nairobi National Park

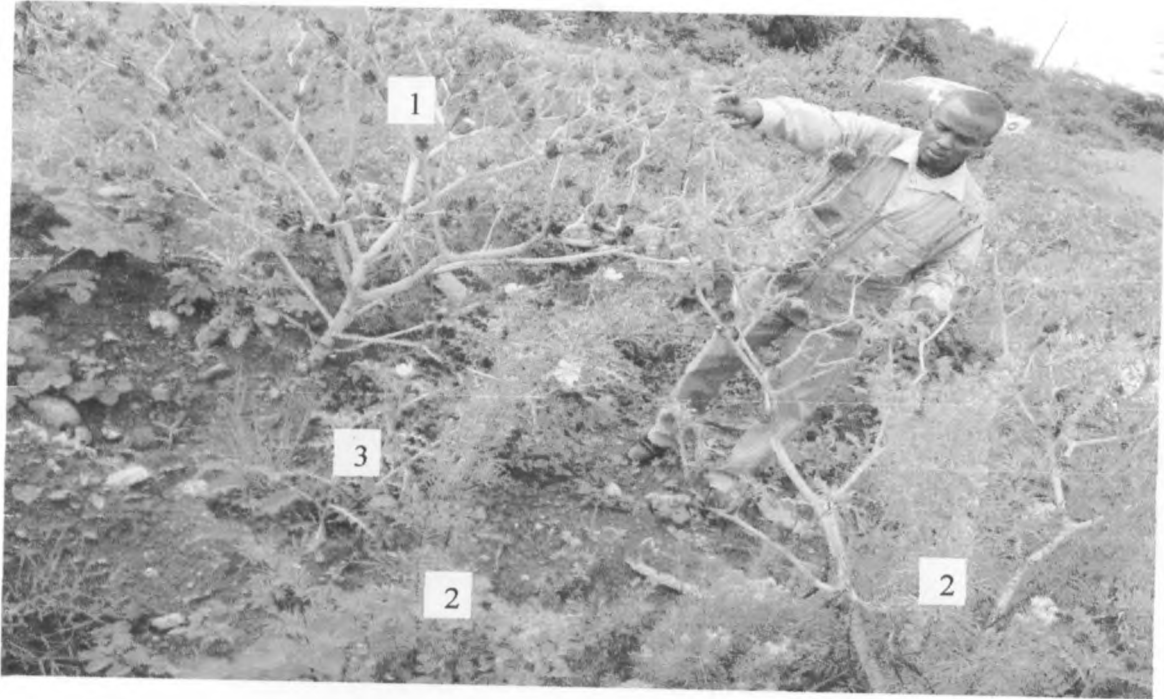
Lantana camara



1. *Opuntia exaltata* growing together with 2. *Lantana camara*



1. Mature *Datura stramonium*, 2. *Tagetes minuta* and 3. *Argemone mexicana* plants



A young *Datura stramonium* plant



1. *Opuntia vulgaris* and 2. *Lantana camara*



Opuntia ficus-indica



Caesalpinia decapetala



Solanum incanum





Ricinus communis