SPATIAL DISTRIBUTION OF *Opuntia stricta (Haworth)* IN TSAVO EAST NATIONAL PARK, KENYA

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university or for any other award.

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We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

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DEDICATION

This thesis is dedicated to all National Parks in Kenya which will help in the success of the tourism industry which is premises in economic growth and development. I also dedicate this work to my beloved family.

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ACRONYMS AND ABBREVIATIONS

ASAL	Arid and Semi-Arid Lands
SAL	Semi-Arid Lands
TENP	Tsavo East National Park
GPS	Geographical Positioning System
UTM	Universal Transverse Mercator Coordinate System
GIS	Geographic Information System
KWS	Kenya Wildlife Service
KNBS	Kenya National Bureau of Statistics
PPM	Process Performance Models
IAS	Invasive Alien Species
CAM	Crassulacean Acid Metabolism
CABI	Common Wealth Agricultural Bureau
CBD	Convention on Biological Diversity
IUCN	International Union for Conservation of Nature
ISSG	Invasive Species Specialist Group
PIER	Pacific Island Ecosystem at Risk
GISP	Global Invasive Species Programme
GISD	Global Invasive Species Database
ANOVA	Analysis of variance

ABSTRACT

Kenya has experienced biological invasions some of which are considered to have significant consequences on the socio-economic status of affected communities. At the ecosystem level, they change community structure and composition. Available data on invasive species in the East African region shows that 34 different species of invasive plants have invaded Kenya. Notable examples of invasive species include *Opuntia stricta* (Haw) and water hyacinth (*Eichhornia crassipes*). This research was aimed at assessing the impact of the invasive *O. stricta* on other plant species and wildlife in the Tsavo East National Park, Kenya (TENP). The study area was divided into twelve transects which was 2km long and ten quadrats each 5m by 5m established systematically along each transect. Data on *Opuntia stricta* coverage, woody plants, dung of elephant to denote their presence and soil samples was collected in each quadrat. ANOVA was conducted on *Opuntia stricta* coverage and confirmed that its distribution differed significantly per the sampled transects. Correlation between *Opuntia stricta* and soil chemical composition, elephant distribution and presence of woody plants was carried out. Among the soil chemical composition investigated, phosphates negatively correlated with *O. stricta* cover at a significance level of p=0.002 for α =5%. Sodium amount and *O. stricta* cover were found to have a positive correlation at a significance level of P=0.039 for α= 5%. A positive correlation between the presence of elephants and *O. stricta* percentage cover was significant with r=0.37 and P=0.000 at α=5%. *O. stricta* cover and woody plant species had an insignificant positive correlation with P =0.177 at $\alpha = 5\%$. Findings of this study are crucial in any strategies adopted to guide in the control of rapid spread of *O. stricta* in Tsavo East National Park and other similar ecosystems.

CHAPTER ONE

1 INTRODUCTION

1.1 Background of the study

Invasive Alien Species (IAS) are among the main threats contributing to the loss of biodiversity (Arne Witt, 2016). These plants have a broader range of tolerances (a bigger bioclimatic envelope) than native species hence are highly adaptable (Ivens, 1989). They spread into native ecosystems, displacing indigenous plants and creating an ecological imbalance between grasses and shrubs in natural and agro-ecosystems (Pimentel, 2002). This imbalance consequently affects the overall structure and functioning of these ecosystems by bringing about changes in species composition, dominant life forms, nutrient cycling, hydrology and decomposition (Oba *et al.,* 2000).

Opuntia stricta (var *stricta),* is one of the world's most destructive invasive alien plant species with a significant threat to conservation of wildlife and agricultural production in many parts of the world (Bright, 1998). Three species of *Opuntia* (*O. monacantha*, *O. ficus-indica*, *O. stricta*) were introduced in Kenya by the British colonial administration in the 1950's (Strum *et al.,* 2015). Of these cactaceae, *O. stricta* has been spreading, outcompeting and displacing native plants and precluding grazing, browsing animals and local people in Laikipia and driving Maasai pastoralists away from their land (Arne Witt, 2016).

Tsavo East National Park (TENP) supports both a high species diversity and high populations of wildlife animals including the `Big Five` and the endangered Hilora antelope. Its capacity to support such a high diversity is slowly being undermined by the rapid spread of *O. stricta* in the park. This poses a threat to wildlife survival due to reduced forage resources since this invasive plant species adapts well to its colonized environment out-competing and eventually eliminating indigenous species (Githae, 2018).

Due to the extensive spread of *O. stricta* in the park, its management remains a priority. There are challenges however with the main obstacles to being the limited understanding of the mechanisms of invasion in TENP (Pyseke *et al.,* 2008) and limited data on how and why the distribution of *O. stricta* changes over time (Fox *et al.,* 2009). In order to prioritize control efforts, there is need to establish the spatial distribution and abundance of *O. stricta* within the TENP as an initial step towards the development of a management strategy.

1.2 Problem Statement

Most of the Kenya`s National Parks, Reserves and other tourism infrastructure are located in rangelands in Arid and Semi-Arid Lands (GOK, 2005). They are important natural landscapes in the country which support the country’s wildlife resources. A paradigm shift in the production systems on Kenya's rangelands has been observed since the mid-1970s. These include changes from extensive farming systems to more intensive agro-pastoral system, competition between wildlife conservation and other land uses and proliferation of human settlement (Mohammed, 2007). These changes in addition to climate change will add a new dimension to wildlife conservation. It’s therefore imperative that range conditions and productivity of the current wildlife conservation areas be enhanced.

TENP is changing rapidly due to *O. stricta* invasion (Witt. ABR, 2017) negatively impacting on the survival of wildlife. According to Llewellyn *et al*. (2008), effective management of plant invasions requires an accurate spatial data on the overall distribution within an area, patterns of presence/absence and abundance across the area and coexistence with other species. Such data is crucial for formulating management interventions, setting realistic goals and monitoring the success of control operations. There's limited information on the occurrence, distribution, the intensity of invasion of *Opuntia stricta*, animal species which spread the invasive plant, inter specific association between *Opuntia stricta* and woody plants and its management in Kenya. This information is critical in reclaiming and the restoration of the environmental integrity of the TENP. Lack of this information may contribute to reluctance by various stakeholders to participate in the effective management of this threat. There is need for both basic and applied research to address the control and management of this invasive plant species.

1.3 Research Questions

The study was guided by the following research questions:

i. How is *O. stricta* distributed in Tsavo East National Park?
ii. Do soil chemical compositions determine the distribution of *O. stricta*?
iii. Which plant species are associated with *O. stricta*?
iv. Does the distribution of *O. stricta* correlate with presence of elephants?

1.4 Hypotheses

The following hypotheses guided the study:

i. There is no pattern of *O. stricta* distribution in TENP.
ii. There is no significant relationship between soil chemical composition and *O. stricta* prevalence in TENP.
iii. There is no significant relationship between other plant species and *O.stricta*.

iv. There is no significant relationship between *O.stricta* and elephant presence in TENP.

1.5 Objectives of the Study

1.5.1 General Objective

The main purpose of the study was to investigate spatial distribution of *Opuntia stricta* in Tsavo East National Park and establish its relationship with soil chemical composition, presence of other woody plants and presence of elephants.

1.5.2 Specific Objectives

The following objectives guided the study:

i. Establish the distribution of *O. stricta* in TENP.

ii. Assess the effects of soil chemical composition on the distribution of *O. stricta* in TENP.

iii. Determine the inter-specific associations between *O. stricta* and other woody plant species in TENP.

iv. Determine the relationship between the distribution of *O. stricta* and presence of elephants in TENP.

1.6 Justification of the Study

The influx of invasive species in protected natural ecosystems represents the second greatest threat to biodiversity after habitat infringement (Vitousek *et al.,* 1996; Lonsdale, 1999; Mack *et al.,* 2000). Invasive plant species have a great reproductive capacity in addition to their ability to disperse rapidly over a large area (Richardson, and Pysek, 2001). These species out-compete indigenous species and alter the functioning of an ecosystem with estimated economic losses of up to billions of USD (Wilcove *et al*., 1998; Yurkonis *et al.*, 2005).

Despite having no forage value, *O stricta* is spreading fast in the TENP while replacing forage species that are important to wildlife. This invasion should be controlled since the park is an important landscape in Kenya for wildlife conservation. Maintenance of its ecological integrity, processes and functions is key to its ability to support viable and diverse wildlife populations. There is need for data on spatial distribution and abundance of *O. stricta* in relation to soil chemical factors, presence of elephants and woody species which co-occur with *O. stricta*. This data is essential in the management of *O. stricta* within the TENP and the Tsavo eco-region as a whole. The information may also help in the development of management strategies for other invasive plant species.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Invasive Plant Species

Exotic invasive species pose a serious threat to the health and sustainability of rangeland ecosystems. These plant species are ranked as the second greatest threat to biodiversity after habitat destruction (CBD, 2005; Baillie *et al.*, 2010) and number one in Island nations (Mack, 2000). The Convention on Biodiversity (CBD) defines invasive species as ‘’any foreign species that threatens the balance of an ecosystem through its introduction and proliferation’’ (Born, 2004). They become invasive when they are introduced to new areas beyond their native ranges, either accidentally or deliberately where they survive, reproduce, and spread causing negative effects on local biodiversity (Tu, 2009).

Adequate evidence exists which shows that invasive plant species perceived to be a major threat to wild ecosystems globally are of great continental concern especially in arid and semi-arid parts of Africa, Asia, Australia and North America (Davies and Svejcar, 2008; Davies, 2011). Intrusion by invasive species is likely to cause extinction of indigenous species as well as complete alterations to habitats and biodiversity (Chornesky and Randall, 2003). Exotic invasive plant species have been linked to biodiversity loss (CBD, 2007) and alteration to ecological processes such as water, nutrient, and energy cycling, thus completely changing how ecosystems function.

In Lake Nakuru National Park, invasive plants were found to affect forage production by limiting, through effective competition, the availability of growth aspects such as light, water, temperature and nutrients (Mwangi and Western, 1998; Brent and Cushman, 2007). It’s estimated that there are over 751 invasive trees and shrub species globally (Rejm’anek and Richardson, 2013). These biological invasions are a major component of global change as they cause negative impacts on biodiversity, ecosystem services and human well-being (Pimentel, 2002; Simberloff *et al.*, 2013).

2.2 Invasive Species in Kenya and their Impact on Terrestrial Ecosystems

The World Conservation Union identified 35 invasive alien species in Kenya out of which nine were plants (IUCN/SSC/ISSG, 2004). Major invasive plant species in Kenya include the water hyacinth (*Eichhornia crassipes*), water fern (*Salvinia molesta*), wild garlic (*Allium vineale*), prickly pear (*Opuntia species*.), mexican marigold (*Tagetes minuta*), *Lantana camara* and morning glory (*Ipomea pp*) (Gichua *et al.*, 2013).

In the Global Invasive Species Database (GISD), *Opuntia stricta* is listed among the top 100 world’s worst invasive alien species (Lowe *et al.*, 2000). *Opuntia stricta* forms dense stands that impedes movement and access across the landscape and is believed to transform the savannas and arid grasslands (Henderson, 2001).

2.3 Description and Biology of *Opuntia stricta*

Opuntia is the most diverse genus of plant family cactaceae consisting of 202 species compared to an average of 20 species for other genera (Reyes-Agüero *et al.*, 2006). They exhibit various adaptation strategies that include protective epidermis covered by a thick waxy waterproof cuticle and a shallow root system (Sudzuki Hills, 1995). They also have fleshy stem to store water, wide spread roots to absorb water and Crassulacean Acid Metabolism (CAM) which is a photosynthetic adaptation to periodic drought that allows gaseous exchange to take place at night when air temperatures are cooler and water vapor pressure deficits are lower. The efficient water utilization and stress tolerance characteristic of *Opuntia* makes it efficient to invade the semi-arid open rangelands (Osmond *et al.*, 2008).

Opuntia stricta is a perennial succulent shrub (Pier, 2003) with an erect or sprawling structure of up to 2m in height. The plant propagates by both seeds and fleshy cladodes which become dislodged from the plant and produce roots (CABI, 2011). Cladodes are dispersed by becoming attached to animals, footwear, vehicles as well as by flood waters and in dumped garden waste. *Opuntia stricta* produces lemon yellow-flowers in the spring and summer that develop into purple-red fruits (Benson, 1982). These fruits are eaten by various animals like birds and rodents which disperse the seeds in their droppings.

The base stem-segments sometimes are thickened and trunk-forming with elliptic to obovate upper segments which are 10-35cm long, 7-20cm wide, glabrous, dull green to grey-green (Pier, 2003). The leaves are conical measuring 4.5-6.0mm long, spines are up to 11 per areole measuring 1-6cm long and are yellow to brown in colour while glochids are yellow. Flowers are 5.0-6.5cm in diameter and petiole lobes spreading. Fruits are purple, obovoid (Figure 2.1) with depressed apex and measure 4-6cm long and 2.5-4.0cm diameter. It's borne on the modified succulent stems, the cladodes that have spines and hairy features (Ramadan and Morsel, 2003; Wright and Setzer, 2013). The seeds are 4-5mm long and are pale brown in colour (George, 1984). The cladodes are unpalatable having spines and have a dense, low growing form.

Figure 2.1: Diagram of *Opuntia stricta*

The only commercial use recorded so far comes from extraction of betacyanine for production of fruit juice (Merin *et al*., 1987). Due to its impact and mechanisms of competition as well as rapid growth and production of spines, it's highly likely to be transported internationally and thus become costly to control. In addition, animals tend to avoid infested areas and so the land becomes less productive for livestock farming thus increasing grazing pressure on uninfected areas (Larson, 2004).

2.4 Origin and Distribution of *O. stricta*

Opuntia stricta is native to North and Central America (Pier, 2003). It has been naturalized in several African countries, India and Sri Lanka in Asia, Yemen and Saudi Arabia in the Middle East, France, Italy, Spain, Galápagos Islands, Cuba, Madagascar and Australia (CABI, 2016). It is also found in many other regions around the world including the Canary Islands, the Mediterranean, Peninsula, and St. Kitts and Nevis (Weber, 2003; Novoa *et al.*, 2015; Strum *et al.*, 2015).

Initially, it was introduced to many regions for both aesthetic and hedging purposes (Foxcroft *et al.*, 2008). However, it has invaded cultivation areas and spread to even conservation lands (Vila *et al.*, 2003; Foxcroft *et al.*, 2004), rangelands (Strum *et al.*, 2015) and agricultural areas(Vila and Gimeno, 2003) causing a range of negative impacts that have not been systematically quantified (CABI, 2016).

Countries that have reported serious invasions include Australia, South Africa, Namibia (Henderson, 2001), India, Madagascar (Middleton, 1999) and recently Spain and some North African Countries (Le Houerou, 2002). There is a possibility that it has been naturalized in many other countries in Africa such as Eritrea, Ethiopia, Somalia and Zimbabwe; and in Asia, Pakistan and Thailand. Due to deforestation, erosion and overgrazing in South Africa and Namibia, the species has become invasive with large infestations being reported in dry savanna bushels (Henderson, 2001).

Selective grazing allows *O. stricta* to colonize degraded sites rapidly, become established in abundance thereby preventing other plants from re-establishing (Hobbs and Huenneke, 1992). Change in land use such as a shift to intensive livestock grazing in the Southern parts of TENP has led to its invasion (Pemberton and Liu, 2007). This may be attributed to intensive grazing.

2.5 Distribution and Spread of *Opuntia stricta* in Kenya

O. stricta was introduced to East Africa and in Kenya during the colonial times in the 1950s as an ornamental plant capable of adapting in arid regions. Since then, the plant has colonized thousands of acres of fragile rangelands in northern Kenya, putting at risk the livelihood of animal herders (Lazarides *et al.,* 1997). It thrives in arid and semi-arid regions making valuable pasture species inaccessible to livestock while blocking access to water and other resources (CABI, 2017).

After its introduction in Kenya, it has spread in Northern part of the country across the high altitude semi-arid savanna on the Laikipia plateau where it’s abundant. The region is comprised of valuable commercial rangelands and conservation areas (Kunyaga *et al.*, 2009). In addition, it has naturalized Tsavo East National Park (TENP) and is estimated to have invaded about 2000 km^2 (Ross *et al.*, 2017). Other infested parts of the country include along the Coast, Rift Valley, Nyanza regions and Eastern shore of Lake Victoria (Mathews and Brand, 2004; Chenje and Katerere, 2006).

Opuntia stricta invasion was not a challenge in Kenya until in the late 1990s when rapid deterioration of the rangeland condition created a perfect opportunity for its rapid spread (Bradley *et al*., 2010). This has curtailed pasture production posing a major threat to livestock production and wildlife conservation in Arid and Semi-arid regions of Kenya. Munyasi (2004) observed that degraded areas were more likely to be dominated by invasive plant species than the bushed or wooded areas. Strum *et al*. (2015) also demonstrated the role of range degradation, reduced ground vegetation cover and suppressed herb layer leading to growth by *O. stricta* in Laikipia Plateau. It has also been documented in Kenya (Western, 2009; Kioko *et al*., 2012; Groom and Western, 2013; Kaye-Zwiebel and King, 2014).

According to Strum *et al.* (2015), the invasion of *O. stricta* into Laikipia Plateau is as a result of land use primarily sedentarization by pastoralists due to overgrazing producing an ecological state transition to degraded rangelands. This has created an opportunity for the invasion of *O. stricta*. There is a strong correlation between intensity of livestock grazing and distribution of both native and non-native species of

O. stricta (Pemberton and Liu, 2007). Selective feeding of palatable plant species by predominantly grazer herbivores in open grasslands led to increased invasion of *O. stricta* which is less palatable (Hobbs and Huenneke, 1992; Mwangi and Western 1998).

Being an arid adapted species, it thrives well in low resource conditions thus allowing it to out compete native species during drought. In addition, it's highly successful because it has two modes of reproduction (Padrón *et al.,* 2011). Sexual (through seed dispersal agents such as mammals and birds) and asexual (if the plant paddles drop on the ground can root and grow into new plants) (Strum *et al.,* 2015). It produces fruits throughout the year that are consumed by animals while its seeds are viable for up to 15 years (Mandujno *et al.,* 2001).

In Kenya`s North-Eastern Laikipia Plateau including Dol Dol and Ol Jogi ranches, the dispersal agents of *O. stricta* were found to be elephants, baboons, man, and livestock (Witt, 2017). Elephants were found to carry *O. stricta* seeds furthest; over 53 km from the point of origin (Strum *et al.,* 2015). Similarly, in South Africa, baboons and elephants which feed extensively on the ripe fruits have contributed to the rapid dispersal of the plant in the Kruger National Park (Hoffmann *et al*., 1998). Seed dispersal by baboons and elephants through faecal matter increases germination rate since the seeds are scarified when passing through animal's digestive system (Kunz and Linsenmair, 2008).

2.6 Invasive Species in Protected Areas

The global strategies to protect biodiversity and conserve a representative sample of the earth's ecosystems are establishment and management of a network of protected areas (Arne *et al.*, 2017). Invasive non-natives get access into protected areas via seeds and plant parts that are brought into these areas by wildlife, wind, water and humans. Invasive plants grow fast once established outside protected areas and spread to undisturbed as well as disturbed areas when inside these areas (National Park Service, 1996). Additionally, they pose significant threats to protected ecosystems worldwide (Foxcroft *et al*., 2013a). De Poorter (2007) identified 487 protected areas worldwide where invasive alien species were recorded as a threat.

The ecological collapse of invaded conservation areas is currently a threat in many African countries such as Ghana, Uganda, Zambia and other Southern African countries (Arne *et al*, 2018). Wildlife based tourism in these countries have been adversely affected since the invasive plants cause diminished wildlife habitats and cause reduced species diversity of native biota thus creating environmental conditions not suitable to sustain wildlife populations. It has been observed that obstructive thickets of invasive alien plants make wildlife viewing difficult causing some national parks and reserves to lose their appeal. The resultant economic implications are incalculable (Gordon and Arne, 2013).

Arne *et al., (*2017) identified six invasive plant species that pose the highest risk to Serengeti-Mara ecosystems as *Parthenium hysterophorus, Opuntia stricta, Tithonia diversifolia, Lantana camara, Chromolaena odorata* and *Prosopis juliflora*. A survey in these ecosystems found that *Opuntia stricta* and *Caesalpinia decapetala* are grown as living fences in villages within and adjacent to the areas from where they have established population of the natural vegetation (Arne *et al.*, 2016**)**.

In Kenya, *Opuntia* cacti are ubiquitous in many of the protected areas. TENP has been invaded by *O. stricta* where it occupies more than 2000 hectares of terrain along the park's South-Eastern boundary and is spreading in adjacent areas as well (Gordon and Arne, 2013). *Parthenium* weed has invaded Nairobi National Park and the Maasai Mara National Reserve in Kenya with the latter also having been invaded by *Tithonia diversifolia* (Gordon and Arne, 2013).

In Lake Nakuru National Park, the most dominant invasive plants, *Solanum incanum, Lippia javanica, Ocimum gratissimum, Sida schimperiana, Lantana trifolia, Achyranthes aspera* and *Urtica massaica*, have been identified (Ng'weno *et al.,* 2010). *Lantana camara* (Verbeinaceae), one of the most serious invasive plant species has colonized large areas of Nairobi National Park (Simba *et al.,* 2013) as well as Karura forest (KFS, 2010). However, in Africa, with the notable exception of South Africa, little is known about invasive alien species across the continent's protected areas (Foxcroft *et al.*, 2013b).

Although *O. stricta'*s effect on mammals may be positive in the short-term**,** long-term interactions between introduced plants and native wildlife can cause loss of biodiversity especially where there exists disruptions in native mutualism network (Traveset and Richardson, 2014). Loss of grazing pastures due to the displacement of native forage by *O. stricta* limits available food resources for both livestock and wildlife. To restore native species interactions, it's important to understand factors that facilitate the establishment and spread of *O. stricta*

2.7 Economic Importance of *Opuntia stricta*

The economic impacts of invasive species constitute both direct and indirect costs (Global Environmental Governance Project, 2014**).** Direct costs are those related to controlling the spread of invasive species, such as the use of herbicides applied to contain the spread of the shrub while indirect costs are related to ecosystem services lost through such destruction **(**Global Invasive Species Program, 2007**)**. Global costs associated with *O. stricta* were estimated to be billions of dollars annually as a result of invasive species (Global Invasive Species Programme, 2007). Since this is not a recent estimate, it is likely that current costs are higher.

Invasive alien species (IAS) cause negative impacts at the species, population and community levels. The most significant harm is the alteration of ecosystem functions since these species threaten the survival of native plants and animals by competing for resources, altering vegetation structures and community composition thereby upsetting the ecosystem balance. Additionally, they are costly to control, spread easily if not adequately controlled, endanger human health by harboring pests and diseases and can hybridize with native species, resulting in negative genetic implication (IUCN, 2000).

Opuntia stricta is regarded as an environmental weed in many parts of the world. It has been nominated among 100 of the worlds' worst invaders by the IUCN invasive species specialist group (ISSG) as well as listed as a noxious weed in South Africa and most Australian states (Henderson, 2001). Negative effects associated with invasive alien plants such as *O. stricta* include reduced surface water runoff and groundwater reserves, increased biomass and fire intensity, and loss of biodiversity.

These plants also reduce the capacity of ecosystems to provide goods and services to the society by altering ecological processes, displacing desirable plant species, reducing quality of wildlife habitats, integrity of riparian areas as well as economic value of rangelands.

The estimated damage from invasive species worldwide is approximately US $1.4 trillion a year with negative impact across a wide range of economic sectors such as agriculture, forestry, aquaculture, transportation, trade, power generation and recreation (Stern, 2006). In a national beef quality audit, it was found that 22.5% of United States cattle were unsuitable for market and human consumption after feeding on cactus fruit (Garcia *et al.*, 2008).

Opuntia stricta is a problematic weed as it infests fields reserved for food production as well as pasture lands thereby reducing food production and lowering the capacity to feed the livestock leading to their loss. It causes heavy diarrhea to livestock wherever the fruits are consumed (Larsson, 2004). Unlike other *Opuntia species*, the plant has no benefits as the fruit cannot be used as fodder (Larsson, 2004). In Kenya, research in affected areas reveals the magnitude of negative effects caused due to competing and interfering with the indigenous plant populations. Its invasion in Laikipia has contributed to land degradation through overgrazing in un-invaded areas (Lazarides *et al*., 1997).

When livestock consume cactus fruits, glochids, which are small spines on the cactus lodge in their mouths, throats, stomachs and intestines contributing to secondary infections that lead to death .Large spines on the modified stems, called cladodes often pierce the eyes of livestock as they try to access forage, causing blindness (CABI, 2016). Excessive consumption of cacti fruit may result in constipation, impairs rumen function, leading to loss of livestock (Ueckert *et al.*, 1990; Hanselka and Paschal, 1991). Additionally, it leads to reduced lactation and consequently the loss of young livestock (Merrill *et al.*, 1980). Invasive cacti inhibit the movement of people and decreases availability of native plants primarily used for medicinal purposes (Ross *et al.*, 2017).

2.8 Management of *O. stricta*

Many of the invasive species possess undesirable effects that most likely result in substantial monetary costs and/or alterations to entire ecosystems and social systems (McNeely, 2006; Kumschick *et al.*, 2012), and threatens native biological diversity (IUCN, 2013). Therefore, effective control is imperative to mitigate against these negative impacts.

The stages of spread of invasive alien weeds include arrival, adaptation and establishment, an exponential growth phase and a phase where alien plants invade and dominate the available area **(**Vermeij, 1996). Thus the responses of society in general and ecosystem management in particular ought to align effectively with these stages. For instance, effective control can be achieved by early detection and eradication more appropriate for the first two stages because options may severely be limited once the weed population reaches the final stage of total ecosystem domination (Van Wilgen *et al.,* 2001).

2.9 Control of *O. stricta*

The negative effects of *O. stricta* on human well-being, ecosystem services and biodiversity highlights call for the need to manage these invasions. When large areas are infested by invasive alien weeds, their control, in conjunction with restorative habitat management may be the only realistic recourse. An effective control programme aims at reducing the abundance and density of infestations while keeping harmful effects of an invasion within manageable limits (Gordon and Arne, 2013).

Varied successful control methods for invasive plant species exist with the most recent efforts focusing on mechanical, chemical and biological control. Management measures adopted for any plant invasion will depend upon factors such as the terrain, cost, availability of labour, the severity of the infestation and the presence of other invasive species (IUCN, 2013). Manual method may not be effective given that it forms thick clusters once established. In addition, burning may not be successful because sufficient fuel on the ground is required to sustain its combustion making this method inapplicable (Lotter and Hoffmann, 1998).

Chemical control methods involving the judicious use of approved herbicides can boost the efficacy of manual and mechanical clearing activities. There is however challenges associated with chemical control which, apart from their potential harmful side-effects on the broader ecology of ecosystems, is laborious, costly and some target species may develop resistance. In addition, many countries have prohibited use of herbicides.

Biological control has in recent decades gained acceptance in many countries as the most cost-effective and reliable means of managing large infestations of invasive alien plant species (Gordon and Arne, 2013). In South Africa, two herbivorous insect species, *Cactoblastis cactorum* (Lepidoptera: Phycitidae) and *Dactylopius opuntiae* (Homoptera: Dactylopiidae) have attacked *O. stricta* since their successful introduction into the country during the 1930s for biological control of a related weed species, *Opuntia ficus-indica* (Beinart, 2003).

Cactoblastis cactorum Berg a phycitid moth was introduced into Australia and successfully controlled *Opuntia stricta* (Dodd, 1940), although it was less successful in the Kruger National Park (KNP) (Lotter and Hoffmann, 1998). It was also released in Kenya in 1971 but did not establish (Greathead, 1971).

Another genotype of *D. Opuntiae*, originally from Texas in the USA was introduced to South Africa from Australia in 1997, where it had successfully controlled *O. stricta*, and *O. inermis* (Dodd 1940., Hosking *et al.*, 1994). This genotype showed a strong preference for *O .stricta* (Hoffmann *et al.,* 1999). Its release in the KNP resulted in a drop in the biomass of around 35 *O. stricta* cladodes per metre square to under 5 cladodes per metre square (Patterson *et al*.,2011). This negated the need for physical or chemical control.

Genotype *Cochineal D. opuntiae* which attacks *O. ficus indica* was introduced in South Africa in February 2014 and established well in Ol Jugi conservancy through a CABI initiative. It then spread from the initial release sites reducing flowering, fruiting and in many cases resulted in the death of plants (Winston*et al*., 2015). The *D. opuntiae* was accidentally introduced into Kenya in the 1990s where it established in Laikipia County and significantly reduced the abundance of sweet prickly pear.

For maximum effect, various control options exist which need to be integrated and coordinated especially in conservation areas as done in the Kruger National Park (KNP) in South Africa (Lotter and Hoffmann, 1998; Foxcroft and Richardson, 2003).

Effective control demands an integrated approach that blends mechanical, chemical and biological methods that emphasize management at the expense of controlling noxious rangeland weeds. It also aims at using the most economically, ecologically, and environmentally effective combination of principles, technologies, and systems to meet management goals (Sheley *et al.*, 1996).

CHAPTER THREE

3 MATERIALS AND METHODS

3.1Location of Tsavo East National Park

TENP is situated in South Eastern Kenya lying on the opposite side of Tsavo West National Park (Figure 3.1) It borders Chyulu game reserve, South Kitui National reserve and Mkomazi Game Reserve in Tanzania (Ayieni, 1975). It covers 11,747 km^2 low lying and semi-arid area with an altitude of between 150 m - 1,200 m above sea level located at co-ordinates 2.77861^0S and 38.77167^0E. It spreads over four counties which include Kitui, Taita Taveta, Tana River and Makueni. Tsavo East was gazetted as a National Park in 1948 and is currently the largest protected area as well as the most visited park in Kenya (Tsavo Conservation, 2008-2018). It has the highest population of elephants (Ngene, 2011). The park attracts close to 75,000 tourists per annum, majority of who are attracted by the “Big Five” mammalian species (KNBS, 2015).

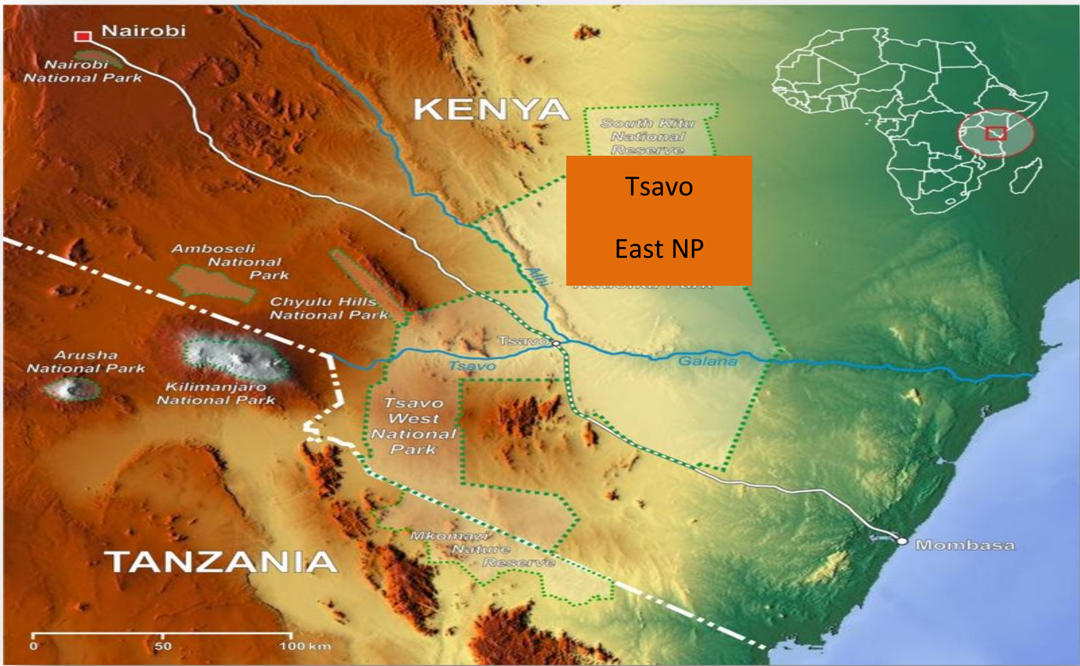

Figure 3.1: Map of Kenya in relation to TENP

3.2 Rainfall

Rainfall distribution in TENP is bimodal and is unevenly distributed throughout the year. The average annual rainfall ranges between 200mm in the interior to 900mm in the extreme South East and 700mm in the North West (TENP Research Station, 2011). More than half of the area lies within Agro Ecological Zone VI, one third within Zone V and one tenth within Zone IV. The long rains are experienced in the months of March, April and May (Figure 3.2) and tend to be relatively reliable in the South Eastern region. The short rain season is usually in October, November and December (Figure 3.2) and is often more reliable and less erratic relative to the long rains. These short rains are often of importance in the North-West. The probability of rain falling is usually less than two-third of the potential evaporation during the rainy season and varies from 80% to over 90% in the major part of the area. In the South-East and North-West, this probability is in the range of 60-80%. The temperatures are fairly constant all year round ranging from $27^{0}{}_{C}$-$31^{0}{}_{C}$ during day time and $20^{0}{}_{C}$ -$22^{0}{}_{C}$ at night. The park has one permanent river called River Galana and water pans that are scattered and tend to dry up during the dry season (Parks and reserves 2000; Tsavo East, 2003).

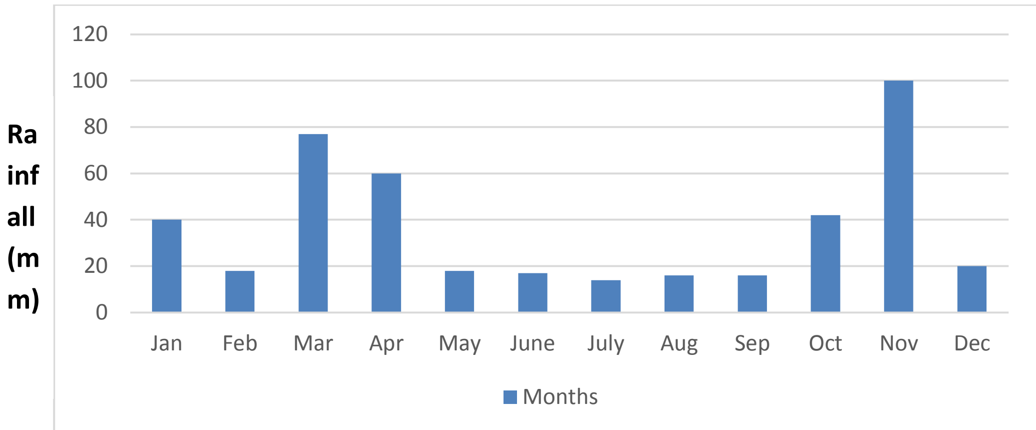

Figure 3.2: Mean monthly rainfall of TENP (source: TENP Research station, 2011).

3.3 Topography

The area topography is dominated by gentle undulating and extensive plains that are often interrupted by hills with their associated foot slopes in the South-West and West. In the North-West and South-East, undulating uplands border the plains. Special physical features include the Yatta Plateau which rises to about 1200m above sea level developed from various types of parental material. The soils are deep and well drained despite being acidic especially near major rivers. However, the soils tend to be shallow, stony and fairly rich in areas where the landscape has been rejuvenated (Ayieni, 1975).

3.4 Study site

The study was conducted between Ndara plains and Bachuma area (Figure. 3.3).

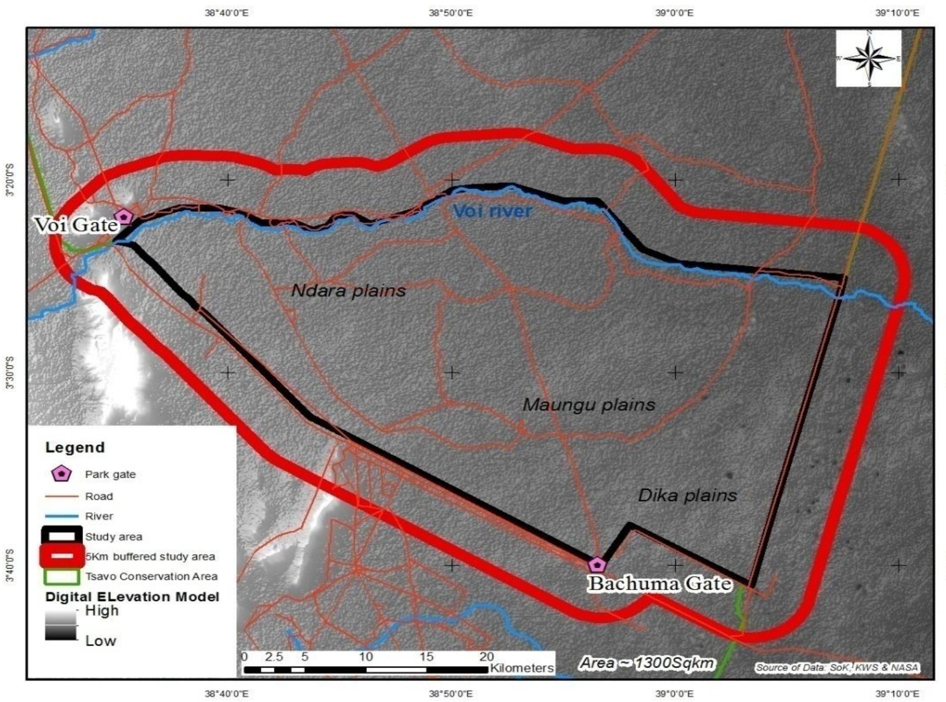

Figure 3.3: Satellite image of the study area (Wright and David, 2005).

3.5 Vegetation

TENP is mainly inhabited with drought tolerant thorny-bush shrubs which are occasionally broken by the green vegetation of River Galana and other smaller seasonal rivers that run through the national park (Gillett and Wood 1966). The vegetation of the area is strongly related to the soil and prevailing climatic conditions and its composition reflect the physical environment. The main vegetation is *Acacia commiphora* which encompasses varying densities of trees and shrubs that include open plains, bushed grassland, shrubs and woodlands.

The tree species include *Acacia tortilis*, *Acacia nilotica*, *Commiphora africana*, *Commiphora campestris* and *Commiphora confusa*. There are occasional taller hardwood tree species and shrubs such as *Terminalia spinosa*, *Melia volkensii*, *Boscia coracea*, (Figure 3.4) *Grewia species*, *Lannea species*, *Premna resinosa*, and *Cassia abbreviata* (Wijngaarden *et al*., 1985). The thick *Acacia-Commiphora* forest thins and eventually transits to patches of grassland (Gillett and Wood, 1966).

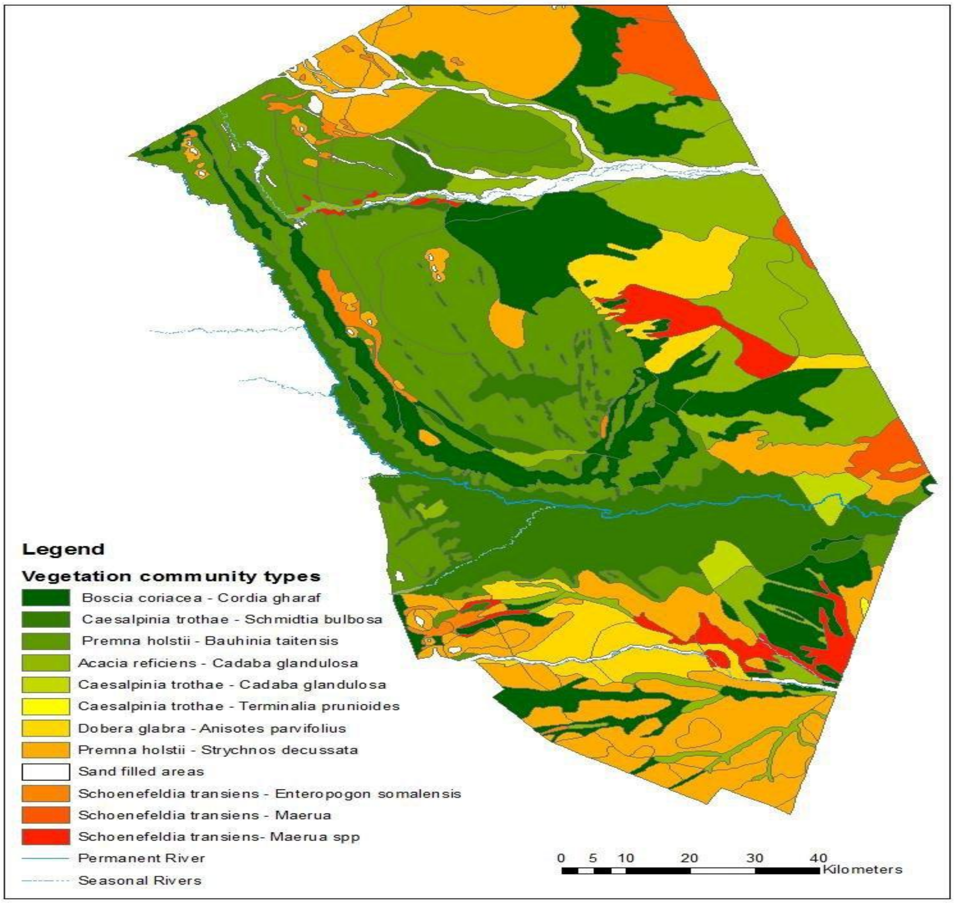

Figure3:4: Distribution of woody vegetation types in TENP.

3.6 Fauna

The fauna in the region include the African Buffalo (*Syncerus caffer*), African elephant, (*Loxodonta africana*), leopards (*Panthera pardus),* lion (*Panthera leo*), black rhino (*Diceros bicornis*), burchells zebra (*Equus burchelii*), hippopotamus (*Hippopotomus amphibious*), waterbuck (*Kobus elipsip rimnus*), reticulated giraffe (*Giraffa camelopardilis reticulata*), grants gazelles (*Gazella grantii*), gerenuk (*Litocranius walleri*), lesser kudu (*Tragelaphus imberbis*), impala (*Aepyceros melampus*), warthog (*Phancochoerus africanus*), dik-dik (*Madoqua kirkii*), Hunter's hartebeest (*Beatragus hunteri*), eland (*Taurotragus oryx),* fringe –eared Oryx (*Oryx beisa callotis*) among others (Ayieni, 1975).

The avian fauna consists of approximately 500 bird species that have been recorded in the area. They include the ostrich (*Struthio camelus*), migratory kestrels (*Falco naumanni*), sacred ibis (*Threskiornis aethiopicus*), black kite (*Milvus migrans*), crowned crane (*Balearica regulorum*), lovebirds (*Agapornis spp*) among others (Ayieni, 1975).

3.7 Survey and Sampling Strategy

Data collection was done both during the rainy and dry season in order to detect seasonal variations and was executed in duration of six months. The total area covered was 24km^2.Using GPS, a total of 12 line transects (Figure 3.5) each measuring 2km was established between Bachuma and Ndara plains. A long each transect, 10 quadrats each measuring 5m by 5m were systematically placed at intervals of 200m. All transects and quadrats were geo –referenced using hand- held GPS units that were placed between one transect to another and from one quadrat to another.

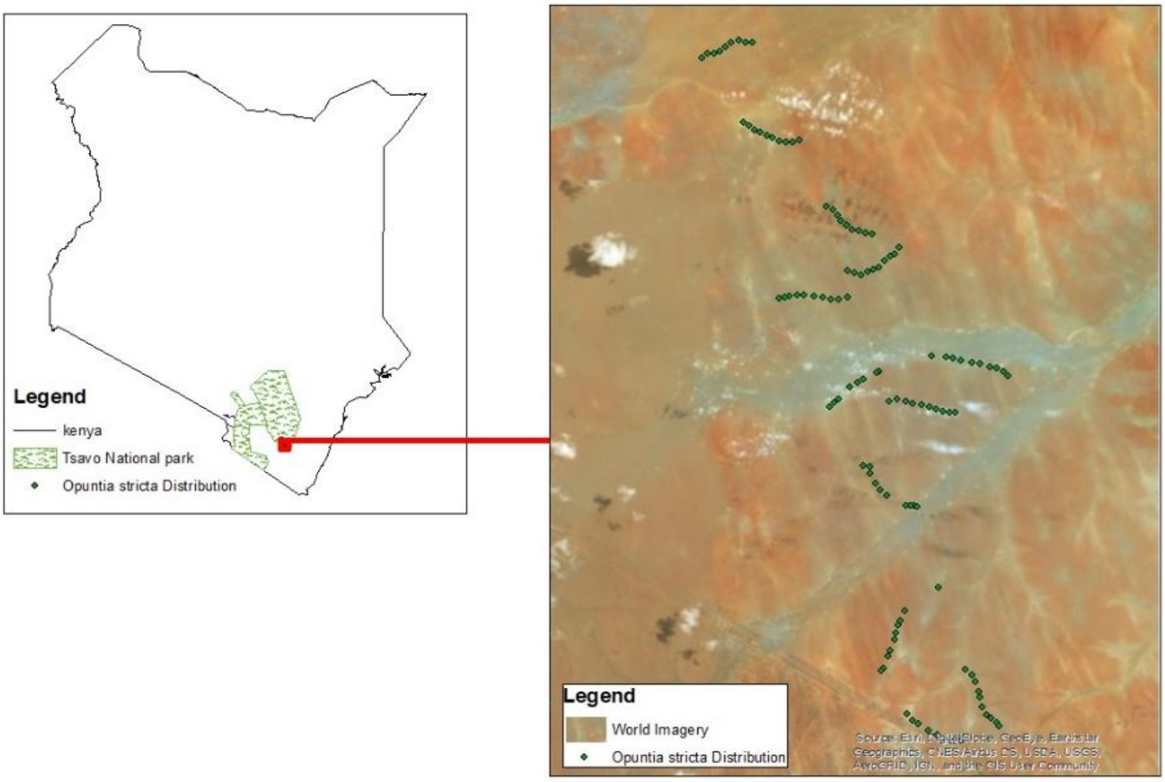

Figure 3.5: Spatial location of sampling transects in the study site

3.7.1 Spatial Analysis of *Opuntia stricta* Cover

Braun Blanquet cover abundance scale which is used to measure plant cover in vegetation science and based on percentages was utilized to record the percentage coverage where by 5= 75%-100%, 4=50-75%, 3=25-50%, 2=5-25%, r=<5 %((Braun –Blanquet, 1932). This was recorded for the 120 quadrats. The collected data was used to show the spatial spread of *Opuntia stricta* using coordinates taken by hand – held GPS unit.

3.7.2 Collection and Chemical Analysis of Soil Samples

A total of ten soil samples were collected from each transect from a depth of 15cm at the centre of each quadrat. The samples were sundried for three days and 15 grams of soil from each quadrat packed in a khaki bag and stored in a well aerated room. Five soil samples were randomly selected from each transect and analyzed for Nitrates, Phosphates, Calcium, Magnesium, Sodium and Potassium. A total of 60 samples were analyzed for each soil element.

3.7.2.1 Determination of the Concentration of Nitrates

From each transect, five soil samples were randomly selected from the quadrats, prepared and analyzed using UV-VIS spectrophotometer. The UV-VIS measurements were recorded over a range of 350-700 nm using 3 cm^3 quartz cuvettes with Nicolette Evolution 100 Spectrometer (Thermo Electron Corporation, UK). The concentrations of the solutions were recorded directly from the calibrated UV-VIS spectrophotometer (Amponsah *et al.*, 2014).

3.7.2.2 Determination of the Concentration of Phosphates

Analyses of the prepared soil were done using UV-VIS spectrophotometer. The UV-VIS measurements were recorded over a range of 350-700 nm using 3 cm^3 quartz cuvettes with Nicolette Evolution 100 Spectrometer (Thermo Electron Corporation, UK). A calibrated UV-VIS spectrophotometer was used to record the concentrations of the solutions directly (Amponsah *et al.*, 2014).

3.7.2.3 Acid Digestion of Soil Samples to Determine the Concentrations of Calcium and Magnesium

Two grams of soil samples from each plot were picked, sun-dried for three days, packed in a khaki paper and five samples randomly selected from each transect for analysis. A total of 60 samples were analyzed. 30mL of dilute hydrochloric acid was added into a beaker followed with weighed soil sample. The mixture was heated on a hot plate that had been set at low heat till it boiled (Anderson *et al.*, 1993). The mixture was left to cool before filtering into 100mL volumetric flask using a medium filter paper (whatman 540). The residue was rinsed with portions of distilled water until the volume reached about 80ml. The volume was topped up to 100ml using distilled water and thoroughly mixed by shaking.100ml of the mixture was then liquated into 60 Cuvettes.

Calcium and Magnesium standards were prepared and analyzed using Atomic Absorption Spectrometry (AAS). Analysis of the samples was also carried out by AAS. To determine Calcium in the air-acetylene flame, silicon was removed since it alters the soil composition forming new clay minerals which are characterized by high biogeochemical activity. Presence of magnesium ions was also determined using the flame method as described (Talanta, 1999).

3.7.2.4 Flame Photometer Method for Extraction of Sodium and Potassium

A dry soil sample (2g) was weighed and put in a clean dry glass beaker into which 30ml of dilute hydrochloric acid was added. The mixture was heated to boil at low heat then allowed to cool to room temperature after which it was filtered. The filtrate was rinsed and transferred into 100ml volumetric flask which was then topped to the mark. Distilled water was aspirated and the scale of flame photometer adjusted to zero deflection (0% reading).

Calibrated solutions of Sodium and Potassium at 2mg/l, 4mg/l, 6mg/l, 8mg/l and 10mg/l concentrations were aspirated from the lowest concentration to highest with addition of water between each measurement while recording the corresponding deflection for each standard. Each sample solution was also aspirated and the corresponding deflection recorded. The total samples were analyzed for their chemical properties.

3.7.3 Plant Species Associated with *Opuntia stricta*

Quadrats of 5m × 5m were placed systematically within each transect at a distance of 200m from each other within the study site and geo-referenced (Cox, 1990). Data on the frequency of individual and total number of woody plants in each transect was recorded (Appendix 9). Shannon – Wiener Index (H') was used to calculate diversity evenness of woody plants in each transect using PAST (Paleontological statistics) program version 1.97 in the following equation:

$$H' = -\sum (P^{i}) (\log P).$$

Where H represent Index of species diversity and $P_i = n_i / N$ where n_i is the individual of a species and N is the total number of individuals of all species and evenness (E) =H/Hmax (Tucker *et al.,* 2017). Correlation between mean diversity of woody species in each transect in relation to *Opuntia stricta* percent cover was calculated to establish their relationship.

3.7.4 Elephant Distribution Using Dung Piles

Data on elephant distribution was collected from all the quadrats along the 12 transect and geo-referenced using elephant dung piles as indicators (Appendix 1). Presence of elephant dung was denoted as 1, while absence as 0 (Zero). This data was correlated with *O. stricta* percentage cover to establish their relationship.

3.8 Data Analysis

Data on percentage coverage of *Opuntia stricta* in the sampled area was transformed first before analysis in order to meet the parametric statistical assumptions for inference reasons or improve the interpretability and presentation of the findings. The arcsine formula was used in data transformation. Analysis of Variance (ANOVA) was used to determine if the distribution of *Opuntia stricta* differed significantly among the transects. A post hoc multiple comparison (turkeys HSD test) was used to find means that were significantly different from each other.

A Pearson Correlation test was used to separately determine the correlation between the soil chemical components, presence or absence of elephants, woody plant species and *Opuntia stricta* cover each at a time. The analysis was to determine if there existed a relationship between the *Opuntia* and the highlighted factors. A correlation coefficient of 1.00 indicated perfect positive correlation, -1.00 perfect negative correlation while zero implied no correlation. Statistical significance in both directions was tested using two- tailed test.

CHAPTER FOUR

RESULTS

4.1 Spatial Distribution of *O. stricta*

Spatial distribution of *O. stricta* cover was determined in the 12 transects. Transect one, two, three and six recorded high cover of *Opuntia stricta* while the rest recorded low percentages and there was no *O. stricta* cover in transect nine (Appendix 2).

The study carried out the mean analysis for the *O. stricta* distribution per the sampled transects and the findings summarized in the table below (4.1).

Table 4.1: Mean percentage cover of *Opuntia stricta*

Transect	Mean	Std Error
1	23.800	9.844
2	19.700	8.691
3	17.850	10.944
4	1.700	0.790
5	0.810	0.552
6	20.350	13.029
7	1.810	0.608
8	0.010	0.010
9	0.000	0.000
10	1.000	1.000
11	0.500	0.500
12	2.000	1.105

From Table 4.1 above, the highest percentage mean was observed in transects one, two, three and six while the lowest were recorded in transects eight, nine and eleven. The maximum percentage was 99 percent in transect one and zero percent in transect 9 (Appendix 2).

Table 4.2: Transformed data of the *Opuntia stricta* percentage cover

Transects	1	2	3	4	5	6	7	8	9	10	11	12
Opuntia stricta	23	19.7	17.9	1.7	0.4	20.4	0.9	0.1	0	1	0.5	2
log10(*O.s*)	1.36	1.29	1.25	0.23	-0.4	1.3	-0.05	-1		0	-0.3	0.5
Arcsine	0.50	0.59	0.51	0.30	0.20	0.48	0.32	0.10	0.00	0.10	0.10	0.27

Since the log transformation method resulted to some negative and undefined values, this study adopted the arcsine transformed values for further data analysis. The arcsine formula was used to transform the raw data into radians for easy interpretation and representation.

$$y = \text{arcsin}\, e\sqrt{p} = \sin^{-1}\sqrt{p}$$

From the formula, P is the proportion or the percentage of the variable of interest while y is the transformed value of the observation.

The study conducted the Analysis of Variance (ANOVA) to establish whether the *O. stricta* percentage cover differed significantly per the sampled transects as shown in table 4.3.

Table 4.3: Analysis of variance

Source of Variance	Sum of Squares	Df	Mean Square	F	Sig
Between	10313.789	11	937.617	2.416	.010
Within	41917.057	108	388.121		
Total	52230.846	119			

From Table 4.3 above, *O. stricta* mean percentage cover differed significantly among different transects at $p < 0.05$ level with the computed $F = 2.416 > F_{0.05}(11{,}108) = 1.38$.

A post hoc multiple comparison (turkeys HSD test) was used to find means that were significantly different from each other and the results shown in the table 4.4 below.

Table 4.4 Turkey's pairwise comparisons (Q below diagonal, p(same) above diagonal).

Transects	Transect 1	2	3	4	5	6	7	8	9	10	11	12
1		1	0.9999	0.3449	0.2617	1	0.2984	0.2445	0.2445	0.2984	0.2676	0.3659
2	0.6587		1	0.662	0.5586	1	0.6067	0.5345	0.5345	0.6067	0.5666	0.6851
3	0.9479	0.2892		0.792	0.7003	1	0.7442	0.6775	0.6775	0.7442	0.7078	0.811
4	3.551	2.892	2.603		1	0.6067	1	1	1	1	1	1
5	3.76	3.101	2.812	0.2089		0.5025	1	1	1	1	1	1
6	0.5463	0.1125	0.4017	3.004	3.213		0.5505	0.4788	0.4788	0.5505	0.5105	0.6306
7	3.663	3.004	2.715	0.1125	0.0964	3.117		1	1	1	1	1
8	3.808	3.149	2.86	0.2571	0.0482	3.262	0.1446		1	1	1	1
9	3.808	3.149	2.86	0.2571	0.0482	3.262	0.1446	0		1	1	1
10	3.663	3.004	2.715	0.1125	0.0964	3.117	0	0.1446	0.1446		1	1
11	3.744	3.085	2.796	0.1928	0.01607	3.197	0.08033	0.06427	0.06427	0.08033		1
12	3.503	2.844	2.555	0.0482	0.2571	2.956	0.1607	0.3053	0.3053	0.1607	0.241	

From table 4.4 above, there was a significant difference between transect one and eight, transect two and nine, three and twelve. Therefore, the study rejected the null hypothesis (H_0) and concluded that *O. stricta* percentage cover differed in the 12 sampled transects.

4.2 Correlation between the Soil Chemical Composition and *Opuntia stricta* Percentage Cover

The study sought to establish the relationship between some selected soil chemical composition and the *O. stricta* percentage cover. The results were summarized in Table 4.5 below.

Table 4.5: Correlation between *Opuntia stricta* percentage cover and soil chemical composition

Soil Chemical Composition	*Opuntia* Pearson Correlation	Sig. (2-tailed)	Soil Samples
Opuntia s. cover	1.000	.	60
Nitrates	-.014	.918	60
Phosphates	-.404	.002	60
Calcium	.062	.636	60
Magnesium	-.044	0.369	60
Sodium	.247	.039	60
Potassium	.008	.476	60

The strength of the Pearson correlation values were based on the Cohen (1988) guidelines where; $\text{Small} = |0.10 < r < 0.29|$, $\text{Medium} = |0.30 < r < 0.49|$ and $\text{Large} = |0.50 < r < 1.00|$ Therefore, from the results in Table 4.4, there was a small negative correlation between nitrate and the *O. stricta* at $\alpha = 5\%$ given that $[r = -0.014$ $p = 0.918$ and $n = 60]$. Phosphate concentration showed a moderately medium negative correlation at $\alpha = 5\%$ $[r = -0.404$, $p = 0.002$ and $n = 60]$ .There was moderately medium positive correlation between *Opuntia stricta* percentage cover and sodium at $\alpha = 5\%$ $[r = 0.247$, $p = 0.039$ an $n = 60]$. Calcium and potassium was positively correlated at p=0.636 and p= 0.476 respectively though it was not significant. Nitrates and magnesium correlated negatively with *O. stricta* at P=0.918 and 0.369 which was insignificant.

4.3 *Opuntia stricta* Cover and the Associated Woody Species

Figure 4.1 below shows the distribution of different woody plant species along the 12 transects.

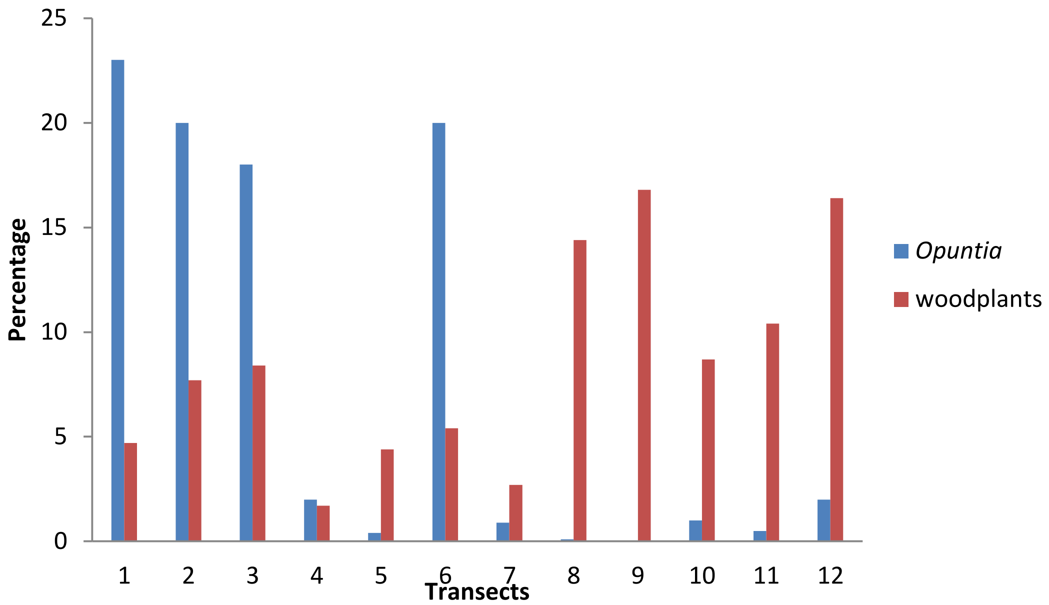

Figure 4.1: *Opuntia stricta* and the associated woody plants

From Figure 4.3 above, it is evident that presence of *O. stricta* in a transect in large percentages hinder the growth of woody plants. For instance, in transects one, two, three and six where *O. stricta* was in large numbers, the number of woody plants counted tended to be lower than in transects seven, eight, nine, ten, eleven and twelve in which the number of woody plants was higher in relation to *O. stricta*. There was a difference in the frequency of woody plants present in the study area (Appendix 8)

The relationship between mean diversity evenness of woody plants and *Opuntia stricta* mean percentage cover was established. The findings were summarized in Figure 4.2

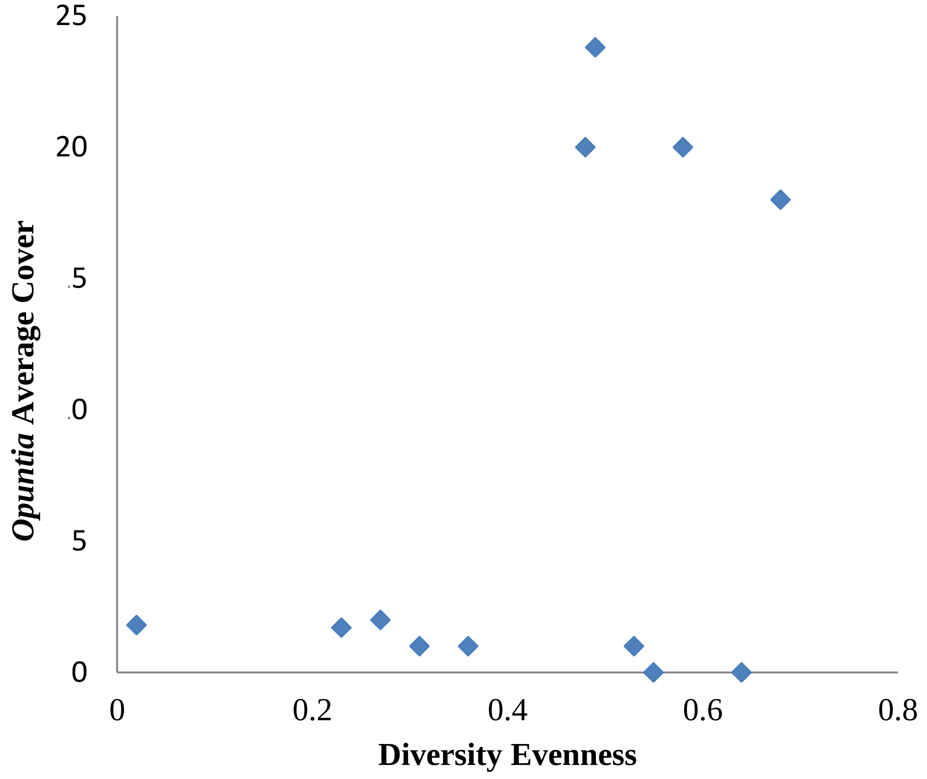

Figure 4.2: *O. stricta* mean percentage cover and diversity evenness of woody plants.

The higher the diversity evenness of woody plants, the low was the *Opuntia stricta* Cover.

The study established the correlation between *Opuntia stricta* mean cover and diversity evenness of woody plants. The findings are shown in the Table 4.6

Table 4.6: Correlation between *Opuntia stricta* and presence of woody plants

Tests	Distribution
Pearson Correlation	0.417
Sig. (2-tailed)	0.177
Total (N)	12

A weak and insignificant positive correlation between *Opuntia stricta* cover and woody plants was observed (r=0.417 and P=0.177).

4.4 Elephant Distribution in Relation to *Opuntia stricta* Percentage Cover

There was a strong association between the *Opuntia stricta* percentage cover and the presence of Elephants as shown in Figure 4:3 below. The arcsine formula was used to transform the raw data into radians for easy interpretation and representations.

$$y = \arcsin e\sqrt{p} = \sin^{-1}\sqrt{p}$$

Where p is the proportion or the percentage of the variable of interest and y is the transformed value of the observation.

Table 4.7: Presence of elephants and *Opuntia stricta* mean percentage cover

Transects	Elephant % present(x)	*Opuntia stricta* mean% cover(y)	*Transform (x degrees)*	*Transform (y degrees)*	*x in radians*	*y in radians*
1	90	23	71.26	28.69	1.24	0.50
2	80	31	63.38	33.85	1..11	0.59
3	90	24	71.26	29.34	1.24	0.51
4	70	9	56.82	17.46	0.99	0.30
5	80	4	63.38	11.54	1.11	0.20
6	90	21	71.26	27.26	1.24	0.48
7	70	10	56.82	18.42	0.99	0.32
8	60	1	50.81	5.74	0.89	0.10
9	60	0	50.81	0.00	0.89	0.00
10	70	1	56.82	5.74	0.99	0.10
11	60	1	50.81	5.74	0.89	0.10
12	60	7	50.81	15.37	0.89	0.27

Each transect was 2 km long and quadrat was 5m by 5 m. The total number of quadrats along the transects was 120

It was established that there was presence of elephants in all the transects but at varying percentages (Appendix 1)

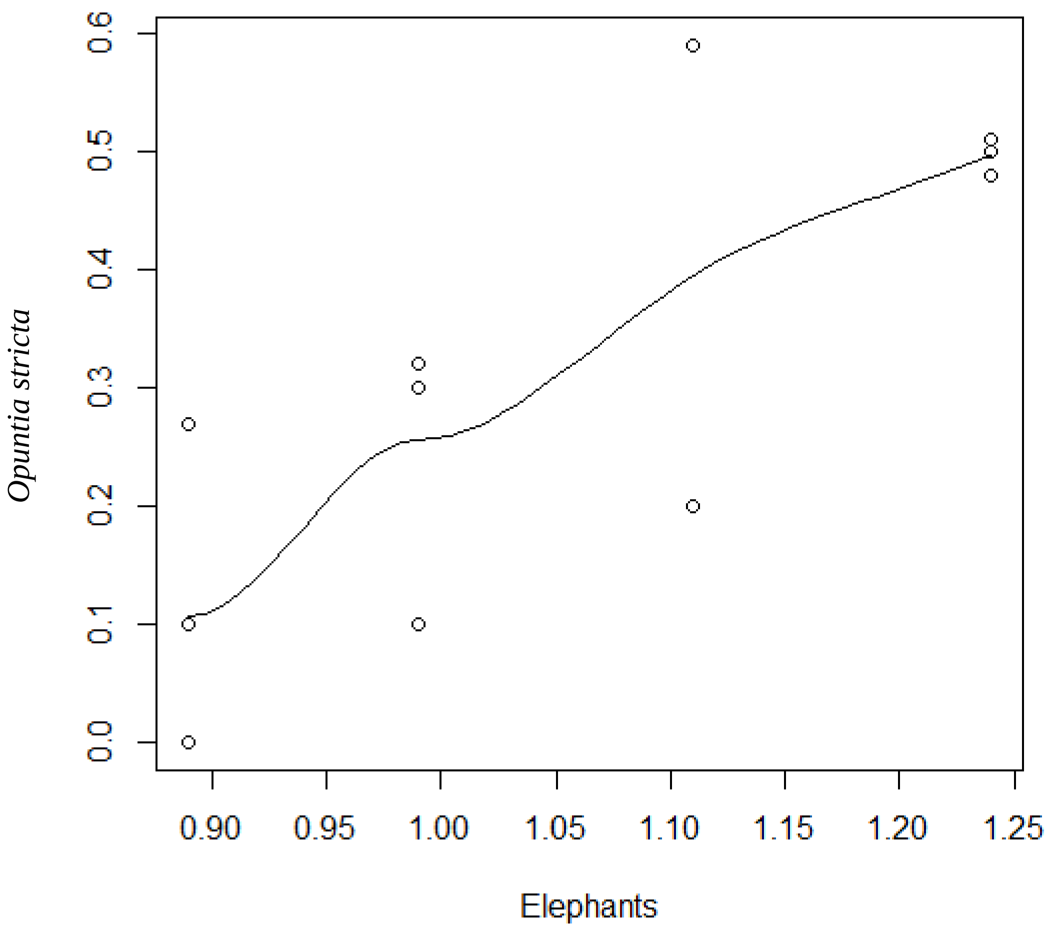

Figure 4.3: *Opuntia stricta* and elephants correlation

Opuntia stricta cover and elephant distribution correlated positively and significantly with r=0.8077 and P=0.000 at α=5%. This showed a strong positive correlation implying that presence of elephants indicates presence of *O. stricta.*

CHAPTER FIVE

5 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Spatial Distribution of *Opuntia stricta* Within the Study Area

Studies have consistently acknowledged that *O. stricta* invasion is widely spread across the rangelands and conservation areas of Kenya (Shackleton *et al.*, 2017). This invasion is abundant in Laikipia County especially in overgrazed communal rangelands and Tsavo East National Park. According to Shackleton *et al.,* (2017), approximately 2000km^2 of the TENP has been invaded by *O. stricta*. This invasion may have been accelerated by the rapid deterioration of rangeland conditions in TENP (Bradley *et al*., 2010).

In the current study, transects one, two, three and six which were placed in Ndara plains and Mackinon road area in Southern parts of TENP, were found to have the highest mean *O. stricta* percentage cover at 23.80, 19.70, 17.85 and 20.35 .The other transects recorded low mean cover (Table 4:1). The spatial distribution of *O. stricta* cover differed significantly among different transects at $p < 0.05$ .The Southern area of the study area was highly invaded while the Northern sides recorded low *O. stricta* invasion.

5.1.2 Soil Chemical Composition in Relation to the *Opuntia stricta* Cover

According to Omari (2009), the density of invasive plants in Nairobi National Park slightly increased as the concentration of potassium increased, but decreased with increase in concentration of phosphorus and nitrogen in the soil. Results from this study show a significant negative correlation between the concentration of phosphates with *O. stricta* cover at a significance level of p=0.002 for α =5%. Nitrates and magnesium negatively correlated with *O. stricta* insignificantly at p=0.918 and 0.369 respectively. Sodium concentration positively correlates with *O. stricta* cover at a significance level of P=0.039 for α= 5% while calcium and potassium correlated positively but insignificant at 0.636 and 0.476 (Table 4.5).It is therefore not possible to identify the exact soil minerals influencing the distribution of *O. stricta*.

These findings align well with Foxcroft *et al* (2004) that prickly pear (*Opuntia stricta*) is forces driven by propagule pressure (which entails propagule size, propagule numbers as well as temporal and spatial patterns of propagule arrival and environmental factors play less of a role).

5.1.3 Wood Plant Species Associated with *Opuntia stricta* Cover

There was an insignificant positive correlation between *O. stricta* cover and presence of woody plant species in the present study with P =0.177 at $\alpha = 5\%$. This implies poor coexistence between *O. stricta* and woody plant species. Transect eight which had the lowest mean percent cover of *O. stricta* and nine without *Opuntia stricta* recorded the highest mean diversity of woody plants at 0.64 and 0.55 .(Figure 4.2)

Transect one with the highest mean of *O. stricta* showed moderate mean diversity of woody plants. This can be attributed to its competitive nature of invasive plant species. This affects forage grass production by limiting, through effective competition, the availability of growth factors such as light, water, temperature and nutrients (Mwangi and Western, 1998; Brent and Cushman, 2007). Once the plant colonizes degraded areas, it becomes established in abundance (Coetzee *et al.*, 2007), and prevents woody plants from re-establishing (Hobbs and Huenneke, 1992). A study in Southern Madagascar in the late 1950s showed a linear increase of plant diversity with decreasing *O. stricta* density as the survey moved further away from the introduction site (Brolin, 2004).

5.1.4 Elephant Distribution in Relation to *Opuntia stricta* Cover

O. stricta growth forms dense thickets and produce many seeds that are dispersed by baboons, birds and large mammals (Foxcroft *et al.*, 2011). The study confirmed presence of elephants in all the 12 transects studied in TENP. There was a significant positive correlation between elephant distribution and *O. stricta* cover with r=0.37 and P=0.000 at α=5% as shown in Figure 4.3. This implies that increase in the number of elephants and migration in search for food and water has over time led to the observed *O. stricta* distribution. The cactus bears fruits throughout the year encouraging consumption by these mammals. In addition to facilitating seed dispersal, the animals' digestive system increases the germination rate of seeds in elephant's faecal matter through a scarification process (Kunz and Linsenmair, 2008). These seeds are viable for up to 15 years (Mandujno *et al.,* 2001).

5.2. Conclusions

The results from this study have revealed that *Opuntia stricta* is spreading fast in the Southern parts of TENP. The key dispersal agents are elephants as evidenced by presence of piles of dung along all the transects within the study area. Correlation between *Opuntia stricta* cover and presence of elephants was confirmed to be strong.

Phosphates had a moderate negative correlation with *O .stricta* indicating that increased concentration leads to decrease in the invasive plant. Sodium concentration had moderate positive correlation with *Opuntia stricta*. There was an insignificant positive correlation between *O. stricta* and woody plants.

Although there's a positive correlation between some of the environmental variables investigated in this study and the distribution of *O. stricta*, it's evident that there are more factors influencing the growth of *O. stricta* plant as it exhibits an ability to grow in a wide variety of habitats as well as in unlikely places such as in rock crevices, tree forks and on corrugated iron sheets. A study on prickly pear (*Opuntia spp*) by Foxcroft *et al* (2007) concluded that other driving forces such as propagule pressure which entails propagule size, numbers, temporal and spatial patterns of propagule arrival may influence its coverage and that environmental factors played a lesser role.

5.2.1 Research Hypothesis

Hypothesis 1. There is no pattern of *Opuntia stricta* distribution in TENP

This hypothesis was rejected because *Opuntia stricta* is spreading rapidly in the Southern parts of Tsavo East National Park.

Hypothesis 2. There is no significant relationship between soil chemical composition and *O. stricta* prevalence in TENP

Soil chemical composition influence on the distribution of *O. stricta* was negligible. As a result, it was not possible to describe specific soil factor that was influential in determining or predicting the population density of *O. stricta* hence accepting the null hypothesis.

Hypothesis 3. There is no significant relationship between other plant species and *O. stricta*

From the results, there is a very weak correlation between *Opuntia stricta* cover and presence of woody plants. This implies that it does not significantly contribute to the spread of *Opuntia stricta* thus accepting the null hypothesis. In the study area, woody plant species included *Sericocomophis pallida* with the highest frequency. Other species were *Boscia coracea, Euphorbia species, Grewia similis, Grewia bicolor, Acacia tortilis, Bauhinia taitensis, Acacia senegalese, Premna resinosa, Cordia* *monoica, Strychnos dessicata, Platycelyphium voensii, Thylacium thomasii, Lanea triphyla, Rasalphine species, Maerua dehydetorium.*

Hypothesis 4. There is no significant relationship between *O. stricta* and elephant presence in TENP

Elephant presence led to Increase in the logistic significant correlation which was attributed to the long distance dispersal. The null hypothesis was thus rejected.

5.3 Recommendations

At the time of this study, the conditions indicated that *Opuntia stricta* is present in TENP and has contributed negatively on biodiversity. The rate of spread is high in the southern parts of the park and if this trend continues, it will cause more serious impact on the survival of wildlife. Consequently, this will negatively affect the Kenyan tourism sector hence the country will end up losing millions of money. There is thus an urgent need to control the spread of this invasive species with a view of improving the health and sustainability of the national parks. A more detailed research therefore should be carried out in order to formulate a management strategy for *O. stricta* in the TENP and similar ecosystems.

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APPENDICES

Appendix 1: Elephant Distribution

Sampling block	Coordinates		Presence of Elephants
	X	Y	
Transect one 1	493594	9594824	1
2	493496	9594810	1
3	493299	9594792	1
4	493199	9594797	1
5	493013	9594825	1
6	492801	9594955	1
7	492535	9595110	1
8	492227	9595288	0
9	492085	9595402	1
10	491902	9595581	1
Transect two 1	492820	9599335	1
2	491855	9598635	1
3	491721	9598350	1
4	491660	9598211	1
5	491588	9597973	1
6	491553	9597778	1
7	491432	9597467	1
8	491355	9597284	0
9	491224	9596946	1
10	491138	9596874	0
Transect three 1	493627	9596911	1
2	493809	9596733	1
3	493909	9596533	1
4	494008	9596256	1
5	494057	9596093	1
6	494123	9595783	0
7	494238	9595545	1
8	494376	9595472	1
9	494522	9595321	1
10	494610	9595243	1
Transect four1	492089	9601751	1
2	491991	9601755	1
3	491870	9601775	1
4	492202	9601744	1
5	491316	9602068	1
6	491105	9602218	0
7	490986	9602427	0
8	490823	9602724	1

9	490823	9602897	0
10	490617	9602951	1
Transect five 1	491074	9605745	1
2	491017	9605707	1
3	490625	9065503	1
4	490449	9605405	1
5	490238	9605289	0
6	489893	9604902	1
7	489769	9604821	0
8	489629	9604678	1
Transect six1	491382	9604846	1
2	491614	9604920	1
3	491890	9604852	1
4	492088	9604792	1
5	492332	9604748	1
6	492572	9604671	1
7	492749	9604621	0
8	492966	9604562	1
9	493149	9604519	1
10	493310	9604518	1
Transect seven1	494878	9605596	1
2	494736	9605746	1
3	494547	9605831	1
4	494338	9605871	0
5	494040	9605950	1
6	493814	9606000	1
7	493491	9606070	0
8	493254	9606127	1
9	493059	9606173	0
10	492628	9606202	1
Transect eight 1	490181	9607945	1
2	489894	9607873	1
3	489688	9607868	0
4	489436	9607919	1
5	489192	9607980	1
6	488889	9608000	0
7	488681	9608006	1
8	488471	9607975	0
9	488329	9607922	1
10	488174	9607909	0
Transect nine 1	490181	9608720	1
2	490361	9608638	1
3	490559	9608600	0
4	490747	9608673	1
5	490925	9608767	1

6	491090	960880	1
7	491249	9609001	1
8	491401	E9609135	0
9	491538	9609218	0
10	491689	9609409	0
Transect ten1	489543	9610621	1
2	489558	9610617	0
3	489749	9610509	1
4	489865	9610357	1
5	489987	9610204	1
6	490130	9610054	1
7	490297	9609945	1
8	490490	9609895	1
9	490682	9609840	0
10	490882	9609812	0
Transect eleven 1	488763	9612586	1
2	488566	9612542	1
3	488366	9612538	0
4	488169	9612574	0
5	487979	9612642	1
6	487795	9612723	0
7	487618	9612811	1
8	487437	9612900	0
9	487269	9613010	1
10	*487102*	*9613123*	1
Transect twelve 1	485886	9615027	0
2	485893	9615031	1
3	486063	9615136	0
4	486267	9615145	1
5	486441	9615231	1
6	486589	9615358	0
7	486747	9615485	1
8	486989	9615558	0
9	487178	9615492	1
10	487378	9615465	1

Key

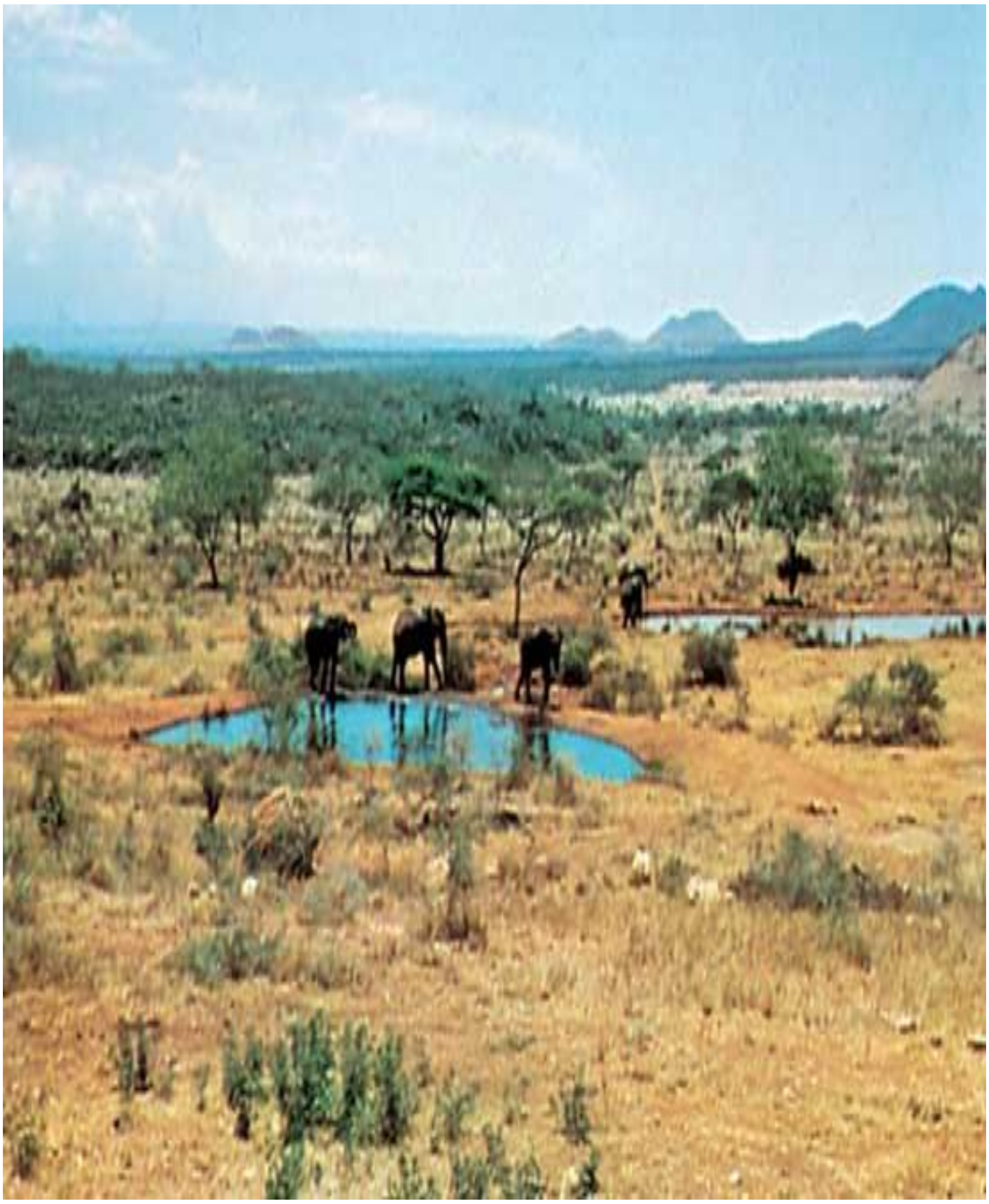
1 Dung - Presence of elephants

0 Absence of elephants

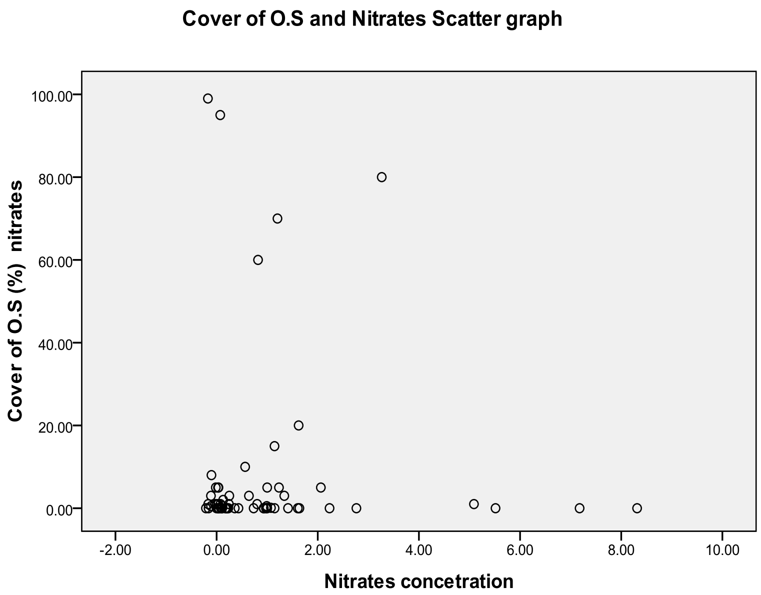
Appendix 2: Mean Percentage Cover of *Opuntia stricta* in the Study Area

Quadrat Transect	1	2	3	4	5	6	7	8	9	10	MEAN % COVER
1	40	15	5	10	99	10	50	1	5	3	23.8± 9.9
2	5	20	0	80	8	1	60	8	5	10	19.7±8.7
3	95	0	70	1	5	1	1	3	2	1	17.9±11.0
4	1	0	5	0	1	0	0	3	7	0	1.7±0.8
5	0	3	0	0	1	0	0	0	0	0	0.4±0.3
6	0	99	0	0	1	0	3	2	1	98	20.4±13.0
7	0	0	1	2	1	1	3	1	0	1	0.9±0.3
8	1	0	0	0	0	0	0	0	0	0	0.1±0.0
9	0	0	0	0	0	0	0	0	0	0	0.0±0.0
10	0	0	0	0	0	0	0	10	0	0	1.0±1.0
11	0	0	0	0	0	0	0	0	5	0	0.5±0.5
12	0	0	0	0	0	0	0	5	10	5	2.0±1.1

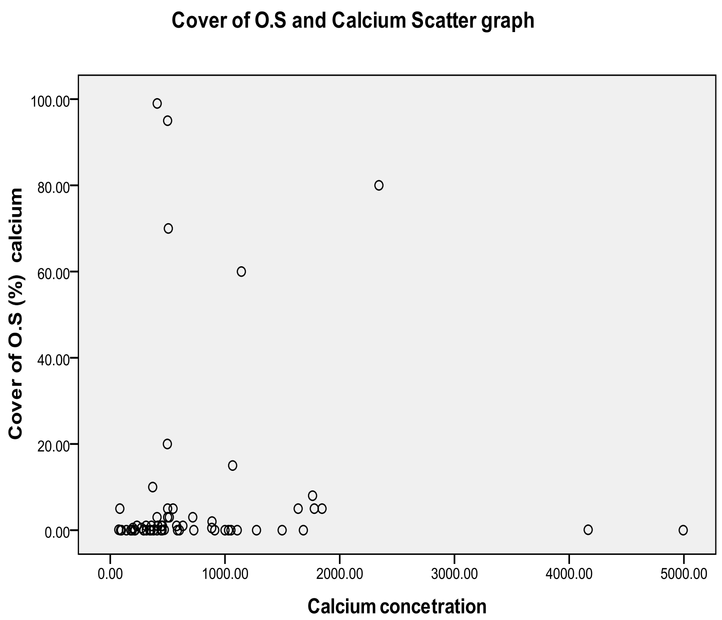
Appendix 3: Tsavo East National Park showing Water Pans



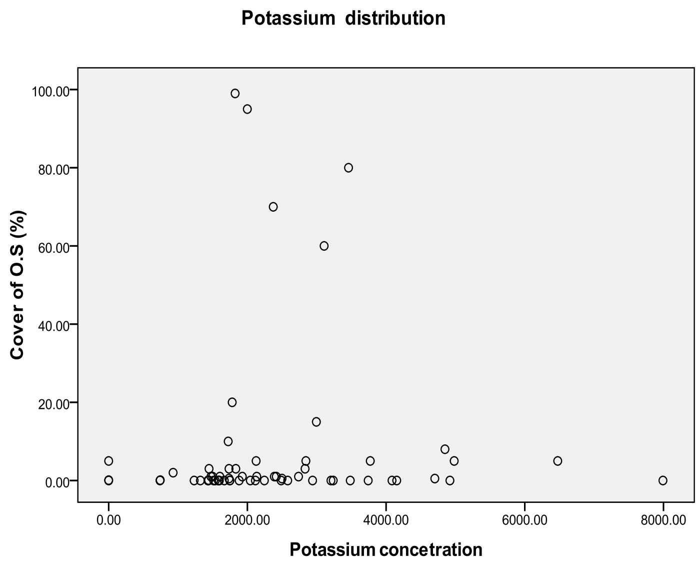
Appendix 4: Nitrate Concentration and Cover of *Opuntia stricta*



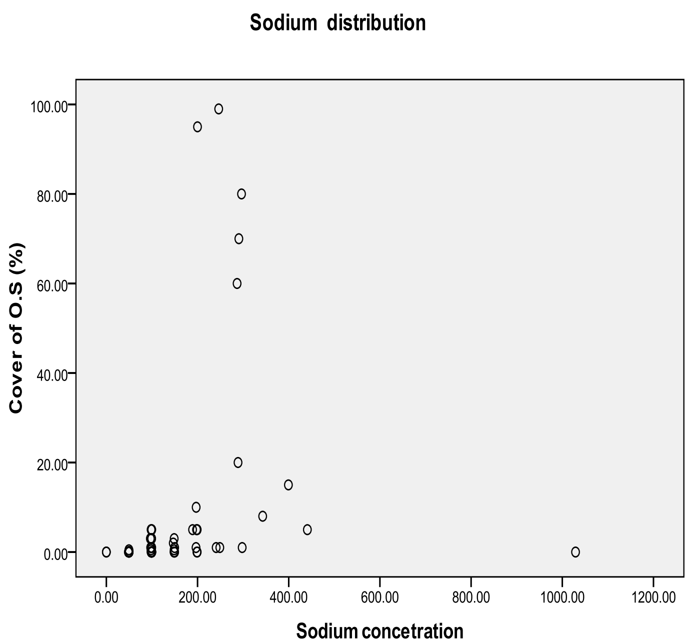
Appendix 5: Calcium Concentration and Cover of *Opuntia stricta*



Appendix 6: Potassium Concentration and Cover of *Opuntia stricta*



Appendix 7: Sodium Concentration and Cover of *Opuntia stricta*



Appendix 8: *Opuntia stricta* and the Associated Woody Plants

Transects 1 and 2

Transect	% *O.stricta* cover	Woody plants	Total Frequency
1	40 99 10 50 5 3	*Bauhinia taitensis (2), Boscia coracea (1), Thylacium thomasii (3), Bauhinia taitensis(1), Bauhinia taitensis(1), Lannea triphyla (1), Bauhinia taitensis(1), Rasalphine spp(1),Boscia coracea(2)*	13
2	5 20 80 8 1 60 8 5 10	*Grewia bicolar (2), Bauhinia taitensis (1)* *Euphorbia spp (2), Thylacium thomasii (1)* *Acacia tortilis (2), Bauhinia taitensis (1)* *Thylacium thomasii (2), Boscia coracae (1),* *Cordia monoica (1), Grewia similis (1)* *Boscia coracea (4), Cordia monoica (1),* *Boscia coracea (1), Bauhinia taitensis (1)* *Boscia coracea(2))*	23
Transect	% *O.stricta* cover	Woody plants	Frequency
3	70 1 5 1 3 2 0.5	*Euphorbia spp (4), Grewia bicolar (1) ,Boscia coracea(1),Bauhinia taitensis(1), Euphorbia spp(2), Bauhinia taitensis,(2),Cordia monoica(1), Boscia coracea(2), Cordia siniensis(2), Boscia coracea(2), Acacia tortilis(1)* *Boscia coracae (3), Grewia bicolar (1), Cordia siniensis (1), Boscia coracea (1)*	25
4	8 7	*Boscia coracea(3), uphorbia spp(2)*	5
5	3 0.5 0	*Boscia coracea (4) Cordia monoica (1) Cordia siniensis(2), Boscia coracea, (4), Cordia monoica(1), Bauhinia taitensis(1)*	13

Transect 6, 7 and 8

Transect	% *O.stricta* cover	Woody plants	Frequency
6	5 99 1 98	*Boscia coracea (6), Thylacium thomasii(2),Acacia polycantha(1)* *Bauhinia taitensis(2), Boscia coracea(2), Strychnos desssicata(1)Cordia siniensis(1), Cordia siniensis(1)*	16
7	2 0.5 3 1	*Grewia bicolor (1) Boscia coracea (2), Bauhinia taitensis (2), cordia siniensis (1)* *Boscia coracea(1), Cordia monoica(1)*	8
8	0.1 0	*Strychnos dessicata (1), Lannea triphyla (1)* *Boscia coracea (4), Platycelythium voensii (4), Grewia similis (3), Boscia coracea (1), Premna resinosa (1), Premna resinosa(1), Strychnos dessicata (1)Sericocomophis pallida (4), Boscia coracea(2),Sericocomophis pallida(7)* *Sericocomophis pallida(2),Grewia similis(1),Boscia coracea(2),Cordia monoica(1),Premna resinosa(1), Ochna inermis(1)Ochna inermis (2), Strychnos dessicata,(1)Boscia coracea,(1) Sericocomorphis Pallida (1)*	43

Transects 9 and 10

Transect	% *O.stricta* cover	Woody plants	Frequency
9	0	*Sericocomorphis pallida (3), Strychnos dessicata(3), Strychnos dessicata (3),Ochna inermis(1), Grewia similis(2),Strychnos dessicata(7),Boscia coracea(1), Strychnos dessicata (3), Maerua dehydetorium(1) Thylacium thomasii (1), Strychnos dessicata (3), Sericocomorphis pallida (7), Grewia similis (2), Thylacium thomsii(1),Premna resinosa,(1),Sericocomorphis pallida(1) Strychnos dessicata(3), Acacia tortilis(1), Premna resinosa(2),Boscia coracea(1), Strychnos dessicata(3)*	50
10	0 10 0	*Strychnos dessicata (1) Premna resinosa (1), Sericocomorphis pallida (1), Premna resinosa (1), Sericocomorphis, pallida (3), Acacia tortilis (1), Sericocomophis pallida (1)* *Sericocomorphis pallida (1) Premna resinosa (1) Sericocomorphis pallida, (1), Boscia coreacea (2), Strychnos dessicata (1)* *Ochna inermis(1),Strychnos dessicata(2), Sericocomorphis pallida(1) Boscia coracea(2),Strychnos dessicata(3), Premna resinosa(2)*	26

Transect 11

Transect	% Cover of *O.stricta*	Woody plants	Frequency
11	0 0 0 0 0 0 0 5 0 0	*Boscia coracea(1), Premna resinosa (1) Boscia coracea (1), Sericocomorphis pallida (2) Boscia coracea (1), Strychnos dessicata(1),Grewia similis(1) Sericocomorphis pallida, (3) Sericocomorphis pallida (3) Sericocomorphis pallida (1), Boscia coracea (1) Cordia monoica (1), Premna resinosa (1), Sericocomorphis pallida (2) Platycelyphium voensii (2), Boscia coracea (2), Strychnos dessicata(1), ,Sericocomorphis, pallida(3), Sericocomorphis pallid(3)*	31

Transect 12

Transect	% Cover of *O.stricta*	Woody plants	Frequency
12	0 0 0 0 0 0 0 5 10 5	*Sericocomorphis pallida (2), Boscia coracea (1), Boscia coracea (1), Sericocomorphis pallida (2), Sericocomorphis pallida (1), Boscia coracea (4), Grewia similis (1), Sericocomorphis pallida (1), Boscia coracea (2), Grewia similis (2), Boscia coracea (1), Sericocomorphis pallida (3), Sericocomorphis pallida (5) Sericocomorphis pallida (7), Sericocomorphis pallida(4)), Bauhinia taitensis(1), Grewia bicolor(1)Bauhinia taitensis(1), Sericocomorphis pallida(3), Boscia coracea(2), Sericocomorphis pallida (3), Acacia senegalese(1)*	49