Website:www.jriiejournal.com ISSN 2520-7504 (Online) Vol.5, Iss.4, 2021 (pp. 290 - 303)

The Inter-specific Associations between *O. stricta* with Woody Plant Species and Elephant Distribution in Tsavo East National Park

[1]Elizabeth Kambua Titus, [2]Francis Kariuki, [3]Dr. Shadrack Ngene
[1,2] Kenyatta University, Kenya
[3]Kenya Wildlife Service
Corresponding Author : Email: lzbthkambua@gmail.com

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 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 elephant distribution and presence of woody plants was carried out. 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 formulate a management strategy for O.stricta in the TENP and similar ecosystems.*

Keywords*: Invasive Plants, Opuntia stricta, Elephant, Woody Plants, Correlation, Wildlife*

How to cite this work (APA):

Titus, E. K., Kariuki, F. & Ngene, S. (2021). The inter-specific associations between O. stricta with woody plant species and elephant distribution in Tsavo East National Park. *Journal of Research Innovation and Implications in Education, 5*(4), 290 – 303.

1. Introduction

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 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).). They 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).

O. 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 (Strum et al., 2015). Of these cactaceae, *O. stricta* has been spreading, outcompeting and displacing native plants. It has precluded browsing animals and local people in Laikipia 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 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. This study was done to determine the spatial distribution and abundance of *O. stricta* in relation to 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.

1.1 Statement of the problem

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 require an accurate spatial data on the overall distribution within an area, patterns of presence/absence, 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. This study was done to fill the knowledge gap and the findings provide scientific data essential for the control and management of this invasive plant species.

1.2 Research Question

Which plant species are associated with *O. stricta* and does the distribution of *O. stricta* correlate with presence of elephants?

1.3 Hypothesis

There is no significant relationship between other plant species and *O. stricta* nor is there significant relationship between *O. stricta* and elephant presence in TENP

1.4 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.

2. Literature Review

2.1 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).

2.2 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).

The plant has spread in Northern part of the country across the high altitude semi-arid savanna on the Laikipia plateau where it is 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 of the Park (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).

Figure 1: **Diagram of *Opuntia stricta***

3. Methodology

3.1 The study Area

TENP is situated in South Eastern Kenya lying on the opposite side of Tsavo West National Park (Figure 2) It borders Chyulu game reserve, South Kitui National reserve and Mkomazi Game Reserve in Tanzania 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(Ayieni,J., (1975).). 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).

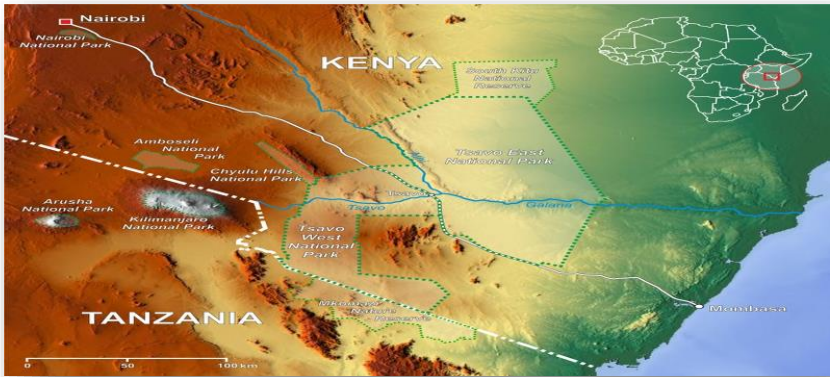

Figure 2: Map of Kenya in relation to TENP

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 (Patterson.,et al (2004*).* 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*, *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

3.2 Study site

The study was conducted between Bachuma and Ndara plains

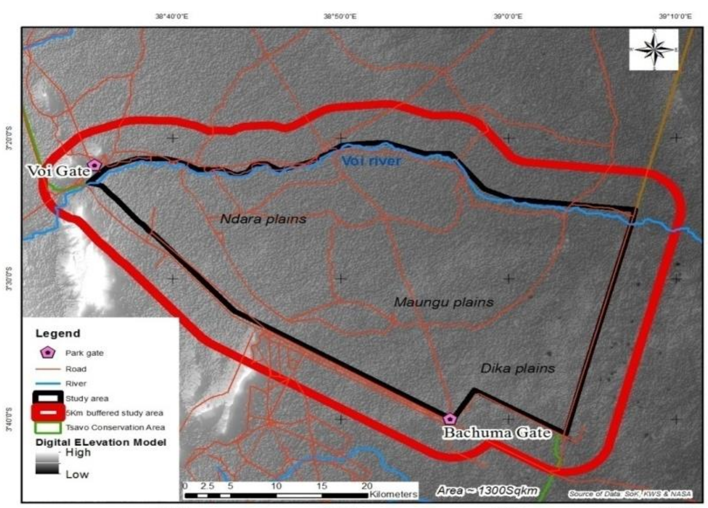

Figure 3: Satellite image of the study area (Wright and David, 2005).

3.3 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 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.

3.4 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.

3.5 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. 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.

3.6 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. 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.

3.7 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.

4. 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 (Figure. 4) and there was no *O. stricta* cover in transect nine.

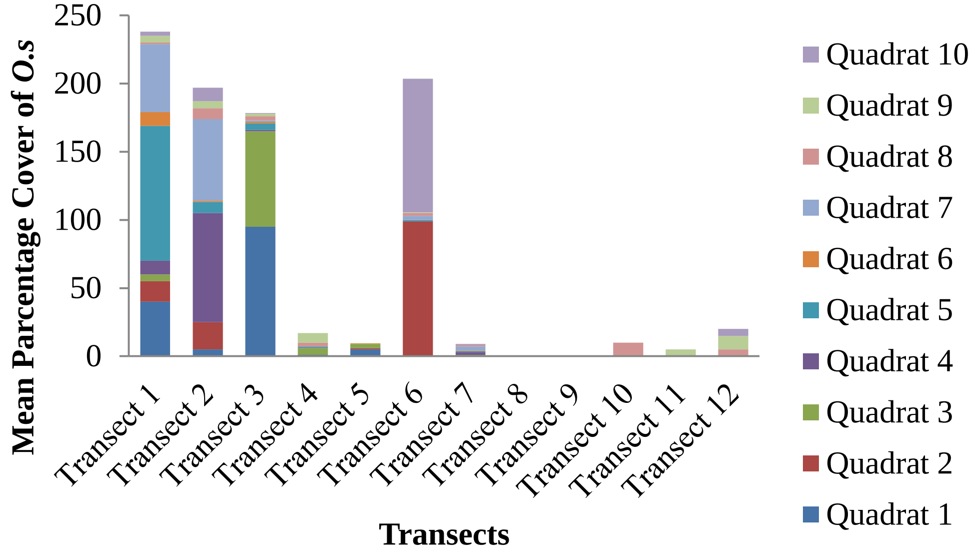

Figure 4. Mean Percentage cover of *Opuntia stricta* in the sampled area

4.2 Descriptive Statistics of *Opuntia stricta* Percentage Cover

The study carried out the descriptive analysis for the *O. stricta* distribution per the sampled transects and the findings summarized in the table below (1).

From Table 1 below, 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

Table 1: Descriptive statistics of *Opuntia stricta* percentage cover

Transect	Mean	Std Dev
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

Table 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.

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

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

Table 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 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 in the transects and the results shown in the table 4 below.

There was a significant difference between means of quadrat 1.00 and 8.00, 2.00 and 9.00, 2.00 and 6.00, 10.00 and 6.00. Therefore, the study rejected the null hypothesis (H_0) and concluded that *O. stricta* percentage cover differed in the 12 sampled transects. (Table 4)

Table 4: Separation of Means Cover of *Opuntia stricta*
Turkey B[a]

Quadrat	N	Subset for alpha =0.05
		1
6.00	12	1.4167
8.00	12	2.7500
9.00	12	2.8750
3.00	12	6.7500
4.00	12	7.7500
7.00	12	9.7500
10.00	12	9.7917
5.00	12	10.3333
2.00	12	11.4167
1.00	12	11.7750

Means for groups in homogenous subsets were displayed

a. Uses Harmonic Mean sample size = 12.000

4.3 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 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 5: 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.

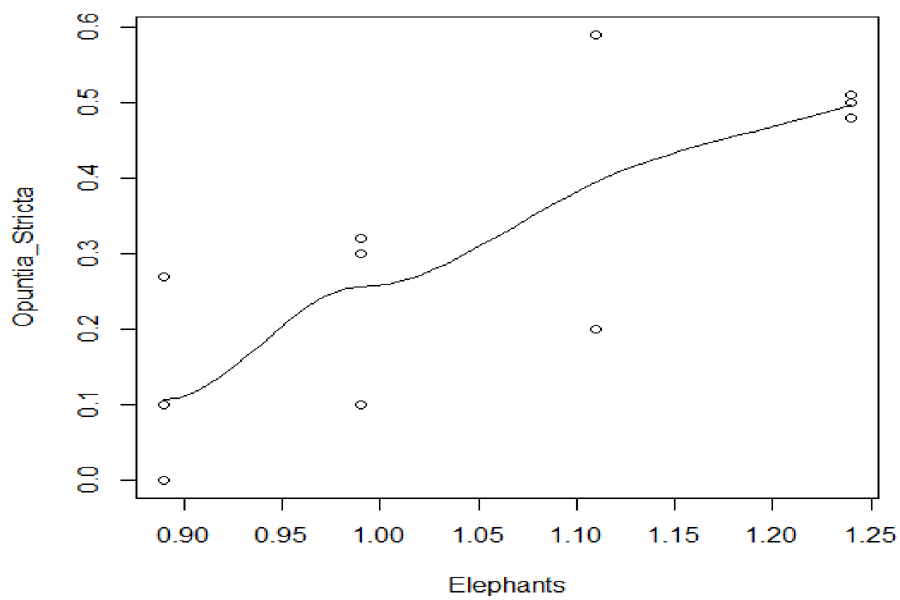

Figure Fig 5: *Opuntia stricta* and elephants correlation

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.*

4.4 Discussion

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, respectively .The other transects recorded low mean cover (Table 4). 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. 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).

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).

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. 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 rates 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). 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 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.

4.5 Hypothesis

There is no significant relationship between other plant species and *O .stricta* nor is there significant relationship between *O. stricta* and elephant presence in TENP

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.* 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. Conclusion and 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.

References

Arne, W., (2016). Invasiveness towards an International Association for open knowledge on invasive Alien Species. Management of Biological Invasions, Volume 7, Issue 2

Ayieni,J., (1975).Utilization of waterholes in Tsavo National Park (East).*E.Wildl. J.* 13, 305-323.

Bradley, B. A., Blumenthal, D. M., Wilcove, D. S., Ziska, L. H., (2010). Predicting Plant Invasions in an era of global change. Trends Ecol. Evol.25, 310-318.http//doc.doi.org/10.1016/j.tree.2009.12.003

Braun-Blanquet ,J., 1932. Plant sociology (Transl.G. Fuller and H.S. Conrad). McGraw-Hill, New York. 539 pp

Brent, E. J., Cushman, H. J., (2007). Influence of a large herbivore reintroduction on plant Invasions and community composition in California grassland. Cons. Biol. 21,515.

Bright, C., (1998). Life out of bounds. The World Watch Environmental Series. Norton, New York.

Brolin, K., (2004). Impact on plant diversity of introduced *Opuntia stricta* (Cactaceae) in southern Madagascar. Minor Field Studies International Office. *Swedish University of Agricultural Sciences*, No.287:23pp.

Brooks,G.P and Johanson, G.A.(2011). *Sample size considerations for multiple comparison procedures in ANOVA. Journal of Modern Applied Statistical Methods*. Vol. 10. No. 1, 97-109

Common Wealth Agricultural Bureau, (2017). Invasive Species eroding the Serengeti MaraEcosystem Cause Wildebeest Migration, Affecting Wildlife and Tourism ow.ly/Ey) 630 eodsy.

Common Wealth Agricultural Bureau, (2011). Invasive Species Compendium online datasheet. *O.s* (erect prickly pear). CABI publishing 2011.www.cabi.org/ISC. Accessed March,2011.

Convention on Biological Diversity, (2005). *Invasive Alien Species. Convention on Biological diversity*. http://www. Biodiv.org/programmes/cross-cutting /alien/.

Convention on Biological Diversity, (2007). *Invasive Species in an International Contest*: *IPPC, CBD, European Strategy on Invasive Alien Species and other legal instrument.*

, M., Mohamed, K., (2006). *Invasive Alien species in Africa Environment Outlook 2: Our Environment,* Our wealth (Chapter 10). United Nations Environment Program Nairobi .http://www.Unep.org/dewa/africa/docs/en/aeo-2/chapters/aeo-2-PRELIMS.pdf

Cox, G., (1990). *Laboratory manual of general ecology 6th Ed*. Dubuque, Lowa: William C. Brown;

Foxcroft, L. C., Pyšek, P., Richardson, D.M., Genovesi, P., (2013a). 'Plant Invasions in Protected Areas: Patterns, Problems and Challenges', Springer, Dordrecht.

Foxcroft, L.C., Witt, A., Lotter, W. D., (2013). 'Icons in peril: Invasive alien plants in African protected areas, pp. 117–143, Springer, Dordrecht.

Foxcroft, L. C., Hoffmann, J. H., Viljoen, J. J., Kotze, J. J., (2007). Environmental factors influencing the of *Opuntia stricta* an invasive alien plant in the Kruger National Park, South Africa. *South African Journal of Botany*73 109–112

Foxcroft, L. C., Richardson, D. M., Rouget, M., (2009). Patterns of alien plant distribution at Multiple Spatial Scales in a large National Park. Implications for Ecology Management and Monitoring. *Divers Distribution* 15: 367-378.

Foxcroft, L. C., Richardson, D. M., Wilson J. R. U., (2008). Ornamental Plants as Invasive Aliens: Problems and Solutions in Kruger National Park, South Africa. *J Environment management* 41:32 -51.

Foxcroft, L. C., Pickett, S. T. A., Cadenasso, ML., (2011). Expanding the conceptual frameworks of plant invasion ecology. *Perspectives in Plant Ecology, Evolution and Systematics*2011; 13:89–100.

Foxcroft, L. C., Rouget, M., Richardson, D. M., Macfayden, S., (2004). Reconstructing 50 years of *Opuntia stricta* Invasion in the Kruger National park, S. A: Environmental determinants and propagate pressure. *Diversity and Distributions,* 10 PP, 427-437.

Foxcroft, L. C.,Rejmánek, M., (2007). What helps *Opuntia stricta* invade Kruger National Park, South Africa: Baboonsor elephants? Vegetation Science, Conservation, Restoration and Survey of Plant Communities, Volume10, Issue 2

Foxcroft L.C., Richardson D.M., (2003). Managing alien plant invasion in the Kruger National Park, South . In Child LE., Brock G, Brundu G, Prach K, Pysek P, Wade P. M., Williamson M (eds) plant invasions: ecological threats and management solutions. Backhuys Publishers, Leiden, pp 385-404.

Gichua, M., Njoroge. L., Shitanda D., Ward D., (2013). Invasive Species in East Africa: Current Status for Informed Policy Decisions and Management.

Gillett, J.B., Dr. D. Wood., (1966). Check list of plants recorded in Tsavo East National Park

Githae E.W., (2018). Status of *Opuntia* invasions in the arid and semi-arid lands of Kenya. CAB Reviews 2018 No.003.

Global Environmental Governance Project**, (**2014). Direct and indirect economic impact of invasive species

Global Invasive Species Program, (2007**).**Indirect costs of invasive species in ecosystem Destruction.

Gordon and Arne, (2017). Biological Control of Hakea seilea.Schrad and J.C. Wendi and Hakea gibbosa (SM) Cav. (Proteaceae) in Africa.

Government of Kenya, (2005) '*ASAL National Vision and Strategy'; Natural Resource Management* 2005-2015, Government of Kenya http://csdes.uonbi.ac.ke.

Government of Kenya, (1996). A Strategic Plan for Managing Invasive Non native Plants on National Park System Lands. Invasive Species Management. U. S. Department of the Interior. National Park Service.

Groom, R. J., Western, D., (2013).Impact of Land Subdivision and Sedentarization on Wildlife in Kenya's Southern Rangelands. Rangel. Ecol. Manag. 66,1e9.http://dx.doi.org/10.2111/REM-D-11-00021.1.

Hanselka, C. W., Paschal, J. C., (1991). Pricklypear cactus: a Texas rangeland enigma. *Rangelands* 13: 109-111

Henderson, L., (2001). Alien Weeds and Invasive Plants. Plant Protection Research Institution. Handbook No 12 Cape town South Africa Pearl Printers.

Hobbs, R. J., Huenneke, L. F., (1992). Disturbance, Diversity and Invasion: Implications for Conservation. *Conservation Biology,*6: 324-333.

Hoffman, J. H., Moran, V. C., (1998).Evaluation of *Cactoblasis cactorum*(*Lepidoptera Phyccitidae)* as a biological control agent of *Opuntia stricta (cactaceae)* in the Kruger National Park, South Africa. *Biological control,*12(1):20-24:26 ref

Hoffmann, J. H., Moran, V. C., Zeller. D. A., (1998). *Long-term Population Studies and theDevelopment of an Integrated Management Programme for Control of Opuntia strictain Kruger National park,* S.A.J. Appl.Ecol.35,156-160:http://dx.dol.org/10.1046/j.1365-2664.1998.00283.x

Hoffman, J. H., Moran, V. C., Zimmermann, H. G., (1999.). Integrated Management of *Opuntia stricta* (*Haworth)* Haworth *(Cactaceae*) in South Africa: an enhanced role for renowned insect agents. *Biological Control of Weeds in South Africa* (1990-1998), 15-20.

Hosking, J. R., Sullivan, P. R., Welsby, S. M., (1994). Biological Control of *Opuntia stricta* (Haw.) Haw. Var*stricta* using *Dactylopius opuntiae*(Cockerell) in an area of New South Wales, Australia, where *Cactoblastis cactorum* (Berg) is not a successful biological control agent. *Agric Ecosyst Environ*48: 241–255

International Union for Conservation of Nature/ Species survival commission /Invasive Species Specialist /SSC/ISSG. (2004).*Global Invasive Species Database*. *IUCN- The world Conservation Union Species Survival Commission, Invasive Species Specialist Group.* http://www.issg.org, Accessed December 2011.

Ivens, G. W., (1989). East African Weeds and their control (second edition). *Oxford University Press, New York*, PP, 64-261

Kaye, Z. E., King, E., (2014). Kenyan Pastoralist Societies in transition. Varying Perceptions of the value of ecosystem services. *Ecology and Society*19 (3): 17.

Kenya Forest Service, (2010). Alarming Decline in Biodiversity: Invasive Species a Threat to World Biodiversity and the Global economy. Available at: http://www.enviroconserve.org/articla.php?Article =106.

Kioko, J. and Kiringe, (2012). Impacts of Livestock Grazing on a Savanna Grassland in Kenya. Arid Land 4, 29-3 of the larger grain borer, Arusha Tanzania16-21 May 1988, pp 28-52.

Kenya National Bureau of Statistics, (2010). The Kenya population and housing census. KNBS, Nairobi.

Kenya National Bureau of Statistics, (2015).Change in the Number of Visitors (in 000) to National Parks and Game Reserves, 2011-2015.

Kunyanga, C., Imungi. J. K., (2009). Nutrient Contents of the *Opuntia* cactus Fruit, Syrup and Leaves /Pads. University of Nairobi: Department of Food Science, Nutrition and Technology, Faculty of Agriculture.

Kumschick, S., Bacher, S., Dawson, W., Heikkila, J., Sendek, A., Piuess, T., Robinson, T. B., Kuhn., (2012). A Conceptual Framework for Prioritization of Invasive alien species for Management according to their impact. *Neo Biota*. 15-69-100.

Kunz, B. K., Linsenmair, K. E., (2008). The role of the olive baboon as seed disperser in a savanna Forest Mosaic of West Africa. *J, Trop. Ecol*.24.235-246.

Lazarides, M., Cowley, K., Hohnen, P., (1997). CSIRO Hand book of Australian weeds

Llewellyn, C., Foxcroft, M., Parsons, C.A., M.C Loughlin., D.M Richardson (2008).Patterns of Alien Plant Distribution at Multiple spatial scales in a large national park: Implications for ecology, Management and Monitoring.

Lotter, W. D., Thatcher L., Rossouw L., Reinhardt CF., (1999). The influence of baboon predation and time in water on germination and early establishment of *Opuntia stricta* in the Kruger National Park.*Koedoe,* 42(1):43-50;

Lowe S., Browne M., Boudjelas S., De poorter M., (2000).*100 of the World's Worst Invasive Alien Species. A selection from the Global Invasive Species Database. ISSG, Auckland, New Zealand* http://www.issg.org/database/species/reference-files/100 English. Pdf .

Mandujno, M. C., Montana, C., Franco, M., Golubov, J., Flores Martinez, A., (2001).Integration of Demographic Annual Variability in a Clonal Desert Cactus. *Ecology*.82:344-359.

Mathews, S., Brand, K., (2004). Africa Invaded–The growing danger of IAS. Global Invasive programme.

Merrill, L. B., Taylor, C. A., Dusek, R., Livingston, C. W., (1980). Sheep losses from range with heavy prickly pear infestation in: Ueckert DN, Huston JE (eds). Rangeland resources research. Texas Agricultural Experiment Station. Consol. Prog. Rep 3665 pp.

Merin U., Gagel S., Popel G., Bernstein S., Rosenthal l., (1987). Thermal degradation kinetics of Prickly pear fruit red pigment. *Journal of Food Science* 52:485-486.

Middleton, K., (1999). Who killed Malagasy cactus? Science environment and colonialism in Southern Madagascar *(1924-1930). Journal of Southern African Studies*25: 215-248.

Mohammed, Yasseen Y.,Barringer S.A., Splittoesser., (2007). A note on the uses of *Opuntiaspp.* In Central/ North America. Journal of Arid Environments 32:347-353

Moran, V. C., Hoffmann, J. H., Zimmermann, H. G., (2005). Biological control of invasive alien plants in South Africa: necessity, circumspection and success. *Front Ecol Environ* 3:7177.

Mwangi and Western, (1998). Habitat selection by large herbivores in Lake Nakuru National Park, Kenya. *Biodiversity and Conservation.***7**:1-8.

Munyasi, (2004). Ecology and Management of Invasive plants in Africa. Pages 161–174 Print ISBN: 978-1-4398-8126-2.

National Park Service, (1996). The guide to Managing the National Park System. U.S. Department of Interior, Washington DC. Google scholar.

NCSS Statistical Software Error-Bar Charts. Retrieved March 16, 2019 from https://ncss-penginenetdnassl.com/wp-Content/themes/ncss/pdf/Procedures/NCSS/Error –Bar-Charts.pdf

Ngene, S.M. (2011). Aerial census of elephants, Tsavo-Mkomanzi ecosystem.

Padron, B., Nogales, M., (2011). Integration of invasive *Opuntia spp* by native and alien seed dispersers in the Mediterranean area and the Canary Islands .Biological Invasions , 13:831-844.

Pimentel, D., (2002). Biological invasions: economic and environmental costs of alien plant, animal and microbe species. CRC Press. Google Scholar

Patterson, Bruce D. (2004*). The Lions of Tsavo: Exploring the Legacy of Africa's Notorious Man-Eaters. McGraw-Hill. p. 29.*

Oba, Zelalem, M., Nils, C., Stenseth., (2000). Compensatory Growth of the African Dwarf Shrub Indigofera spinosa following simulated herbivory. Ecological Applications, 10(4): 1133-1146.

Reyes-Agüero, J. A., Aguirre, R., Valiente-Banuet, A., (2006). Reproductive Biology of *Opuntia*: *A review*. *J. Arid. Environ*. 64, 549-585.

D. M., and Pysek., (2001). Naturalization and Invasion and Alien Plants- Concepts and definition. *Divers.Distribution*.6: 93-107

Ross, T. Shackleton., Arne B.R. Witt., Francis M. Piroris., Brian W., Van Wilgen (2017) .Distribution and Socio-Ecological Impacts of the Invasive Alien Cactus *Opuntia stricta* in Eastern Africa. Biological Invasions.

Shackleton R.T., Le Maitre D.C., Richardson D.M., (2015). Stakeholder perceptions and practices regarding prosopis invasions and management in South Africa. Ambio 44:569-581.

Sheley, R. L., Svejcar, T. J., Maxwel, B. D., (1996). A Theoretical Framework for Developing Successful Weed Management Strategies for Rangeland. *Weed Technol* .10:766-773

Simba, 1., Abel, M., Kamweya 2., Peter N. Mwangi 3., John M.Ochora 4., (2013). Full text of August 2013: *International Journal of Science and Research (IJSR*), India Online ISSN 231:9-7064

Simberloff, D., Martin ,J.L.,Genovesii, P., Maris, V., Wardle, D.A., Aronson, J.,(2013).Impacts of biological invasions. Whats what and the way forward .Trends in Ecology and Evolution 28,58-66.

Strum, S. C., Stirling, G., Kulusi Mutunga, S.K., (2015). The perfect Storm: Land use change promote *Opuntia stricta* invasion of pastoral rangelands in Kenya. *J Arid Environ* 118: 37-47

Tsavo Conservation Area Management Plan, (2008-2018.) Nairobi: Kenya Wildlife Service .p,6-8.

Tsavo East National Park Research Station, (2011). Rainfall distribution in Tsavo East

Tucker, Caroline M., Cadotte, Marc W., Carvalho, Silvia B., Davies, T.Jonathan., Ferrier, Simon, Fritz, Susanne A., Grenyer, Rich., Helmus, Matthew R., Jin, Lanna S., (May 2017). A guide to phylogenetic metrics for conservation, community ecology and macro-ecology. A guide to phylogenetic metrics for ecology. Biological reviews 92 (2): 698-715. dol.1111/bvr.12252.

Western D., (2009). Better grazing practices hold key to Kenyan draught (www.Document). URL:http://www.scider.net/global/desent-science/opinion/better-grazing practices-hold key-to-Kenyan -draught. Html (accessed 10.01.14)

Wijngaarden, W.V., (1985). Soils and Vegetation of the Tsavo Area. Geological Survey of Kenya, Nairobi.

Wilcove, D., Rothstein, D., and Losos, E., (1998). Quantifying Threats to Imperiled Species in the United States

Witt A., (2017). Guide to the Naturalized and invasive plants of Laikipia. CABI, Oxford shire, UK

Wright, D.,(2005). New perspectives on early regional interaction networks in East Africa. A view from Tsavo National Park Kenya. *African Archeological Review 22(3):*

Yurkonis, Scott, J., (2005). Invasion Impacts Diversity through Altered Community Dynamics