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Assessment of the Effective Methods to Eradicate *Opuntia cylindrica* and *Opuntia stricta* in the Serengeti Ecosystem

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Abstract

Invasive alien plant species are increasingly invading natural habitats posing a major threat to sustainable biodiversity conservation (Pauchard et al., 2009). *Opuntia* species have invade the Serengeti National Park since the 1950s (Bukombe et al., 2017). However, their distribution, extent and effects on natural habitat have less been investigated. The park was surveyed to map and assessed the level of *Opuntia* spp infestation in terms of cover and diversity within the park. Point Centered Quadrant sampling method was used where by 50 x 50 m & nested quadrant of 2 x 2 m for soil sampling. Five Quadrates were established in each hectare plot in infected and uninfected sites. In each quadrant, *Opuntia* species were identified and their canopy cover visually estimated. The total cover of all two species was approximately 6.9 km² in the five different sites. It was further found that each of the two invasive species suppressed the growth of native plant species within the nearby sites as the diversity of native herbaceous species was far lower in plots that were located closer to *Opuntia* patches. For this case the p-value was (4.34E-09 ≤ 0.05) indicating strong evidence against the null hypothesis. The p-value is less than the significance level thus the null hypothesis was rejected and concluded that there is a significant difference in the effectiveness of methods used to eradicate *Opuntia* species in Serengeti National Park. The management of the park should put more commitment on the management to controlling the two species and other exotics in order to avoid any further negative impact on the ecosystem.

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1.0 Introduction

1.1 Background Information

Serengeti National Park is among the Parks considered a primordial environment designated for the protection of its ecological integrity, thus prohibiting any introduction of alien or non-native flora and fauna (Bukombe et al., 2018). Apart from it being a Protected Area invasion of exotic species is inevitable due to various operations done in the park. The use of *Opuntia* species in tourists' facilities for ornamentation due to showy yellow flowers and the attractive purple-reddish fruit makes this cactus a favored pot and hedge plant and it is by this means that *Opuntia stricta* probably arrived in other parts of the world (Wakibara and Mnaya, 2002, Foxcroft et al., 2009). Later on, it was adopted by cattle herders for fencing their bomas before the park was gazetted a National Park and large number of nomadic Maasai being shifted to Ngorongoro Conservation Area Authority in 1959. However, the invasion of African savannas by numerous alien plant species is a key environmental problem confronting natural resource managers (Henderson, 2007). Alien species is a species, subspecies, or lower taxon introduced outside its normal past or present distribution, whereas an invasive alien species is an alien species whose establishment and/or spread threaten ecosystems, habitats or species with economic or environmental harm (Koike et al., 2004). Invasive alien plants can alter the structure, diversity and functioning of African savanna ecosystems by modifying fire regimes (Brooks et al., 2004), nutrient cycling (Ehrenfeld, 2003), causing the loss of native biodiversity (Levine et al., 2003), as well as by changing river flow regimes thus exacerbating water scarcity (Enright, 2000).

The increasing threats from invasive alien plants have triggered adverse environmental

and socio-economic effects worldwide. Evidence shows that landscape structure and land use altogether are key driving factors of alien plant invasions (FAO, 2003; Pauchard et al., 2009). Biologists reveal several drivers of plant invasion at the land use scale, which include anthropogenic disturbances (Davis et al., 2000) and increased propagules pressure (Colautti et al., 2006, Coautti et al., 2006).

This concern is particularly acute in East Africa where protected areas are not only globally significant centers of biodiversity but also important sources of revenue via wildlife tourism. While the importance of biodiversity for wildlife and human livelihoods and wellbeing is widely recognized, the response to invasive plant species in East African savannahs has been largely underdeveloped (Braun, 1973, Obiri, 2011). The establishment and management of a network of protected areas is a key component of global strategies to protect biodiversity and to conserve a representative sample of the Earth's ecosystems.

In Tanzania, human introduction of some tree species for specific reasons such as shade and fences has been observed to contribute to the invasion of some alien plant species (Wakibara and Mnaya, 2002). However, some invasions are associated with anthropogenic disturbances which are not clearly identified (Edward et al., 2009).

In Serengeti National Park (SENAPA), some alien plant species were previously reported to grow within borders (Bukombe et al., 2013a). However, the implementation of physical removal management control program by the SENAPA ecology department has been in place since then. Moreover, until the year 2013, after a survey which was conducted in 2011 (Bukombe et al., 2013a) no survey was conducted to assess the current status and sources of

introduction, spread and eradication methods of alien species in the park.

1.2 Problem Statement

The Serengeti National Park which is the larger part of the Serengeti - Maasai Mara Ecosystem is an internationally iconic protected area that receives several hundred thousand visitors annually (TANAPA, 2017) and as part of wildlife policy in Tanzania the Serengeti National Park is among others which are considered “pristine” or “semi-pristine” environment designated for the protection of its ecological integrity, thus prohibiting any introduction of alien or non-native flora and fauna (Bukombe et al., 2018). In spite of its iconic status, the Park continues to experience spread of alien invasive plants which if not promptly controlled may cause a decline of its state of integrity. Currently, about 20 alien plants have been reported to occur in the SENAPA (Bukombe et al., 2017), however, most of the alien plants have been naturalized within roads and some facilities (Witt et al. 2017), but except for *Opuntia cylindrical* and *Opuntia stricta* which are invasive outside of tourist facilities within the park such as at Ikoma, Nyasirori and other parts of western Serengeti National Park.

1.3 Justification

This work is in line with the requirements of the Tanzania wildlife policy in that it mainstreams both management and research work whereby the output of research are components of management plans. For Serengeti National Park, little information exists and no documentation on the spread and initiative to eradicate this notorious *Opuntia* species.

Similarly, their threats have not been studied to help conservation managers to formulate the appropriate strategies to control and eradicate *Opuntia* species. This will help to understand the spread, threats to others

species and best method to control and eradicate them. Removing or controlling further spread of existing invasive plants in Serengeti National Park is currently crucial for conserving native biodiversity, maintaining ecosystem functioning and ensuring that the savanna system continues to provide wildlife goods and services properly. This research has addressed the management of the threat of invasive alien plants such as *Opuntia* spp and suggested the eradication method.

2.0 Literature Review

Opuntia cylindrical and *O. stricta* have a common name “Sweetprickly pear”. *Opuntia cylindrical* and *O. stricta* are native from Ecuador to the USA; they were introduced as ornamental plants and spread widely, mainly in Africa and Australia, but also more recently in the Mediterranean basin and in disturbed areas in Caribbean (Bardsley & Jones 2006). Successful chemical and mechanical control methods have been applied and severely reduced the spread of these species in many areas which they were introduced. Though, there continues to be a risk of further introduction through the nursery trade. The species propagates easily from the leaf - pads or cladodes. Even a small piece lying on the ground can produce roots and flourish. These two species have become troublesome plants by being invasive in North western Serengeti (Bukombe et al., 2017) by invading grasslands.

2.1 Description

Plants are sprawling or erect, much-branched succulent shrubs reaching a height of 2 m. The cladodes (stems) are green to bluish-green, flattened, and about 10-25 cm long and usually 7.5- 15 cm broad. From the areoles develop the stout, slightly curved yellowish spines, varying in numbers from entirely absent to groups of one or two or more, normally clusters. Glochids (spine clusters) are yellow and relatively few, up to

5 mm long. The flowers are bright yellow and typically cactus-like, appearing during the summer months (Benson, 1982). The species are identified by the typical pear-shaped to spherical fruit, purple-colored at maturity, 4-6 cm long and 2.5-3 cm in diameter. Its outer surface is smooth and spineless except for a few glochids imbedded in the small areoles. The pulp is intense purple in color and sour tasting and contains about 60 hard-coated seeds. Older plants develop woody stems which provide support to the larger plants.

2.2 Distribution

Within the natural distribution, *O. stricta* is found from mainland Ecuador to mainland USA, throughout most of the Caribbean and along the Gulf (Mexico, and Texas, Alabama, Louisiana, Florida, USA) and the Atlantic coast of Florida and South Carolina (Benson, 1982), although USDA-ARS (2007) add presence as far north as North Carolina and Virginia. It is probably present and native to more countries in the Caribbean and Central America than indicated in the distribution list. The spinier variety (*O. stricta* var. *dillenii*) is native only to drier Caribbean Islands, though USDA-ARS (2007) also record it as present on mainland USA (Louisiana and Georgia). *O. stricta* has been introduced to many other countries where it quickly naturalized and became invasive. Countries that have reported serious invasions include Australia, Africa, Namibia (Henderson, 2001), Yemen (Ellenberg, 1982), India, Madagascar (Middleton, 1999) and lately also Spain and some North African countries (Le Houérou, 2002). It has probably naturalized also in many other countries where it has not yet been recorded as a pest and these are likely to include more countries in Africa (e.g.,

Eritrea, Ethiopia, Somalia and Zimbabwe) and Asia (e.g., Pakistan, Thailand). In its native range in some Caribbean countries *O. stricta* has also become invasive because of deforestation, erosion and overgrazing. In South Africa and Namibia large infestations have been reported from mainly dry savanna bushveld (Henderson, 2001), while in Australia all states are invaded (Parsons and Cuthbertson, 1992) with widespread invasion found throughout south-eastern Queensland and north-eastern New South Wales (Mann, 1970).

3.0 Methodology

3.1 Study area

The Serengeti ecosystem is located in northern Tanzania and extends to south-western Kenya between latitudes 1° and 3° S and longitudes 34° and 36° E. It spans some 30,000 km² and forms one of the most important cross-border conservation regions in the world.

3.2 Climate of the study area

The climate is tropical semi-arid with a pronounced dry season from June to October. Average annual rainfall is about 650 mm increasing towards the West with increasing altitude. The mean annual temperature is 28°C with three hottest months from July to September (30-32°C), while March through May is the three coolest months (22.7°C).

3.3 Diversity

The ecosystem is home to about 70 larger mammals some 550 avifauna species – supports one of the largest herds of migrating ungulates and the highest concentrations of large predators in the world (Kideghesho

2008). Its high diversity in terms of species is a function of diverse habitats ranging from riverine forests, swamps, kopjes, grassland, and woodlands.

Figure 3.1; The map of the Serengeti Maasai Mara ecosystem showing network of protected areas



Source: SENAPA GIS (2008)

3.4 Material used in this study/research

Glyphosate 480g/l Turbo Max was applied on foliage, the concentration of Glyphosate was mixed with water at the rate of 300ml-600ml/20L for foliar spray application by using backpack pumps (Knap sac pumps). Machetes were used for cutting, chopping and spear for stem injection, and burning method was applied on the dried patches. Quadrates were established by using the tape measure in each hectare of the sampled plots. GPS was used for collecting spatial data and the Arc GIS version 10.1 software was used to map the distribution of *Opuntia* spp. Camera and note books were helpful to note and capturing the field events, meanwhile, soil corer was used for exhuming soil for nutrients available. Methodology for data collection.

3.5.1 Assessment of *Opuntia* spp

An assessment was conducted in order to determine the coverage of *Opuntia* species in the park and ascertained the level of infestation. Identification was conducted in the experimental blocks. Information collected during this assessment was used as the baseline, or the first measurement, for monitoring.

Point Centered Quadrant sampling method was used where by 50 x 50 m & nested quadrant of 2 x 2 m for soil sampling. Five Quadrates were established in each hectare plot in infected and uninfected sites. In each quadrant, species were identified and their canopy cover visually estimated.

3.5.2 Mapping of *Opuntia* spp by using Arc GIS

The Arc GIS version 10.1 Software was used to map the distribution of *Opuntia* spp in SENAPA. The proposed control of the *Opuntia* spp need occurrence maps of the species which indicated the extent and abundance of the species in the proposed area for control. This helped the implementer of the control process to prioritize areas of concentration in order to optimally use resources.

i. Control methods

a) Physical control

Slashing and burning was used to kill and eradicate patches of *Opuntia* spp. Casuals were used, whereby four casuals each constituting 2 workers were formulated. The casuals were trained prior to work, there after they were supplied with equipment. After surveying the size of infected area, hectare plots were established and the total number of infected areas were put in grids

and later assigned for different experiments. Each grid was named and assigned to one team for control. The number of plots per team was in accordance to the total number of grids obtained. Using the cutters and hoes, the stems of *Opuntia* spp were cut and all attaching stems slashed in to pieces which are gathered at one point before they are burnt on drying.

b) Chemical control

Chemical control was possible with several herbicides, such as glyphosate. This chemical is currently registered as weed control chemical in Tanzania. In this work, Glyphosate was applied on stems of *Opuntia* spp through injection technique. The making of solutions followed the recommended rate for glyphosate, which is 1 part glyphosate (480 g/l) in two parts water (Zimmermann 1989). This solution was then injected in to holes which then were punched in the main stems of prickly pear plants. Experiments involved the lower concentration was also done in order to establish the lowest possible dilution levels to kill *Opuntia* spp. The use of lower glyphosate concentrations helped to minimize costs.

c) Combined physical and Chemical control

This was employed as the combination of Chemical method with mechanical mainly chopping and burning. The invasive plants were injected with glyphosate, and followed up after 20 and 30 days; the whole plant were chopped into pieces when they dried up and the pieces were burnt.

3.5 Data analysis

Data were analyzed using SPSS 17 (Bryman and Cramer, 2011). Regression analysis in SPSS 17 software was used during analysis. The Arc GIS version 10.1 Software was used to map the distribution of *Opuntia* spp in SENAPA.

4.0 Results and Discussion

4.1 Results

During mapping it was found that the area of infestation by *Opuntia* spp in SENAPA was 6.956 km². The areas covered by *Opuntia* spp are Ikoma, Nyasirori, Ndabaka, Speke Gulf, Seronera and Naabi in Serengeti National Park. Spraying of the alien invasive was done during the sunny day to facilitate the uptake of the chemical ingredients by the targeted plant for photosynthetic activities. The chemical ingredients tend to deter the food processing activity and in the later process the plant start wilting. Integrated methods produced the best results and showed the great effectiveness in control of *Opuntia* species where the area of 1.045 hectares which constitutes 64.11% of the total sampled area was cleared of *O.* species. Soil tests were used to measure soil nutrients that are expected to become plant-available in the soil (Table .1). Soil nutrient is an important element in nutrient management. We noted that the soil nutrients diminish at a closer range of *Opuntia* spp's patch and increase as you move away. This suggests that the plant gobbles the larger amount of nutrients available and deprive nutrients flow to other species.

The significance level of 0.05 indicates a 5% risk of concluding that a difference exists when there is no actual difference. For this case the p-value is ($4.34E-09 \leq 0.05$) indicating the strong evidence against the

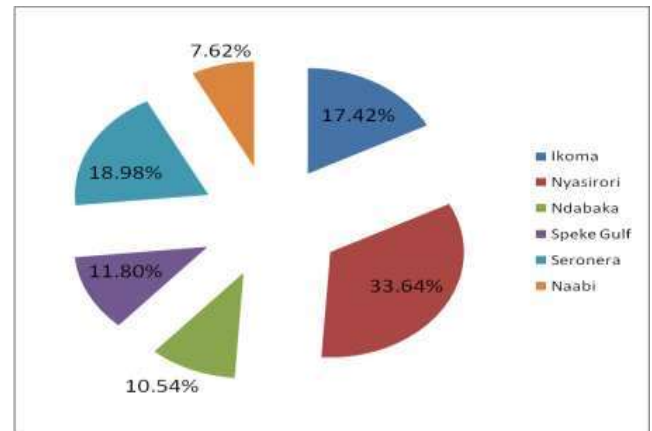
null hypothesis, so the null hypothesis is rejected. The p-value is less than the significance level thus, the null hypotheses is rejected and conclude that there is a significant difference in effectiveness of methods used to eradicate *Opuntia* spp in Serengeti National Park (Table 2). The composition of other plant species was definitely affected by *Opuntia* species. The composition of other plant species is 17 and their abundance in terms of individual number was also very scant as observed from 0 – 2 m from *Opuntia* species (Table 4.3). The increase in the composition of other plant species was observed when you move 7 – 9 m from *Opuntia* species. The areas such as Nyasirori area had an elevated coverage of *Opuntia stricta* by 33.64% compared to other sampled plots. Their abundance in terms of individual number was also slightly, this is due to the presence of the presence of human activities in such areas before this area was annexed to the National Park. The abundance of *Opuntia* species within the control plot was almost negligible compared to the plots with *Opuntia* species that signify *Opuntia* species pose a negative impact to other plants species.

Figure 1; The map showing the distribution of *Opuntia* spp



Source: Researcher, 2020

Figure 2; Percentage coverage of *Opuntia* spp in SENAPA, such areas covered by *Opuntia* spp are Ikoma, Nyasirori, Ndabaka, Speke Gulf, Seronera and Naabi.



Source: Researcher, 2020

Plate 1; Establishment of cover and quadrants for data collection



Source: Researcher, 2020

Table 1; Soil analysis results from the sampled plots

Parameters	Unit	Plot 1 (0 M)	Plot 2 (1 M)	Plot 3 (7 M)	Plot 4 (9 M)	Description	Control Plot	Acceptable Limit
OC	%	0.93	0.92	1.57	0.89	Low	1.57	02-Mar
OM	%	1.61	1.58	2.71	1.54	Low	2.71	2–10
pH		5.06	5.43	5.31	5.43	Low	6.18	6.0 - 7.0
EC. S	dS/m	0.67	1	0.97	0.63	Non saline	1.06	1.0 – 3.0
P	mg kg ⁻¹	5.03	4.32	2.38	3.86	Moderate	5.03	5.3
Ca	cmol (+) kg ⁻¹	0.15	0.07	0.31	0.1	Low	0.55	4.99
K	cmol (+) kg ⁻¹	0.01	0.03	0.03	0.01	Low	6.01	2.6
Mg	cmol (+) kg ⁻¹	0.01	0.02	0.04	0.01	Low	0.12	0.5–1.9
Na	cmol (+) kg ⁻¹	0.03	0.09	0.02	0.02	Moderate	0.09	0.15
Mn	mg kg ⁻¹	3.83	3.52	2.71	5.59	High	6.12	3.64
Zn	mg kg ⁻¹	0.67	0.49	0.55	0.61	Moderate	0.77	1
Fe	mg kg ⁻¹	59.47	85.7	88.1	48.86	High	88.96	41
B	mg kg ⁻¹	0.01	0.01	0.01	0.01	Low	0.01	0.5

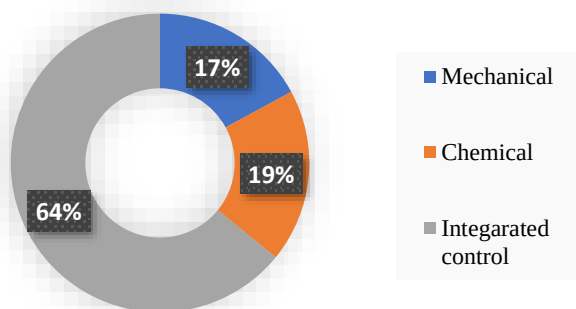
Source: Researcher, 2020

Table 2; Hypothetical test for best method to eradicate Opuntia species in SENAPA

Groups	Count	Sum	Average	Variance		
Mechanical (m)	21	3150	150	7440		
Chemical (m)	21	3070	146.1904762	3339.761905		
Mechanical&Chemical (m)	21	10450	497.6190476	84244.04762		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1710488.889	2	855244.4444	27.00095214	4.34E-09	3.150411311
Within Groups	1900476.19	60	31674.60317			
Total	3610965.079	62				

Source: Researcher, 2020

Figure 3; Effectiveness of control method applied on Opuntia species



Source; Field data, 2020

Plate 2; Foliage spraying of Opuntia species



Source: Researcher, 2020

Plate 3; Chemical and fire action on Opuntia species



Source: Researcher, 2020

4.2 Discussions

The observations suggest that human activities have mainly contributed to the sources of introduction and spread of *Opuntia* species in SENAPA. The sources of introduction or spread of most alien plant species can be found in localities such as road sides, settlement areas and in some wooded grassland areas (Zachariades et al., 2009). These sources include building materials, site decorations, road maintenance, waste dumping, and cattle bomas. In SENAPA large infestations have been noted to originate from ornamentation and fencing by the nomadic cattle herders before those areas were annexed into Serengeti National Park. Road maintenance and building materials contributed ominously to the introduction and spread of alien plant species in the park. This supports the fact that anthropogenic activities can play multiple roles in the growth and spread of invasive alien plants; the first role is that roads and human habitations are suitable habitats and reservoirs of propagules pressure (Parendes and Jones, 2000). And the second role is that roads are major pathways of alien plants due to trade and transport (Tyser and Worley, 1992; Hulme, 2009). Road network and maintenance occurred in different localities of the study area, including settlements and wooded grasslands. Thus, demonstrated the role of road network in increasing propagules pressure for alien plant invasion and spread in the park. Field observation showed that increased propagules pressure due to road maintenance occurred in two major ways which also was a clear demonstration of the known conceptual model of alien plant invasion (Parendes and Jones, 2000): first, road maintenance and mobilization of building materials served as a dispersal

mechanism by moving the propagules from their parent population or sources to several new sites or sinks, second is by creating site exposure (due to land clearance and excavation of barrow pits). Findings by Dukes and Mooney (1999) demonstrated direct links between number alien invasive plants and habitat disturbance and fragmentation levels. Therefore, frequent human activities which are not coupled with routine control would enhance the spread of alien plant species in the park.

4.2.1 Applied Control Methods

Mechanical control of *O. stricta* and *O. cylindrica* infestations was done by digging, slashing and burning. The mixture of kerosene and petrol was used to burn the plant after the chopped stem had dried up. Mechanical control method (Fig.3) 17.1% was effective on the experimental plots compared to other methods used. That constitutes to an area of 0.278 hectares which was subjected to mechanical control method. Mechanical control method was not very efficient and it showed little success in the long history of control against invasions. Digging, burning, crushing and burying the plants were some of the methods tried in previous years in the park but with only vanished for few years and then gradually the problem emerged later. That is because the smallest part of a cladode is able to root and grow when it comes into contact with the soil; mechanical chopping that caused the plants to break and fell on the ground always leads into a considerable vegetative propagation and even the increase on the spread and later on the invasion of the plant. The propagules are capable to remain viable for more than one year and have high genetic variability.

4.2.2 Chemical control

Due to the variable regulations around (de)registration of pesticides, the national list of registered pesticides or relevant authority was consulted to determine which products are legally allowed for use in Tanzania when considering chemical control. Precautionary measures were considered as pesticides should always be used in a lawful manner and in consistent with the product's label.

Chemical control method was applied to during eradication of *Opuntia* species. There are more advanced and less toxic hormone herbicides which are registered for the control of various invasive *Opuntia* species and include Glyphosate 480g/l Turbo Max. The concentration of Glyphosate was mixed with water at the rate of 600ml/20L. The inorganic arsenic-based herbicide, MSMA is used for control; small plants receive a cover spray whereas larger plants are stem-injected (Grobler et al., 2000) and MSMA is considerably less expensive than hormone-based herbicides.

Chemical control method was 18.8% effective on the experimental plots of *Opuntia* species compared to other methods used. In most Park ecologists used to apply chemical control measures during eradication of alien species and properties are still regularly inspected to evaluate the effectiveness of control operations (Goodall, 1996). Due to the high costs of chemical control, most ecologists are reverting to integrated control (Hoffmann et al., 1998) although chemical control is still used to kill isolated plants or small new infestations. During experimentation, stem injections of glyphosate in the summer were found to be the easiest and most effective way of controlling small invasions of *Opuntia*

cylindrica and *O. stricta*. In SENAPA an area of 0.307ha was successively cleared of *Opuntia* species invasion within the sampled area.

4.2.3 Integrated control

Integrated control of *Opuntia cylindrica* and *O. stricta* comprises taking full advantage of mechanical and chemical control. Integrated methods are effective for control of *Opuntia* species using cutting, drilling, stem injection, foliar spray application and burning methods. Therefore, the herbicides (Glyphosate 480g/l turbo Max) are recommended to be used in combination with fire after wilting for the control of *Opuntia* species starting with low dose of 300ml/20l in order to minimize herbicide residues in the soil and environmental pollution.

The combined method produced the best results and showed the great effectiveness in control of *Opuntia* species in SENAPA. The area of 1.045 hectares which constitutes 64.11% of the sampled area was cleared of the notorious invasive species. Large plants and clumps are dosed with the concentration of 600ml/20l in order to speed the action of the active ingredients of the chemical control for the best results, and then be limited to the periphery of the infestations to prevent further spread of the weed to un-infested areas (Reinhardt et al., 1999).

The study site presented a high abundance of the exotic target species, *O. cylindrica* and *O. stricta*, which can be mainly attributed to clonal regeneration, very common in both invasive species (Hoffmann et al., 1998; Baldano & Puignaire 2004). Exacerbating the uncertainty of alien invasive, the damage of *Opuntia* spp to the environment is measurable only years after the causative actions have occurred and once the adverse

impacts set in the effects can be detrimental and irreversible.

4.3 Risk and Impact Factors

4.3.1 Economic Impacts

Decreases grazing capacity and forage quality, browsing and animals may sustain damages to their mouth and digestion system by ingesting the fruit that are covered by small spines of *Opuntia* spp (Dumalisile, 2008). Grazers and browsers tend to avoid infested areas and by doing so the land becomes useless for wildlife and livestock farming, that increases grazing pressure on un- infested areas. A survey of farmers in southern Madagascar considered *O. stricta* to be an economic problem due to loss of livestock (Larsson, 2004). Access to infested areas is restricted for other productive uses. During the mapping of *Opuntia* species it was noted that in Serengeti National Park 6.9 km² has been affected by *Opuntia* spp that reduce the foraging areas for wildlife and cause habitat degradation, the areas which were so densely infested with

Opuntia spp tend to be unproductive and value of the land become decreased. The government may lose of tourism revenue due to the fact that as the habitat quality dwindles the wildlife quality also dwindles hence loss of biodiversity and revenue generated from aesthetic tourism. The invasive plants tend to impair visibility during filming or photographic activities.

4.3.2 Environmental and Ecological Impacts

Opuntia species were introduced in the late 1950s, since then the gradient of plant diversity is decreasing with increasing *O. stricta* density on different localities in SENAPA. There is consideration of the impact of *O. stricta* infestation on indigenous biodiversity since they are highly adaptable

to different environments and pioneering in disturbed areas. During this survey it was noted that there was the increase in plant diversity when you moved further away from the introduction site. Table 3 to 5 on the assessment on the impact of *O. stricta* infestation on assemblages of native plant species in the Serengeti National Park suggest that if the problem persist negative impacts on plant diversity and abundance will result to massive damage to environmental quality because *Opuntia* spp outcompete with native plants for space, light, nutrients, water and gradually displace the indigenous species. During this endeavor, a soil test was used to measure soil nutrients that are expected to become plant-available. It was noted that the soil nutrients diminish as you get closer to *Opuntia* patch and increase when you move away as depicted in (Table 1). This suggests that the plant gobbles the larger amount of nutrients available and deprive nutrients flow to other species. That also leads to change in ecological integrity and disrupting ecological balance of the park because the alien invasive plant dominates the surroundings and suppress the indigenous plants and cause modification of succession patterns.

4.3.3 Social Impact

Opuntia cylindrica and *O. stricta* can form dense plunk restricting tourist access to areas for filming or photographic activities, may impair visibility, and also cause injuries from the plant's spines. In protected areas such as in Serengeti National Park, infestations have a negative effect on aesthetics and recreation to the point that surveyed researchers and Park Ecologists since 1990s had tried to study the mechanism of eradicating the *Opuntia* spp within the park without a good success.

Tourists at the Pilanesburg National Park, South Africa, said they were willing to pay an increased entrance fee (US \$7 per day) for a (hypothetical) programme to control *O. stricta* (Nikodinoska et al., 2014). The similar case can be applied to Serengeti National Park to safeguard the natural vicinity and park pristine.

Countries with the same climatic conditions that have reported serious invasions include Australia, South Africa and Namibia (Henderson, 2001), Yemen (Ellenberg, 1982), India, Madagascar (Middleton, 1999) and lately also Spain and some North African countries (Le Houérou, 2002). The findings suggest that most impacts of the IAPs had serious impacts on the native vegetation, which means it is cognitively recognized that they pose a dangerous threat on any ecosystem (Gautier, (1992). The potential negative values are related to the potential reduced performance of ecosystem functioning and amplified costs for achievement of control programs. The rated the impact to ecosystem function and the expense of control methods as the highest concern, which is similar to the results found in a study in the Mediterranean region (Bardsley & Jones 2006). These were followed by the impacts to landscape aesthetics and by agricultural weeds. However, another study conducted in Spain shows that the changes in ecosystem stability is considered the third greatest impact of alien plants, after competition with native species and the effects on fauna (Andreu, Vilà & Hulme 2009).

5.0 Conclusion and Recommendations

5.1 Conclusion

The mapped area depicts the effects of *Opuntia* spp on herbivory, reduced cover of other species and diversity of foraging

materials within the park. The areas with high intensity were Nyasirori, Ndabaka, Ikoma, Seronera and Naabi whereby patches of *Opuntia* species were mapped with area of 6.9 km². The increase in the composition of other plant species was clearly observed when one move 7 – 9 m from *Opuntia* species. That means the increasing patch size of *Opuntia* species gobbles the nutrients available for other plant species while reducing the foraging material for the herbivores.

The spread of *Opuntia* species is now recognized as among the greatest threats to the environmental and economic well-being of the great Serengeti- Maasai Mara ecosystem. This study laid down the baseline for proper eradication measures to be taken to deal with invasive species before they completely alter the entire ecosystem.

The use of integrated methods to deal with *Opuntia* species produced the best results and showed the great effectiveness on eradication of *Opuntia* species and other notorious Invasive Alien plants. 64.11% of the total sampled area was cleared of *O. stricta* species by using integrated method. This approach showed the great effectiveness on eradication of *Opuntia* species in SENAPA hence that determined the feasible method for eradication of alien invasive in most Protected Areas.

5.2 Recommendations

- Mapping and long-term monitoring for early detection of *Opuntia* species for eradication purposes are vital procedures to ensure proper deterrence of exotics species invasion in any Protected Areas,
- Integrated method is the best approach that produces adequate

results on eradication of *Opuntia* species in Protected Areas is recommended. Ecosystem approach strategy for the management of land, water and living resources promotes conservation and sustainable use in an equitable way,

- Raising awareness and capacity building for TANAPA Park Ecologists and other stakeholders within other ecosystem on eradication and management of invasive alien plants is very ideal.
- Information sharing on alien invasive species builds cooperation and makes this problem more manageable within many ecosystems and at global scale. Continuous monitoring of experimental plots and exploration of other parts of the park by the Park Ecologist in SENAPA is very crucial so as to identify the gaps for continuous assessment.

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7.0 Appendices

Appendix 1: The action of chemical ingredients on Opuntia



Appendix 2: Stem injection of the chemicals



Appendix 3: Fruits eaten by the baboon as seen on the left, the seeds are spread on the poop as depicted on the right



Appendix 4: Coverage of the sampled plots according to eradication method applied

Mechanical (m)	Chemical (m)	Mechanical & Chemical (m)
195	165	600
25	110	400
150	150	375
80	100	525
400	150	200
50	100	225
150	225	400
100	120	400
50	100	300
150	300	1125
100	100	400
225	100	1200
225	225	300
100	100	225
150	100	200
150	100	400
300	150	875
150	100	400
100	200	875
150	225	625
150	150	400
2780	3070	10450
17.10%	18.83%	64.11%