Effect of Disturbance On the Population Structure and Regeneration of Trees: A Case Study of *Acacia xanthophloea (*Benth) Woodland in Ol-Pejeta Conservancy in Kenya

Godwin Leslie Muhati[1], Halima Saado Abdillahi[2]

[1]Kenya Wildlife Service, P.O. Box P.O. Box 40241-00100, Nairobi, Kenya

[2]East African Herbarium, National Museums of Kenya, P.O. Box 45166-00100, Nairobi, Kenya

Abstract: ***Tree damage was assessed in 1540 Acacia species (A. xanthophloea) in Olpejeta Conservancy. Using belt transects measuring (20 x 50 m), trees in the sample sites (closed and open) were counted. Measurements were made of Acacia tree count, recruits count, diameter at breast height, and mortality for both adult trees and seedlings. Densities were significantly higher in enclosed areas (398.3 ± 16.60 trees/ha) than open areas (243.3 ± 10.13) trees/ha. Elephants recorded the highest damage to the sampled trees with 54.55% damage while human beings caused 12.85% of the damage. Browsing was the main form of damage in open areas. Mean height for enclosed and open sites was 3.77 ± 4.61 and 5.35 ± 8.81, respectively. These findings suggest that herbivory damage did not have a significant effect on seedling regeneration but rather had an effect on population structure. Debarking caused by elephants occurred in the open areas with the highest being 96% of the sampled trees in the 11-25% damage class. The diameter class quotients fluctuated, an indication of the unstable population thus suggesting the impact of herbivory on population structure. Key recommendations include the creation of more enclosure zones, winning back more space by controlling the densities of browsers, long-term monitoring and the promotion of recruitment and regeneration rather than reducing mature tree loss.***

Keywords: *Acacia xanthophloea*; Browsers; Ol-pejeta; Regeneration; Herbivory

1. Introduction

Olpejeta Conservancy (OPC), a savannah ecosystem lies in a Black Rhino sanctuary that has a wide range of habitats and biodiversity of which *Acacia xanthophloea* is the key high canopy tree along the riverine habitat. The sanctuary was set up in 1989 to protect the highly endangered black rhino and eventually act as a donor site with surplus rhinos being used to stock other reserves (Brett, 1993). When the last 5-year management plan for black rhinoceros in Kenya was drawn up, it was predicted that OPC had a black rhino carrying capacity of 90(Kenya Wildlife Service, 2012). At this level, however, it was postulated that overcrowding and damage to the environment would begin to reduce the rhino breeding potential, and so the population would need to be controlled at a figure closer to a manageable level of 70, by periodic removals and resettlement. However, the achievement of this capacity was contingent on reducing the elephant population to at most 40 (Brett, 1993). Since the creation of the conservancy in 1988, no elephants have been removed and, with an elephant population of 226, giraffes 178 and a rhino population of 70, the habitat is already being threatened. A matter of concern in this conservancy has been the deterioration in the condition of *A. xanthophloea* woodlands. At present, the woodland is dotted with fallen dead trunks of mature trees and some scattered trees most of which are dying. With an increasing population of the three large herbivores (elephants, rhinos and giraffes), the *A. xanthophloea* woodland is being threatened.

In their overview of African savannas, Scholes and Walker (1993) describe four key determinants of savanna structure and function: water supply, nutrient supply, fire and herbivory. Disturbance is any process or condition external to the natural physiology of living organisms that result in sudden mortality of biomass in a community on a timescale significantly shorter than the accumulation of biomass. The number of many species of plants and animals may decline precipitously sometimes to extinction. Disturbance by humans, megaherbivores and other agents is common to a variety of natural systems and populations and plays a significant role in determining species richness and structure of plant and animal communities (Dublin et al., 1990; Molonel and Levin, 1996). Woodlands loss is a major cause of biodiversity decline in African Savannah Parks and can affect many habitat-dependent taxa, raising the prospects of an overall loss of biodiversity in protected areas (Cumming et al., 1997). In African savannas, large mammals such as elephants, giraffes and various antelopes are known to kill and damage trees via browsing, uprooting and trampling (Dublin et al., 1990). Herbivores may negatively impact plant populations by reducing the survival growth and reproduction of individual plants (Dublin et al., 1990; Mwalyosi, 1990). It can also affect secondary succession often associated with the transition from an open savanna with microphyllous trees to a more closed broadleaf thicket or woodland community. Also, seedling establishment and regeneration of Acacia trees may be a rare event under high browsing pressure by ungulates and may depend on the temporary decline of herbivore populations (Sinclair, 1995).

However at least three pathways exist by which large herbivores could facilitate the growth of tree populations or biomass, one is by dispersing fruits or seeds in dung (Coe and Coe, 1987; Miller, 1994). A second is by increasing germination via nutrient inputs (Augustine and Mcnaughton, 1998). The final potential mechanism is the suppression of other smaller herbivores which could have a stronger direct negative impact than the other large herbivores.

In this study, we examined the effects of disturbance on the population structure and regeneration potential of *A. xanthophloea* in OPC located in central Kenya. This study provides a snapshot of the assessed populations at a single point. The results of this study will assist the management of OPC to adopt appropriate strategies for managing the protected area. The following specific objectives were assessed (1) The Phyto-sociological status of *A. xanthophloea* in OPC, (2) The height and diameter class distribution of *A. xanthophloea* in OPC, (3) The causes and impact of damage to the *A. xanthophloea* regeneration in OPC.

Herbivory theory maintains that the unusual congregation of herbivores in a protected area put a lot of pressure on the resources within the habitats (Western and Maitumo, 2004). It hypothesises that a reduction of herbivore pressure results in regeneration of trees and bushes. It predicts that *Acacia* seedlings will grow in the absence of browsers but not in their presence. The proposed study was designed to test the herbivory theory and show whether *A. xanthophloea* woodlands can be restored.

1.1For purposes of this study, the following terms are defined as:

1) Phyto-sociological status-The structural identification, analysis, and classification of *A.xanthophloea* community.
2) Recruitment-Successive establishment of seedlings to the following height class.
3) Coppicing-Regrowth of damaged stems.
4) Regeneration-Replacement of a population stands with seedlings after a period of population loss due to disturbance.
5) Tree Damage- Defined as that which reduces the height of the main stem or kills the tree.

2. Materials and Methods

2.1 Study site

Olpejeta Conservancy is located in central Kenya, 230 km north of Nairobi, near Nanyuki, on the equator at longitude 36° 56′E and Latitude 0° 00′N covering an area of 36,600ha (Figure. 1). It lies on the Laikipia plateau between Mt. Kenya and the Aberdare Mountains at an altitude of 1800 m above sea level (ASL). The Reserve has a mean annual rainfall of 800 mm and a bimodal rainfall pattern giving long growth periods. The mean annual maximum temperature is 22˚C with a mean minimum of 10˚C. Rainfall normally comes in two seasons, long rains from March to May and short rains from October to December with the first more reliable than the second (Minimum 17mm, Maximum 122mm).The vegetation (White, 1983) is a mosaic of open grassland, *Acacia drepanolobium* dominated wooded grassland, *Eucleadivinorum* dominated scrub woodland and riverine woodland (Birkett, 2002). Along the Ewaso Ngiro River, the dominant tree is *Acacia xanthophloea*. The open grassland is dominated by *Themedatriandra* and the red oat grass species. Swampy areas near the river are dominated by *Typha* species. Large mammalian herbivores common at the study site include African elephants *(Loxodonta african*a), giraffes *(Giraffa camelopardali*s), elands *(Taurotragus ory*x), Burchell's zebras *(Equus burchelli*), Grant's gazelles *(Gazella grant*i). It is home to several bird species and small mammals. The sampling sites included open grassland, open bushland, dense bushland, riverine forest, open water, swamp and cropland (Figure.1).

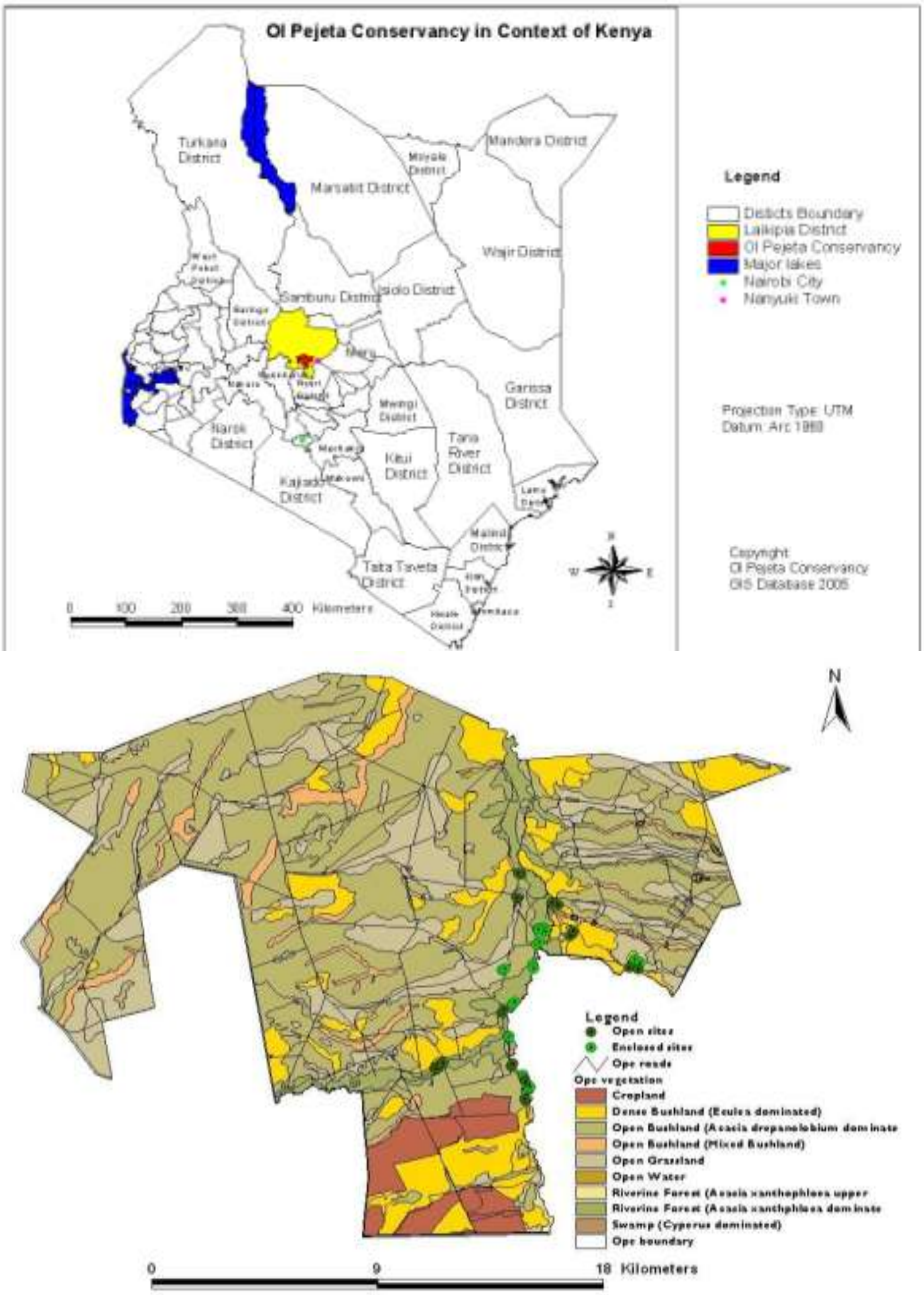

Figure 1: Olpejeta Conservancy vegetation map showing the sample points

2.2 Phyto-sociological status

Data collection was conducted in January to May 2010.The Belt transect method was used to assess the phyto-sociological status of *A.xanthophloea* due to the trees occurring in distinct belts along the EwasoNgiro River. Boma areas enclosed and out of reach of herbivores were delineated as controls and the open sites exposed to browsing as treatments. Twenty-four sampling sites were identified with 12 sites in the open and 12 sites in the enclosed (Figure 1). The predator-proof enclosures have been used by OPC for integrated livestock and wildlife management for over 13 years where livestock grazed in the conservancy during the day and secured in the enclosures at night. Belt transects were laid in replicates measuring 20m by 50 m for both the enclosures and the open areas. Acacia parameters recorded included**:** tree count (n); diameter at breast height (DBH); height (meters); mortality (m) and damage categorization. A total of 1540 trees were sampled with the enclosed area recording 956 trees and 584 trees for the open area.

2.3 Height and diameter class categorisation

Tree heights were determined using a clinometer following the method used by Rosenschein (1990). Tree height was assumed to be the height of the main tree crown, ignoring any small stems protruding from the crown. Stems with basal diameters of <1 cm were regarded as newly derived stems, and classified saplings **(**Height less than 0.5 m). Trees were grouped into seven size classes defined by stem diameter and height following the methods by Pellew (1983) and Ravindranath & Ostwald (2007) as follows,

Diameter size classes 1 = <1 cm; 2 = 1.1-10.1cm; 3 = 10.2-19.2 cm; 4 = 19.3-28.3cm; 5 = 28.4-37.4cm; 6 = 37.5-46.5cm; 7 = 46.51 cm were recorded.

The diameter at breast height (DBH) and height were categorised into seven size classes, with the distribution of the plants in each class recorded.

Height classes, 1 = <0.5 m; 2 = 0.51-1.20 m; 3 = 1.21-3.21 m; 4 = 3.22-5.22 m; 5 = 5.23-7.23 m; 6 = 7.24-9.24 m; 7 = 9.25> m was recorded.

2.4 Diameter assessment

The external damage to the main stem was evaluated on a scale adapted from Cunningham's seven-point scale for stem damage (Cunningham, 1992). Damage to branches was classified as follows based on observation: main stem broken (MSB); main stem snapped off (MSNO); main stem bitten off (MSBO); tree pushed over (PO), and tree browsed or branches broken but main stem intact (BWSE). The natural mortality agents were standing trees but dead with the bark peeling off and showed no evidence of disease or other damage.

2.4.1 Damage by elephants

Browsed distinctively by stripping off or plucking entire shoots, often the whole seedling, pushing over trees, break the main stems and debark and was easily distinguished from other browsers. Preferred feeding heights tended to be below 2m though the height of browsed plants somewhat greater (Birkett & Stevens-Wood, 2005).

2.4.2 Damage by rhinos

Rhinos made a clean cut of the main stem and may break stems with feeding height at 75 cm- 2 m(Brett, 1993; Birkett & Stevens-Wood, 2005).

2.4.3 Damage by giraffes

Giraffes ate the leaves, growing tips of branches and the main stems reaching heights of up to 5.5 m (Pellew, 1983).

2.4.4 Natural mortality agents

These trees will be standing but dead with the bark peeling off and shows no evidence of disease or other damage.

2.4.5 Other potential damagers

Buffalos- debarking (Mapaure and Campbell, 2002), Impalas- browsing, Small mammals- nibbling of shoots and leaves and Elands- hedging (Styles and Skinner, 2000).The above animals reach heights of 2m and below. Elands reach up to heights of 2.5 m.

2.5 Data analysis

Collected data was summarised into Excel worksheets and subjected to statistical analysis using the SPSS programme. Qualitative data depicting tree condition, damage levels, damage types and damagers were analysed using descriptive statistics. Tree density was computed by converting the count from the sample plot to a hectare basis. The population structure of the woodland was described in terms of tree density, diameter and height with the frequency distribution of trees in each class categorisation calculated. Comparative analysis of damage rates, mean basal diameters and mean height in the enclosed and open sites was calculated using T-test. Size class quotients (successive size class/preceding size class = quotient) and Simpson's Index of Dominance (C) (C = 1/N (N-1) Σ Ni (N-1) was used to analyse the stability of the *A. xanthophloea* population.

3. Results

3.1 Phyto-sociological status of *A. xanthophloea*

The tree densities of *A. xanthophloea* were significantly higher in enclosed areas 398.3 ± 14 trees/ha compared to open areas 243.3 ± 22 trees/ha (T = 2.33, d.f = 1, $p<0.05$). Seedling density was low at 32.08 ± 0.08 trees/ha in enclosed areas and 36.70 ± 0.18 trees/ha in open areas with no significant difference (T = 0.96, d.f = 1, $p > 0.05$)(Table1).

Table 1: Population and other parameters for sites (T tests **p<0.05) 0.01 * = Significant while, 0.001 ** = Highly Significant

Parameters	*Enclosed site*	*Open site*	*p Value*
Estimated population Size	956	584	
Population density (Mean ±SD)	398.3(16.60)	243.3(10.13)	**
Recruits density (Mean ±SD)	57.92 (0.07)	29.17 (0.10)	*
Main stem damage (Mean ±SD)	4.93 (2.02)	5.93 (1.70)	*
Damagers (Mean ±SD)	1.60 (0.50)	5.20 (2.10)	*
Flowering stems (Mean ±SD)	0.02 (0)	0.53 (0)	**
Basal diameter (Mean ±SD)	7.26 (9.18)	20.23(19.61)	**
Height (X±SD)	3.77 (4.61)	5.35 (8.81)	**
Seedlings density (Mean ±SD)	32.08(0.08)	36.70(0.18)	
Debarking (Mean ±SD)	4.31(0.82)	4.96 (1.3)	

Recruits density was 57.92 ± 0.07 trees/ha in enclosed areas and 29.17 ± 0.1 trees/ha in open areas with recruitment significantly higher in enclosed areas (T= 0.39, d.f =1, $p < 0.05$).

3.2 Population quotients

The quotients fluctuated in both the open and the enclosed populations (Figure. 2).The diameter class quotients for successive size classes approached a constant value of 0 from 10.7 up to diameter class of 28.4 - 37.4 where it increased to 8.36 and then decreased to the 0-constant value. The size class frequencies were discontinuous in both populations but were more evenly distributed in the enclosed (C = 0.04)than in the open population (C = 0.11).

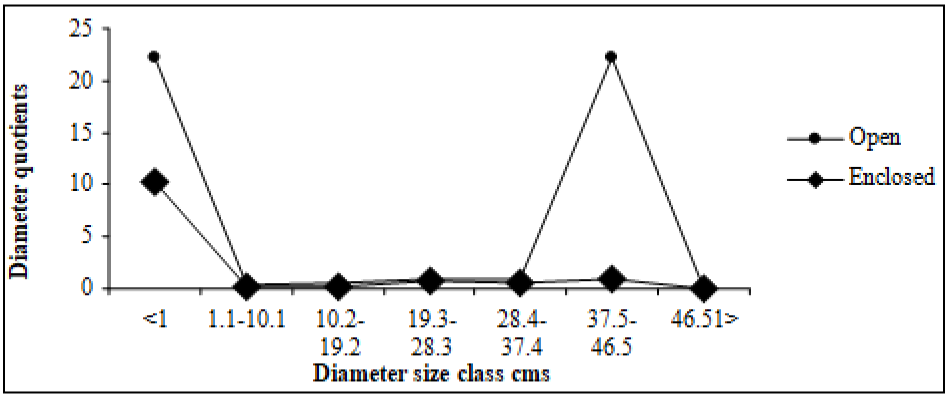

Figure 2: Population quotients diameter size class.

3.3 Diameter size class distribution

The mean basal diameters for the enclosed and open sites varied significantly at 7.26 ± 9.18cms and 20.23 ± 19.61 cm respectively (T = 0.102, d.f = 1, $p < 0.05$) (Figure 3). The highest number of trees (75.8%) are recorded in the 1.1-10.1cm size class while the lowest (0.7%) in the 37.5-46.5cm size class in the enclosed sites. In the open sites, the highest number of trees (33.9%) were recorded in the 1.1-10.1cm size class while the lowest (0.4%) in the 37.5-46.5cm size class. The size class frequency in OPC was irregular with a narrow base with fewer seedlings and more semi-mature trees.

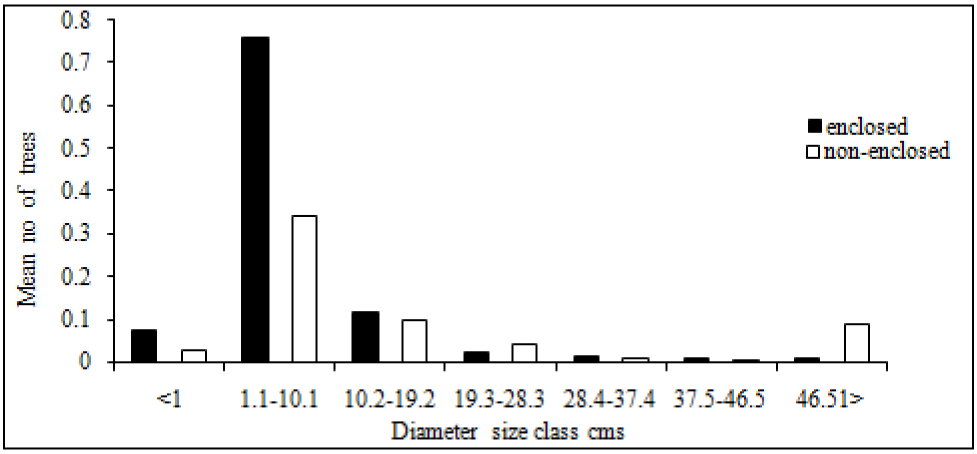

Figure 3: Diameter class in open and enclosed sites

3.4 Height size class distribution

The mean heights for the enclosed and open sites were significantly different at 3.77 ± 4.61 m and 5.35 ± 8.81 m respectively (T = 0.24, d. f = 1, $p < 0.05$). The open sites had more mature trees, i.e. Height class 9.25 > m at 29 % while the recruits, i.e. height class 0.51- 1.20 m comprised of a mean 11% of the population. Majority of trees (30.6% were in the 1.21-3.21 height class in the enclosed areas while (34.2%) in the height class 1.21-3.21 were in the open areas.

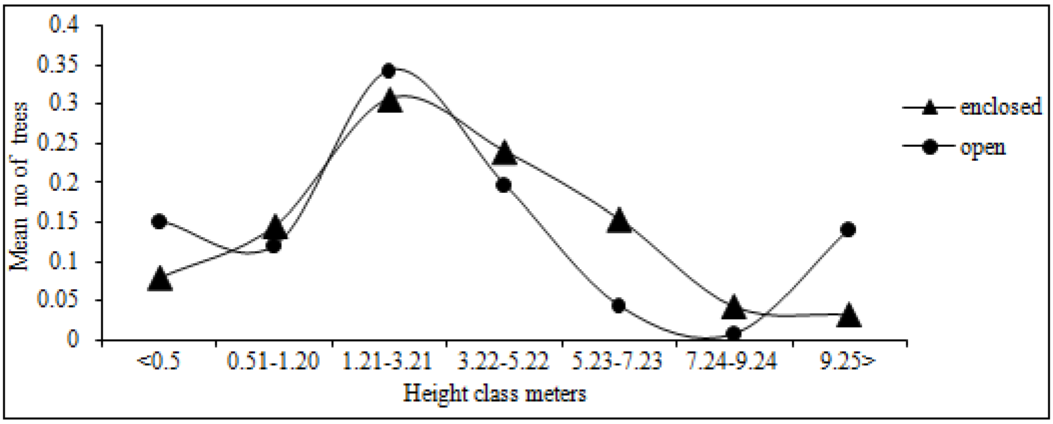

Figure 4: Height class distribution in both open and closed sites

3.5 Main stem damage (debarking)

Elephants were the sole cause of debarking in the open areas accounting for49.6%while human beings the sole cause in the enclosed sites accounting for43.1%. Most of the debarking occurring in the open areas with the highest being 96% of the sampled trees in the 11-25% damage class. Debarking was carried out in the large trees sizes between 19 cms to 46cms. None of the trees in both sites was ring barked(Figure.5).There was no significant difference between the proportions of trees debarked in enclosed and open areas (x^2 = 7.25, d.f =1, $p > 0.05$).

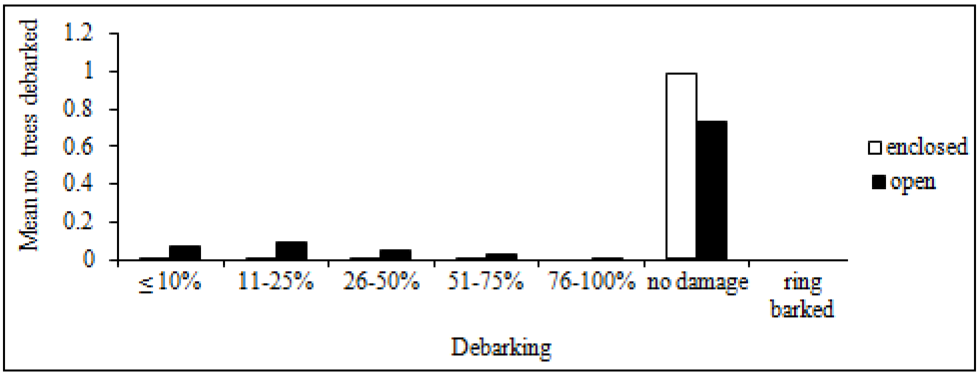

Figure 5: Debarking in open and enclosed sites

Debarking rates: a ≤ 10%, b. 11-25%, c. 26-50%, d. 51-75%, e. 76-100%, f. No damage and g. Ring barked.

3.6 Damage agents

Elephants were the main cause of tree damage in the open sites accounting for 58% of damaged observed while human beings in the enclosed site accounting for 6% of the sampled tree population (Table. 2). Rhinos and giraffes accounted for 7% and 3% of the damagers respectively while natural causes and other damage agents combined accounted for 2% and 3% respectively.

Table 2: Mean damage of other agents.

Damage agents	Mean trees Damaged (Open sites)	% Damagers	Mean trees Damaged (Enclosed sites)	% Damagers
GRE	0.09	9	0	
E	0.58	58	0	
R	0.07	7	0	
G	0.03	3	0	
EG	0.12	12	0	
ER	0.03	3	0	
E/Small ungulates	0.03	3	0	
RG	0.02	2	0	
Natural	0.02	2	0	
Small-ungulates	0.01	1	0	
Livestock	0	0	0.4	40
Humans	0	0	0.6	60

Where: GRE= Giraffe, Rhino & Elephant, E= Elephant, R= Rhino, RG=Rhino & Giraffe, Small UNG= Small Ungulates.

The main form of damage to the main stem was BWSE which accounted for 35% followed by MSNO at 25% in the open areas. MSNO was the main form of damage in the enclosed areas and accounted for 70% of the damaged trees while dead and dying trees accounted for 21% and 29% of the sampled trees respectively. More forms of damage were recorded in the open sites compared to the enclosed sites. T-tests showed a significant difference between damage to the main stem in the enclosed and open areas (T = 0.93, d.f= 1, $p < 0.05$).

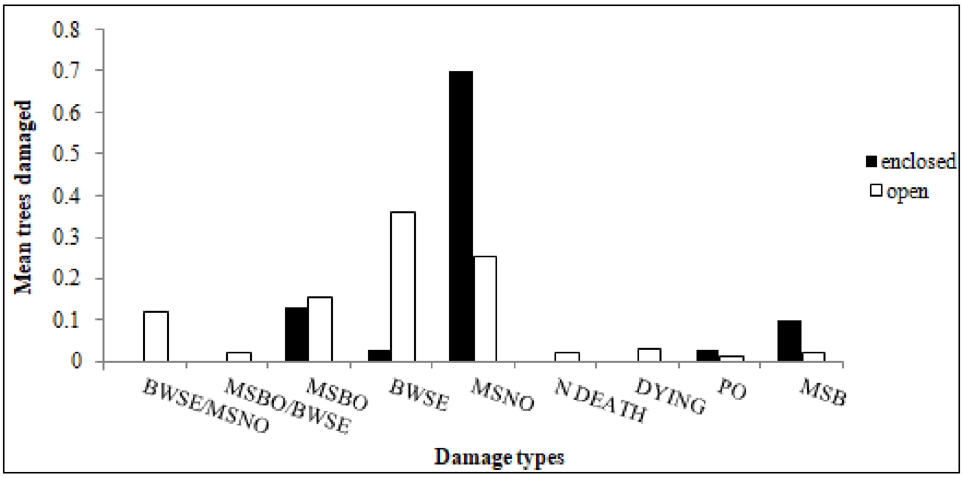

Figure 6: Damage types in both open and enclosed sites.

4. Discussion

4.1 Recruits and seedlings density

Contrary to our predictions, enclosed sites had an unexpectedly low seedlings density compared to open sites. The low density of seedlings in both open and enclosed sites may be a reflection of regeneration being periodic rather than continuous, as opposed to the effects of herbivory a common attribute of many Acacia species (Witkowski and Garner, 2000). A comparable result was observed by Western & Maitumo (2004) in Amboseli National Park predicting that heavy grazing promotes seedling growth. They established that seedling growth was significantly faster in the presence of large ungulates except elephants than over a comparable period in the absence of all large herbivores. They predicted the lower seedling numbers in the enclosed areas might be due to increased competition between grasses and the saplings leading to low seedlings density and possibly perhaps due to lack of grazers and invertebrate browsers. The results are similar toMwalyosi (1990), who established that declining Acacia stands was due to hurdles at the seedling stage, in particular, due to interactions with grass and climate and not elephants compressed into increasingly smaller areas. Apart from the effects on regeneration, the net effect of enclosures from the results appears to be positive for all tree size classes leading to a higher population density as compared to open sites.

Trees improve nutrient and humidity conditions under a canopy promoting the growth of grasses. While the enclosed sites in OPC are protected from the herbivores and thus have heavy undergrowth in the ground layer, the grasses may also suffer from lack of light and increased resource competition directly adding to the recruitment bottleneck via competition with tree seedlings (Scholes and Archer,1997).This observation may explain the low seedlings numbers in the enclosed site in the absence of herbivory damage.

The other plausible explanation for the higher seedling density in the open site may be due to 68.2% of the seedlings suffering the reversal effect from the recruit height class to the seedlings height class (0.51-1.20 m to <0.5 m) and as a result of being severely browsed (Midgley and Bond, 2001). Trees which are tolerant to browsing may be kept short but not killed entirely by browsers. They will then develop an extensive root system, enabling them to respond rapidly if browsing pressure is reduced or removed.From the results, it emerged that apart from herbivory which has the effect of reversing size classes and thus triggering an irregular size class distribution, the other significant aspect is the recruitment bottleneck.

4.2 *A. xanthophloea* size class distribution

The higher mean tree diameter in the open areas compared to the enclosed sites may be attributed to the fact that despite enclosures recording the higher frequency of trees compared to the open areas, the enclosures had a higher frequency of medium size class trees densities which had a net effect of lowering further the mean basal diameter. In comparison, the open sites had a lower ratio of seedlings and medium-sized trees but a higher number of mature-sized trees of 46.5 > cm. The significant difference between the basal diameters suggests that the impact of herbivory damage in the open populations had significantly manifested in the *A. xanthophloea* population. This observation is similar toHiscocks (1999), who observed a change in vegetation structure due to the impact of elephant damage between 1996 and 1998 in SabieSands Game Reserve.

Quotients, which provide a measure of the stability of a population (Harper, 1977) were irregular. The irregular size class distributions similar to those found in OPC have been ascribed to episodic recruitment and irregular growth patterns (Prins & Van der Jeugd, 1993; Wigand et al., 2000).The diameter class quotients in OPC fluctuated in the open site but relatively evenly distributed in the enclosed site suggesting a monotonic decline where there are high recruit frequencies with low frequencies in the larger size classes targeted by browsers. The size class frequency of the open population in OPC was steeper than would be observed from a monotonic decline but the size classes of the enclosed areas were relatively evenly distributed. A monotonic decline would be expected in populations, where there are often high recruit frequencies. This result suggests that the impact of herbivory affects the population structure of the *A. xanthophloea* woodland in OPC. Similar results have been recorded by Russ and Haller (1990), who established that *A. xanthophloea, A. tortilis*and*A. Senegal* appeared to have bimodal size-class distribution and ten years later more of an inverse-J size-class distribution with fewer larger trees due to the impact of herbivory.

Concerning height measurements, a majority of trees from the open and enclosed sites had heights< 9.25 m suggesting that the forest was dominated by recruits and sub-adults between 3-5m. The forest structure was typical of secondary regeneration where the tree numbers decreased as the height of the individual's increases (Cesar, 1992).The significant difference observed in the height class distribution in the open and enclosed sites may suggest that the effect of herbivory may not necessarily be negative in the open areas and might as well be encouraging growth. The enclosed sites lower mean height suggests that the lack of disturbance through herbivory may be negatively influencing tree growth. The form of disturbance in the enclosed sites is via livestock grazing and humans damaging the main stem. These forms of damage may not be sufficient to stimulate vertical growth. Another possible reason for lower mean height in the enclosed sites may be because the enclosed sites are regenerating sites that have not reached full maturity after heavy herbivore browsing in the early 1990s. A comparable result was observed by Western & Maitumo (2004) in Amboseli National Park predicting Acacia growth in the presence of herbivores. Majority of trees (35%) in the open areas were in the 1.21 – 3.21 height class ideal for elephant and giraffe browsing suggesting that they were trapped in the herbivory trap similar to observation by Martin & Moss (1997) who noted that individuals spend several years in the herbivory trap at heights < 2.5 m within reach of most mammal herbivores. They suggested that ageing of acacias will thus give information not on their age but the period since release.

4.3 Causes and effects of damage to regeneration

The main stem damage rates were much higher in the open areas than the enclosed with the main form of damage being browsing which accounted for 35.85% of the sampled trees. With the mean *A. xanthophloea* height in the open sites being 5.35 m, the elephant and the giraffe had adequate access to their preferred browse, and this could then explain 70.2% damage caused in the open areas compared to 3.1% in the enclosed. The main stem damage observed in OPC was largely observed in the 2-5 m and was done by the elephants and giraffes suggesting that large herbivores had an impact on intermediate to large size classes of acacia with recruits and seedlings prefered by rhinos and small ungulates.

Tree damages tend to increase with elephants densities (Wahungu, 2011). The carrying capacity of elephants in OPC is 40 translating to a density of 0.13 km^{-2}(Brett, 1993). Elephant density in OPC was 0.75 km^{-2}, in comparison, elephant densities in Serengeti fluctuated from 0.3 km^{-2} in the 1960s to 0.7 km^{-2} in 1980 with a marked physiognomic effect in the woodland population(Dublin et al.,1990). The density of elephants was much higher than the carrying capacity of the conservancy resulting in the observed tree damage.Despite the substantial debarking and herbivory similar to observations byYoung &Lindsay (1988) in Amboseli, the *A.xanthophloea*trees in OPC displayed a high level of tolerance with less than five percent succumbing to herbivory pressure. The observation of acacia woodlands in OPC dotted with fallen dead trunks of mature trees and some scattered trees most of which are dying may, therefore, be as a result of senescence. This is similar to Young & Lindsay(1988) who speculated through the demographic theory that episodic high rainfall caused pulses of seedling growth leading to even-aged trees that matured and died over several decades. The trees may have been of similar sizes but varying ages that endured periods of herbivory, trampling, debarking, fire and shade. When released, the trees matured together, forming stands of even size but different age which senesced.Abundant Acacia regeneration has been observed when elephants were excluded (Hatton and Smart,1984) or elephant populations have been reduced in other parts of Africa (Leuthold 1996; Lock, 1993). However, in the case of OPC, the enclosed areas excluded herbivory pressure but still recorded lower seedling densities.Seedling establishment is considered the principal demographic hurdle of many trees (Hughes, 1994). *A. xanthophloea* regeneration has also been found to be limited by water stress in dry conditions (Otieno et al., 2001), competition, fire, herbivory pressure and by high proportions of non-viable seeds, which are prone to rotting and heavy parasitisation in their pods (Carr, 1976). The low density of seedlings in both enclosed and open sites suggests that it is likely that various factors acting in concert or isolation may have affected regeneration other than herbivory.

4.4 Debarking

Elephants' utilisation of trees entails switching to bark stripping as tree height increases or during droughts (Smallie and O'connor, 2000). Preferred feeding height tends to be below 2m, the height of the browsed plants being somewhat greater (Jachmann and Bell, 1985; Ruess and Halter, 1990; Smallie and O'Connor, 2000).With the mean height of *A. xanthophloea* in the open sites being 5.35 m slightly beyond their preferred feeding height, it likely that the elephants resulted in debarking, thus the observed 26.71% damage.It is likely that Elephants prefer browsing and only debarked when the height class got beyond 4 m or when the conditions were dry. This may explain the high levels of browsing in the sampled population compared to debarking. All trees debarked by herbivores in OPC had survived exhibited high levels of tolerance similar to *A. xanthophloea* debarked in Amboseli (Young & Lindsay, 1988). Savanna plants have nevertheless evolved with herbivory, and many species demonstrate adaptations to cope with impacts. Survival and regeneration are common where some of the bark (Mwalyosi, 1987) or root system (Croze, 1974b) remains intact and are capable of regrowth even when the whole stem is removed or cut (Shackleton, 2000b).

5. Conclusion and recommendations

Given the current degree of damage in the elephant damaged populations and the tolerance of *A. xanthophloea* to damage, there appears to be little cause for concern regarding possible localised extinction in OPC. The study showed that the forest is dominated by middle-sized trees with fewer seedlings and mature trees. Tree damage was prevalent in the open sites which recorded low density of *A. xanthophloea* and low density of recruits. There were fluctuating quotients in successive diameter classes which is an indicator of an unstable population. Elephants were the main cause of damage in the open areas, while man was the main damager in the enclosed areas. Debarking was more prevalent in the open areas but low in occurrence. Herbivory damage appeared not to be significant enough to influence seedling regeneration with densities low in both open and enclosed areas. The critical concern in OPC should be the promotion of recruitment and regeneration rather than attempting to reduce mature tree loss. Creation of more enclosure zones would help in the recovery of the Acacia woodland in OPC. Further, recovery could be achieved if OPC wins back more space with controlled densities of browsers that are negatively impacting survival the structure of *A. xanthophloea*. A long-term monitoring plan on the recovery of Acacia trees would then quantify the effectiveness of such management interventions.

6. Acknowledgements

We are grateful to Earth Watch Black rhino habitat project for financial assistance. We are grateful to the management of Olpejeta Conservancy for bestowing trust in us to carry out the research and providing the necessary logistical support to facilitate the field work.

References

[1] Augustine, D.J., McNaughton, S.J., 2004. Regulation of shrub dynamics by native browsing ungulates on East African rangeland. *Journal of Applied Ecology*. 41, 45–58.

[2] Birkett, A. & Stevens-Wood, B. (2005) Effect of low rainfall and browsing by large herbivores on an enclosed savannah habitat in Kenya. *Afr. J. Ecol.43*, 123–130.
[3] Birkett, A. 2002. The impact of giraffe, rhino and elephant on the habitat of a black rhino sanctuary in Kenya. *African Journal of Ecology* 40:276–282.
[4] Brett, R.A. (1993) *Conservation Strategy and Management Plan for the Black Rhinoceros (Dicerosbicornis) in Kenya.* Kenya Wildlife Service, Nairobi. Pp 1–105.
[5] Croze, H. 1974b.The Seronera bull problem. II. The trees. *East African Wildlife Journal* 12:29- 47.
[6] Dublin, H.T., A.R. Sinclair and J. McGlade. 1990. Elephants *and fire as causes of multiple stable states in the Serengeti-Mara woodlands*. *Journal of Animal Ecology* 59: 1147–1164.
[7] Harper, J.L. 1977.Population biology of plants.San Diego: Academic Press. Cunningham,
[8] Hiscocks, K. 1999. The impact of an increasing elephant population on the woody vegetation in southern Sabi Sand Wildtuin, South Africa.*Koedoe*42:47–55.
[9] Kenya Wildlife Service (2012) *Conservation and Management Strategy for the Black Rhino (D. b. Michaeli) in Kenya*, (2012-2016), 5th edn. Kenya Wildlife Service, Nairobi, Kenya, pp. 57.
[10] Leuthold, W. 1996 Recovery of woody vegetation in Tsavo National Park, Kenya.1970-94. *African Journal of Ecology*. 34:101-112.
[11] Mapaure, I., and L. Mhlanga. 2000. Patterns of elephant damage to *Colophospermum mopane* on selected islands in Lake Kariba, Zimbabwe. *Kirkia*17:189–198.
[12] Miller, M. F. 1996. Acacia seed predation by bruchids in an African savanna ecosystem. *Journal of Applied Ecology* 33: 1137–1144.
[13] Mwalyosi, R. B. B. 1987. Decline of *Acacia tortilis* in Lake Manyara National Park, Tanzania.*African Journal of Ecology* 25:51–53.
[14] Mwalyosi, R. B. B. 1990. The dynamic ecology of *Acacia tortilis* woodland in Lake Manyara National Park, Tanzania. *African Journal of Ecology* 28:189–199.
[15] Ravindranath, N.H. Madelene Ostwald. 2007. Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Round wood Production Projects*Volume 29 of Advances in Global Change Research*Springer Science & Business Media.
[16] Otieno, D.O., Kinyamario, J.I. and Omenda, T.O. 2001 Growth features of *Acacia tortilis* and *A. xanthophloea* seedlings and their response to cyclic soil drought stress. *African Journal of Ecology*39: 126– 132.
[17] Pellew, R. A. P. 1983. The impacts of elephant, giraffe and fire upon the Acacia tortilis woodlands of the Serengeti. *African Journal of Ecology* 21:41–74.
[18] *Review of Ecology and Systematics* 28:517–544.
[19] Ruess, R. W. and Haller, F. L. 1990.The impact of large herbivores on the Seronera woodlands, Serengeti National Park, Tanzania. *African Journal of Ecology* 28:259–275.
[20] Scholes, R. J., and B. H. Walker. 1993. *An African savanna: synthesis of the Nylsvley study*. Cambridge University Press, Cambridge, England, UK.
[21] Scholes, R. J., and S. R. Archer. "Tree-grass interactions in savannas." *Annual review of Ecology and Systematics* 28.1 (1997): 517-544.
[22] Sinclair, A. R. 1995. *Equilibrium in plant-herbivore interactions*. Pp. 91–113 In Sinclair, A. R. and Arcese, P. (eds), Serengeti II: *Dynamics, management, and conservation of an ecosystem* University of Chicago Press, Chicago, London.
[23] Smallie, J. J., and T. G. O'Connor. 2000. Elephant utilisation of *Colophospermum mopane*: possible benefits of hedging. *African Journal of Ecology* 38:1–9.
[24] Styles, C. V., and J. D. Skinner. 2000. The influence of large mammalian herbivores on growth form and utilisation of mopane trees, *Colophospermum mopane*, in Botswana's Northern Tuli Game Reserve, *African Journal of Ecology* 38:95–101.
[25] Wahungu, G.M., Mureu, L.K., Kimuyu, D.M., Birkett, A., Macharia, P.G. and Burton J.(2011). Survival, recruitment and dynamics of Acacia drepanolobiumseedlings at Olpejeta Conservancy, Kenya, between 1999 and 2009.
[26] Western, D. and Maitumo, D. 2004. Woodland loss and restoration in a savannah park: a 20-year experiment. *African Journal of Ecology*. 42, 111– 121.
[27] Wiegand, K., Ward, D., Thulke, H. and Jeltsch, F. 2000. From snapshot information to long-term population dynamics of Acacias by a simulation model. *Plant Ecology*. 150, 97 - 114.
[28] Witkowski, E. T. F., and R. D. Garner. 2000. Spatial distribution of soil seed banks of three African savanna woody species at two contrasting sites. *Plant Ecology*.149:91–
[29] Young, T. P. and Lindsay, W. K. 1992. Role of even-age population structure in the disappearance of A. *xanthophloea* woodlands. *African Journal of Ecology*. 26: 69–72