INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES Volume 2, No 3, 2012

Research article **ISSN 0976 – 4402**

Impact of African elephants on *Baikiaea plurijuga* woodland around natural and artificial watering points in northern Hwange National Park, Zimbabwe

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doi:10.6088/ijes.00202030022

ABSTRACT

The extent of African elephant (*Loxodonta africana*) induced damage on shrub and mature *Baikiaea plurijuga* trees was investigated around artificial and natural watering points in northern Hwange National Park, Zimbabwe. Damage was assessed in three zones of elephant occupancy during the dry season i.e. high elephant occupancy zone (≤ 1 km from water points), moderate elephant occupancy zone (> 1–2 km from water points) and low elephant occupancy zone (> 2 km from water points). A total of 48 plots along baseline transects were sampled among four artificial watering points and four natural watering points at increasing distance from the watering points. Damage to recruits, mature *B. plurijuga* and overall woody vegetation decreased with distance from artificial watering points. In addition, damage to mature *B. plurijuga* and overall woody vegetation decreased with distance from natural watering points, whereas damage to recruits did not change with distance from water points. Our results show that artificial watering points are associated with higher damage to *B. plurijuga* recruits and overall woody vegetation within ≤ 1 km radius from water points compared to natural watering points. Other changes associated with increasing distance from artificial watering points were increase in canopy cover and decrease in woody species diversity. In the natural watering points, we recorded an increase in canopy cover, mean basal area of *B. plurijuga* shrubs and height *B. plurijuga* shrubs, and a decrease in species diversity with distance from watering points. Overall, woody species diversity was higher around natural watering points than around artificial watering points. Our findings suggest that browsing by large herbivores near watering points leads to the degradation of vegetation.

Keywords: African savanna, herbivory, *Loxodonta africana,* piosphere, water points.

1. Introduction

African elephants (*Loxodonta africana* Blumenbach) can alter habitats by breaking or uprooting trees and shrubs in savannas (Valeix et al., 2011). African savannas are typified by the coexistence of woody and herbaceous species, with relative proportions of each influenced predominantly by soil moisture availability, soil nutrient status, fire and herbivory (Scholes and Walker, 1993). The African elephant is regarded as the main factor determining savanna woody cover, because of its very large body size that enables it to kill mature trees (Owen-Smith, 1988). The response of vegetation to elephants is difficult to interpret as it may

Received on December 2011 Published on February 2012

be influenced by drought, fire, disease and other herbivores (Gillson and Lindsay, 2003; Wiseman et al., 2004). There are, however, clear cases of elephant browsing impact on natural systems as recorded in Tsavo National Park, Kenya, where elephant deaths resulted in the recovery of woodlands typical of that region (Leuthold, 1996).

Despite the long and continuous history of large mammalian herbivory, much emphasis has traditionally been placed on the significance of the elephant in creating instability within savanna ecosystems (Pellew, 1983). At high density, large herbivores, such as elephants, increase tree mortality and may convert woodland to grassland (Guy, 1989). The impact of herbivory on plant performance depends on timing, location, intensity and frequency (Crawley, 1997). According to Guldemond and Van Aarde (2008), large herbivores have a negative impact on woody vegetation at moderate to high population densities. The African elephant is considered to be a keystone species that can radically change an ecosystem through its destructive feeding behaviour (Van De Koppel and Prins, 1998). Elephants play a key role in modifying vegetation in the Hwange National Park (HNP), Zimbabwe (Conybeare, 1991; Valeix, 2002). Elephant impacts on woodland are also dictated by surface water availability. For example, variability in dry-season foraging that is determined by surface-water availability could be the primary factor influencing population dynamics of large herbivores in arid and semi-arid environments (Chamaillé-James et al., 2007a).

In arid and semiarid environments surface-water strongly constrains the distribution and abundance of large herbivores during the dry season (Chamaillé-Jammes et al., 2007b). Consequently, surface water is considered to be one primary driver of elephant population dynamics (De Beer and Van Aarde, 2008; Shannon et al., 2009; Smit and Grant, 2009). It has been suggested that the introduction of artificial watering points in wildlife areas results in most animals becoming sedentary around artificial watering points during the dry season when seasonal watering points dry up (Thrash and Derry, 1999). Such aggregative response may modify the environment around watering points (Bromwich, 1972; Laws, 1970) as the elephant home range decreases (Owen-Smith, 1988). In HNP, it has been reported that wild animals gather in high densities near watering points in the dry season, and with elephants representing approximately 80–90% of the herbivore biomass at some watering points (Valeix et al., 2007).

There had been an extensive development of artificial watering points in HNP. Artificial watering points established between 1936 and 1980 increased the area of HNP available to elephant from approximately 35% to 75% (e.g. Cumming, 1981). Elephant population has increased within the HNP since 1986 when culling was suspended (Valeix, 2002), and the elephant population was at estimated at 45,000 individuals in 2001 (Dunham and Mackie, 2002). The establishment of artificial water points in game reserves is generally accompanied by direct and adverse effects on the environment (Tafangenyasha, 1997a). Smit et al. (2007) suggested that artificial water points in a landscape could change the distribution of herbivores, even in a landscape where natural water is available, thereby transforming patterns of landscape use.

Vegetation gradients developing around water sources (i.e. piospheres) are important features of arid and semi-arid ecosystems (Chamaillé-Jammes et al., 2009). Chamaillé-Jammes et al. (2009) reported that woody cover within the piospheres in HNP was heterogeneous and recommended for further investigation on piosphere. Here we contribute to the understanding of woody vegetation within piospheres in HNP. Our study objectives were: (1) to assess the relationship between elephant induced damage to *Baikiaea plurijuga* dominated woody vegetation with distance from artificial and natural watering points, and (2) to compare and establish structural and compositional changes to *B. plurijuga*-dominated vegetation in elephant occupancy zones at both artificial and natural watering points.

2. Materials and Method

2.1 Study area

The study was conducted in HNP which is located to the north-west of Zimbabwe, between 18º 30' and 19º 50' S and 25º 45' to 27º 30' E. The park occupies some 14,651 square kilometers, (Childes and Walker, 1987), and comprises of three major camps: Hwange Main Camp, Sinamatella Camp and Robins Camp. The present study was confined to Hwange Main Camp area where most of the artificial watering points are located. Hwange Main Camp area covers some 1,251 square kilometers. Mean annual rainfall for Hwange Main Camp is 650 mm (Dudley et al., 2001). The rainy season is from November to March, with January being the wettest month (Rushworth, 1975). The cool dry winter months extend from May to August. Mean monthly minimum and maximum temperature over 40 years for the Hwange Main Camp area ranges from 24 ºC in June to 32 ºC in October (hottest month of the year). July is the coldest month, with an average screen temperature of 4.6 ºC at Main Camp. More detailed description of the water point's distribution and large herbivore population fluctuations in HNP are provided by Martin et al. (2010) and Valeix et al. (2008) respectively.

HNP is classified as an area of mixed woodland and open savanna (Greaves, 1996). Kalahari sands carry a high woody species biomass, and grass is relatively sparse (Rushworth, 1975). Woodland occupies about 64%, shrubland 32% and grassland only 4% (Department of National Parks and Wildlife Management, 1998). The dominant vegetation type for Hwange Main Camp is *B. plurijuga* mixed woodland and shrubland, commonly associated with *Combretum* spp., *Acacia* spp. and *Terminalia sericea* (Valeix, 2002).

2.2 Sample site selection

A stratified random sampling procedure was adopted in this present study. Geographic Information System (GIS) ArcView version 3.2 was used to create three kilometer buffers around each of the watering points. This was followed by an overlay of vegetation types on the three kilometer buffers using Rogers (1993) vegetation map of HNP. Watering points falling within vegetation types containing 50% or more *B. plurijuga* as dominant or co-dominant species were selected. This brought uniformity in type of vegetation sampled among artificial and natural watering points for comparison purposes.

An assessment of pumping history of the selected watering points was carried out. Watering points were divided into natural (seasonal) and artificial points. For the seasonal and natural water points selected, their proximity to artificial watering points was assessed. Natural watering points located within five kilometers of an artificial watering point were discarded as effects of browsing from artificial watering points would likely have an influence on the results. Selected watering points had to be five kilometers or more apart to avoid range degradation and homogenization of vegetation through coalescing of piospheres (Zambatis, 1980), and were above 15 years in age. Consequently, artificial watering points of similar elephant concentration levels were selected for sampling to ensure that there was similarity in elephant numbers based on baseline data from Wildlife and Environment Zimbabwe and Zimbabwe Parks and Wildlife Management Authority.

The development of sampling technique used in this present study followed that of Brits et al. (2002). At each selected watering point, a 3 km long baseline transect was traversed. Direction of each baseline transect from the watering point was determined through a randomization procedure, using a random number table. Random numbers were used as angles that indicated the direction of the baseline transect from the true North. Plots measuring 20 x 20 m were systematically placed at 500 m intervals as follows; 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 km along each baseline transect from the watering point. This gave a total of six plots at each water point.

Sampling was carried out within three elephant occupancy zones around a watering point according to Conybeare (1991). Data were collected in May and June 2006. At this time of the year species composition is most conspicuous. Four artificial and four seasonal watering points were sampled to make a total of 48 plots. Woody vegetation in the plots along baseline transects was examined for any damage by elephant, as guided by damage classification according to Bromwich (1972). The damage scoring was determined by the form of damage and intensity. Other variables measured included number of woody species, height, girth and canopy cover. Woody vegetation data collection procedures were similar to those outlined by Gandiwa and Kativu (2009). Measurements were made on all trees and shrubs of at least 1 m in height. Trees were considered as woody plants above 3 m in height, and with basal diameter ≥ 6 cm (Anderson and Walker, 1974).

2.3 Data Analysis

Statistical analyses were conducted using STATISTICA Version 6 (StatSoft Inc.). Descriptive statistics were used to summarize the data and graphical representation using Microsoft Office Excel 2003 was also used to show trend changes in measured variables. In addition, woody species diversities were calculated using Shannon-Weiner index. Simple linear regression analyses were performed in order to establish the relationship between measured variables with distance from both artificial watering points and natural watering points. Discriminant analysis was used to differentiate the study water points based on woody vegetation structure and composition.

3. Results

3.1 Relationship between damage to *B. plurijuga* plants and distance from watering points

3.1.1 Artificial watering points

Our regression analysis results showed that: (1) there was a significant, stronger negative linear relationship ($r = -0.84$, $P < 0.05$) between damage to *B. plurijuga* recruits and distance from artificial watering points. Damage to *B. plurijuga* recruits decreased with distance from artificial watering points; (2) there was a significant, strong negative linear relationship ($r = -0.93$, $P < 0.05$) between damage to mature *B. plurijuga* and distance from artificial watering points. Damage to mature *B. plurijuga* decreased with distance from artificial watering points; (3) there was a significant, strong negative linear relationship ($r = -0.84$, $P < 0.05$) between proportion of *B. plurijuga* plants damaged and distance from artificial watering points; and (4) there was a significant, strong negative linear relationship ($r = -0.95$, $P < 0.05$) between overall woody vegetation damage (%) and distance from artificial watering points.

3.1.2 Natural watering points

Our regression analysis results showed that: (1) there was no significant linear relationship between distance from natural watering point and damage to *B. plurijuga* recruits ($r = -0.47$, $P = 0.35$); (2) there was a significant, strong negative linear relationship ($r = -0.86$, $P < 0.05$) between damage to mature *B. plurijuga* and distance from natural watering point. Damage to mature *B. plurijuga* decreased with increasing distance from natural watering point; (3) there was no significant linear relationship between proportions of *B. plurijuga* damaged (%) and distance from natural watering point. ($r = -0.33$, $P > 0.05$); and (4) there was a significant, strong negative linear relationship ($r = -0.97$, $P < 0.05$) between overall woody vegetation damage (%) and distance from natural watering points.

3.2 Changes in *Baikiaea plurijuga* structure with distance from watering points

Variables of vegetation structure considered in the present study were density, height, canopy cover and basal area. Artificial and natural watering points discerned different patterns in *B. plurijuga* population structure with distance from watering points (Figure 1). There was no significant linear relationship between mean shrub density and distance from both artificial and natural watering points ($P > 0.05$). Tree density of *B. plurijuga* generally increased with an increase in distance from artificial watering points up to 2.5 km. There was no significant linear relationship ($P > 0.05$) between density of *B. plurijuga* trees and distance from both artificial and natural watering points. Mean height of *B. plurijuga* shrubs did not vary much with distance from watering points. There was no significant linear relationship ($P > 0.05$) between mean height of *B. plurijuga* shrubs and distance from artificial watering point. There was a significant strong ($r = 0.88$; $P > 0.05$), positive linear relationship between mean height of *B. plurijuga* shrubs and distance from natural watering point. There was no significant linear relationship ($P < 0.05$) between mean height of *B. plurijuga* trees and distance from artificial and natural watering points.

Canopy cover of *B. plurijuga* showed a strong and positive significant linear relationship ($P < 0.05$) with distance from both artificial and natural watering points. Mean basal area of *B. plurijuga* shrubs was higher close to artificial watering points than further away. Mean basal area of *B. plurijuga* shrubs was lower closer to water and gradually increased with distance from natural watering point. There was no significant linear relationship ($P > 0.05$) between mean basal area of *B. plurijuga* shrubs and distance from artificial watering point. There was a strong and significant positive linear relationship ($P < 0.05$) between mean basal area of *B. plurijuga* shrubs and distance from natural watering point. Mean basal area of *B. plurijuga* trees was generally low closer to watering points. A further increase in distance beyond 2.5 km from waterholes resulted in a high increase in mean basal area of *B. plurijuga.* However, there was no significant ($P > 0.05$) linear relationship between mean basal area of *B. plurijuga* trees and distance from artificial and natural watering point. Species richness was lowest in high elephant occupancy zones of both artificial watering point and natural watering point. There was an increase in species richness in moderate elephant occupancy zone and relatively lower species richness in low elephant occupancy zones of artificial watering point and natural watering point (Figure 1).

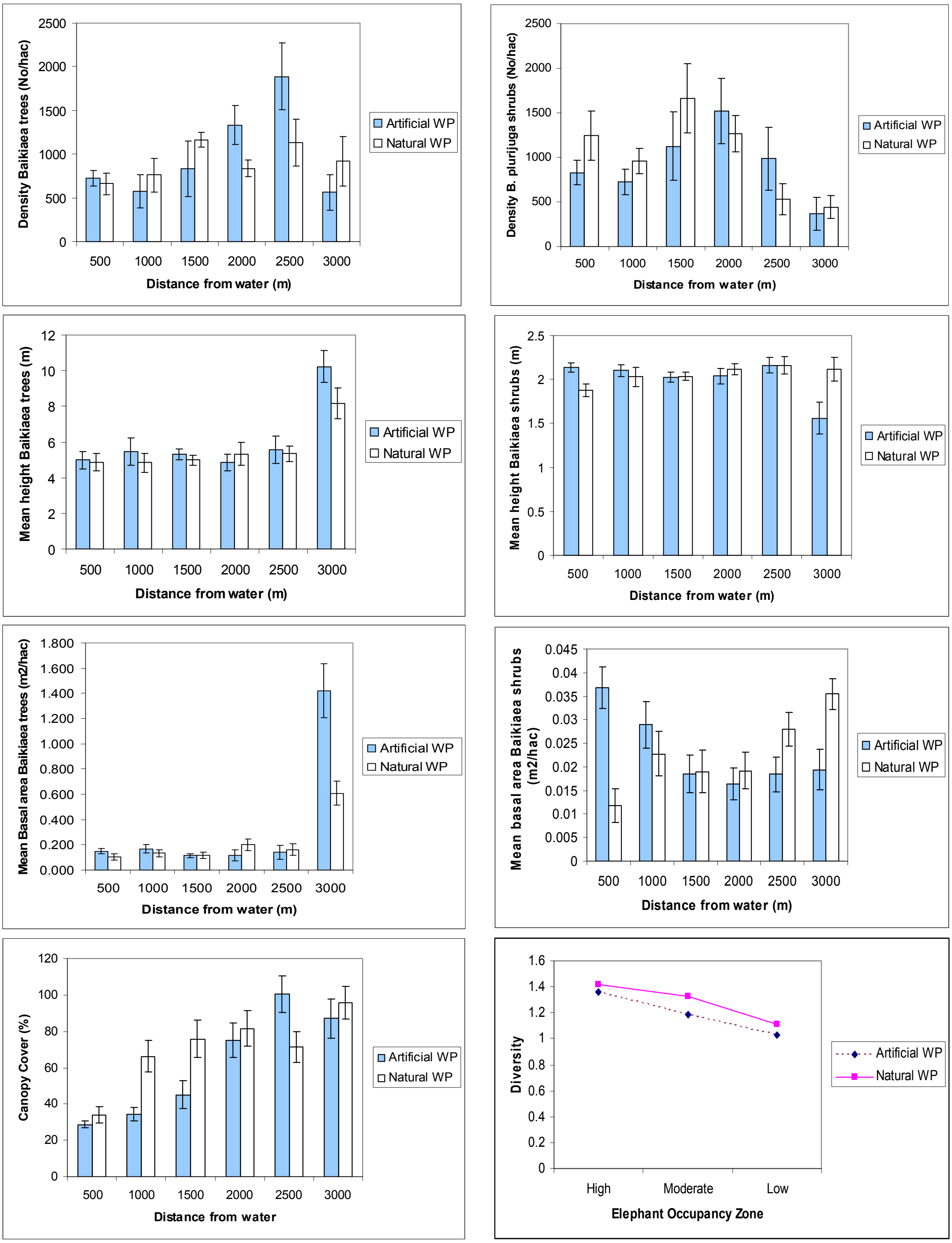

Figure 1: Woody vegetation structure, canopy cover and diversity of sampled plots around study water points in northern Hwange National Park, Zimbabwe. Notes: AWP-Artificial Watering Points; NWP-Natural Watering Points.

3.3 Discriminant analysis of study plots

Discriminant analysis showed the differences among distance classes (elephant occupancy zones) in terms of damage variables (i.e. damage to recruiting *B. plurijuga*, damage to mature

B. plurijuga and proportion of damaged *B. plurijuga* plants) for both artificial watering points and natural watering points. Three pre-specified distance groups for each type of waterhole (artificial/natural) included: high elephant occupancy zone (≤ 1 km from water), moderate elephant occupancy zone (> 1–2 km from water) and low elephant occupancy zone (> 2 km from water). New groups based on dissimilarity in extent of damage to *Baikiaea plurijuga* in elephant occupancy zones were formed (Figure 2). Sample plots in high elephant occupancy zone (≤ 1 km from water) were able to separate from the other groups by 100% (Group 1). The classification matrix showed that some cases were misclassified from their original groups. Fifty percent of cases (plots) were misclassified from Group > 1–2 km of AWP (Artificial Watering Points), 25% misclassified from Group > 2 km of AWP, 13% misclassified from group ≤ 1 km of NWP (Natural Watering Points), 75% misclassified from group > 1–2 km of NWP and 13% misclassified from Group > 2 km of NWP. There was however no distinct pattern in the grouping of plots in Group 2 (Figure 2).

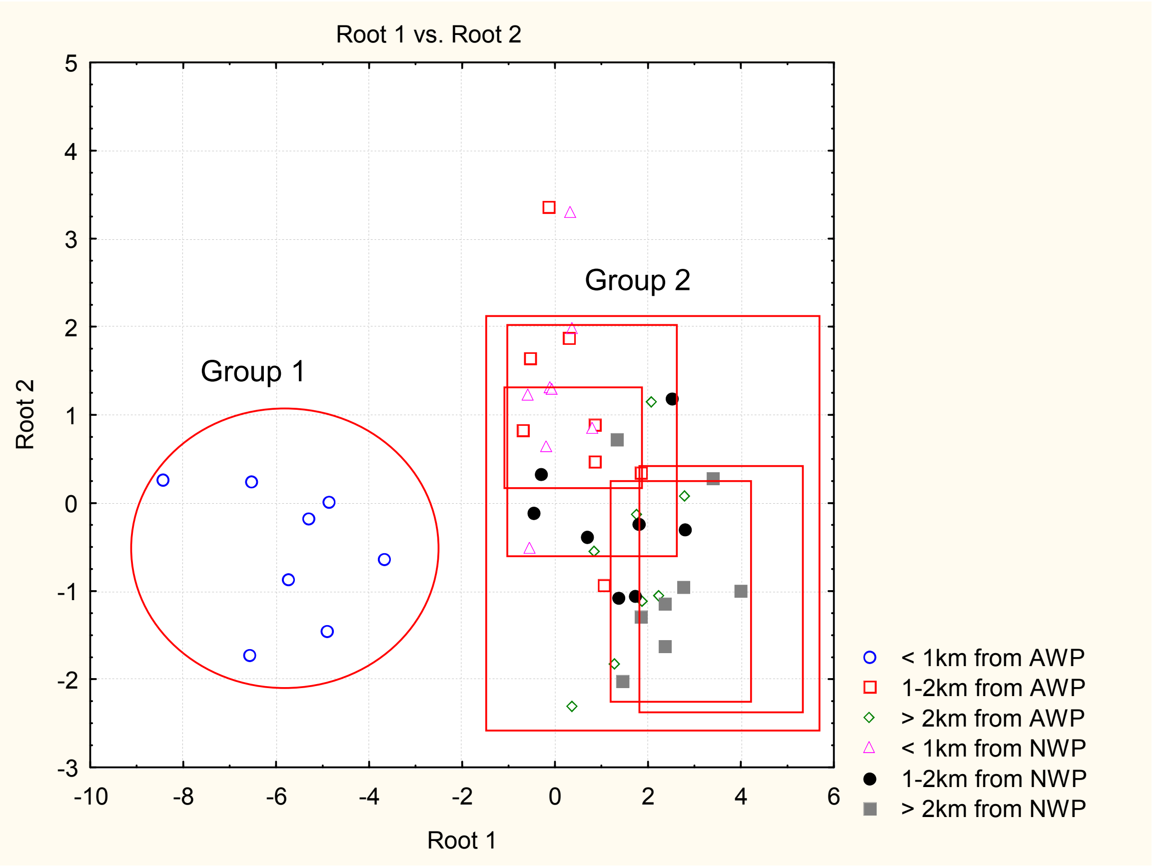

Figure 2: Discriminant analysis plot of sample plots from northern Hwange National Park, Zimbabwe. Notes: AWP-Artificial Watering Points; NWP-Natural Watering Points.

4. Discussion

We recorded a non-significant linear relationship between *B. plurijuga* shrub and tree density and distance from water points in northern HNP in the present study. Tree and shrub density was low close to water, and generally increased as with distance. Only minor changes in tree density with distance from natural watering points were recorded. Canopy cover showed a significant increase with distance from both artificial and natural watering points. *B. plurijuga* woodlands around artificial watering points and natural watering points showed major differences in canopy cover, suggesting that high damage to woody vegetation by elephants is associated with artificial watering points than natural watering points. The linear increase in canopy cover with increase in distance from artificial and natural watering point could partly be explained through a reduction in damage to mature *B. plurijuga* as a result of a decrease in animal density with distance from the water points. Mature *B. plurijuga* occurred further away from watering points. It has been suggested that the long rooted nature of *B. plurijuga* does not favor uprooting of trees by elephants (Guy, 1976). Therefore, root system influences the extent of uprooting by elephants (Guy, 1976). Our results corroborates with an earlier study in HNP which showed that woody cover was on average more reduced in the vicinity of artificial waterholes than at natural waterholes from assessments using remote-sensing data in HNP (Chamaillé-Jammes et al., 2009). However, recorded changes in canopy cover with distance from artificial watering points in this present study contradict results of Conybeare (1991), who found no significant linear relationship with distance from watering points in HNP.

Brits et al. (2002) have observed that few individuals, with larger canopies, were found closer to watering points and more individuals with smaller canopies further from watering points in Kruger National Park, South Africa. Some scholars have associated canopy cover with plant height (e.g. Muller-Dombois and Ellenberg, 1974; Whittaker, 1970). Large trees constitute the greater proportion of canopy (Muller-Dombois and Ellenberg, 1974). Smaller and fewer plants were found closer to watering points and the increase in tree dominance with increasing distance from water supported increased canopy cover. Trees spend much of the photosynthetic energy on woody tissue to support the foliage in the canopy (Whittaker, 1970). This may perhaps partly explain the gradual increase in basal area of *B. plurijuga* trees with distance from watering points in northern HNP.

Small canopy trees found closer to watering points in the current study support the findings of Thrash et al. (1991) from a study in Kruger National Park, South Africa. The distinct aggregation of elephants around permanent watering points may result in the opening-up of the canopy layer. For example, in Kruger National Park, density and canopy cover of *Combretum apiculatum* and survival of all woody plants were affected by the construction of a dam (Thrash et al., 1991). Water, as a key resource in arid areas, is a major driver of ecosystems dynamics (Illius and O'Connor, 2000). Elephants drink water regularly; hence this restricts foraging to within about 15 km from the water source (Conybeare, 2004). Basal area and canopy cover can be used as estimates of biomass (Ben-Shahar, 1996). Elephants over-utilize woody vegetation when they remove more biomass than what plants can produce at any given time (Ben-Shahar, 1996).

The non-linear relationship between mean basal area of *B. plurijuga* shrubs and distance from artificial watering points could be explained by the recorded high diameters at breast height for shrubs in the high elephant occupancy zone which are similar to those for moderate elephant occupancy zone. Trees converted to heights below 3 m were considered as shrubs as described by Anderson and Walker (1974). Thus, there was the possibility of overestimating mean diameter at breast height at the expense of height in this study. The high damage score for *B. plurijuga* shrubs closer to artificial watering points could be linked to trees being converted to shrubs.

An earlier study by Conybeare (1991) in HNP recorded highest elephant occupancy and most severe woody vegetation damage within 1 km radius within an artificial watering point, moderate elephant occupancy at 1–2 km radius, and a fairly low and uniform zone between 2 and 16 km radius. Spatial heterogeneity in elephant distribution in the dry season due to variations in water availability becomes a disturbance factor (Skarpe, 1992). Elephant occupancy gradually decreases with distance from the watering point. This, therefore, creates an elephant concentration gradient (Conybeare, 1991). Woody plant damage, diversity and structure vary in accordance with zone of elephant occupancy. In HNP, a record of 165 plant species was foraged by elephants per year (Rushworth, 1973). Guy (1976) recorded a total of 22 species as being consumed by an elephant per day. Jachmann and Bell (1985) found that there is a significant correlation between utilization of certain tree species and protein and sodium content. Herbivory on woody plants is usually selective, and favored species tend to decline in abundance (Field, 1971).

In Kruger National Park, South Africa, Brits et al. (2002) recorded low shrub density closer to water, and highest shrub density at approximately 2.8 km from water. Shrubs density may not necessarily be related to distance from water, neither within shrubland nor within mixed woodland (Mosugelo et al., 2002). Tree density may not show much change with distance from watering point (Brits et al., 2002). Cronje et al. (2005) postulated that water sources that dry up towards the dry season need to be supplied with water during drought periods in order to maintain game numbers without causing rangeland degradation. Trash (1998) found no evidence of differences in the impact of herbivores at artificial and natural semi-permanent watering points in the Kruger National Park. In northern Gonarezhou National Park, south-eastern Zimbabwe, a recent study by Gandiwa et al. (2012) recorded a slight decrease in plant density with increase in distance from natural water sources suggesting that there were slight degradation of woody vegetation around water points.

Outside the influence of watering points, Childes and Walker (1987) investigated the dynamics of the woody vegetation in the Kalahari sand area of HNP. They noted edaphic factors, together with fire, as the primary determinants of vegetation structure, rather than elephants that only had minor effect. Elsewhere, Tafangenyasha (1997a, b) and Gandiwa et al. (2011) reported low tree density closer to water sources than further away in the Gonarezhou National Park. In northern Botswana, Ben-Shahar (1998) reported that woodlands dominated by *Colophospermum mopane* subjected to obtrusive elephant damage had largely unchanged densities of tall trees. However, the concentration of elephants around watering points exposes vegetation in the vicinity to herbivory or trampling threats (Thrash and Derry, 1999). Ringrose et al. (1996) have observed that woody plant density and cover increases as elephant numbers decreases. This shows that elephant concentration has an influence on woody vegetation changes in ecosystems. The habitat modification that results, particularly at high elephant densities, may alter the compositional, structural, and possibly functional diversity of ecosystems (Dublin et al., 1990).

5. Conclusions

This present study has shown that the impact of elephants on *B. plurijuga* dominated woodlands due to provision of water in northern HNP is largely on the plant species recruitment. Distance from watering points creates an herbivory gradient of woody vegetation utilization that is characterized by changes in *B. plurijuga* structure. The zones of elephant occupancy were not much reflected in woody vegetation utilization on *B. plurijuga* dominated woodlands. Woody species diversity in *B. plurijuga* dominated woodlands was higher around natural watering points than around artificial watering points. Natural watering points seem to provide a sustainable system where light vegetation utilization during the dry season promotes recovery and establishment of *B. plurijuga* recruits. Our study findings have implications for future artificial water management in HNP. Future studies should investigate the impact of herbivores around watering points on *B. plurijuga* regeneration.

Acknowledgements

We thank the Director-General of the Parks and Wildlife Management Authority for permission to carry out this research in Hwange National Park, Zimbabwe and for supporting this study. Staff of Hwange National Park, in particular Hwange Main Camp, assisted with field work. Special thanks go to Nkululeko Hlongwane and Simeon Mudhimba who assisted with data collection. Finally, we are grateful to Prof. C.H.D. Magadza for useful discussions and his invaluable contributions at various stages of this study.

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