The book describes the influence of the African elephant (Loxodonta africana Blumenbach) on Baikiaea plurijuga dominated woody vegetation around natural and artificial watering points in the northern part of Hwange National Park (HNP), Zimbabwe. The interaction of plants and animals in savannah ecosystem can bring changes to the environment. The elephants in HNP interact with woody vegetation around natural and artificial watering points causing structural changes to the vegetation with distance from the water sources. The distribution of elephants in the dry season in HNP is mainly influenced by surface water availability. Natural watering points in the Park contain water during the wet season but are usually dry during the dry season. Elephants therefore aggregate in huge numbers around pumped artificial watering points which contain water throughout the year. Artificial watering points are often sacrificed/damaged by elephants more than natural watering points especially within ≤ 1 km radius from the water points. The elephant induced vegetation damage with distance from watering points have implications on the management of game water supply and elephant population in HNP.

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DEDICATION

“I give all the credit to Jesus Christ, the Lord of Lords and the King of Kings”

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1.0 Introduction

1.1 Background

African savannas are typified by the coexistence of woody plants and grasses, with relative proportions of each influenced predominantly by moisture availability, nutrients, fire and herbivory (Scholes and Walker, 1993). Interplay of savanna determinants can be used to describe the temporal and spatial structure and dynamics of vegetation (Crawley, 1997). Ecologists are generally of the view that plant distribution, abundance and, therefore, community composition, structure and biomass, are largely determined by climate and soils (Bond and Keeley, 2005). Sarmiento (1983) described savannas as essentially the result of interactions between soil moisture and nutrient availability, with fire and herbivores acting as modifiers.

Fire is important in controlling woody seedlings and young trees (Frost and Robertson, 1987), and is a highly interactive factor in savanna ecosystems. In drier savannas, fires often occur after good rainfall periods that allow the production of sufficient grass fuel (Skarpe, 1992). Intense fires can shift vegetation from woodland to grassland. The grassland is then maintained by herbivores (Van de Koppel and Prins, 1998). Herbivory may reduce grass fuel load through trampling effects, thereby reducing fire frequency and intensity. At high density, herbivores, such as elephant, increase tree mortality and may convert woodland to grassland (Guy, 1989). Exclusion of large herbivores from grassland may result in rapid loss of soil nutrients, hence promoting woody growth (Hatton and Smart, 1984). Sinclair and Arcese (1995) argued that African savannas are highly dynamic, alternating between woodland and grassland states.

Herbivory is more like parasitism, and less like predation, as herbivores mostly weaken plants which ultimately succumb to competition by others. This leads to exclusion of highly favored species (Crawley, 1997). The impact of herbivory on plant performance depends on timing, location, intensity and frequency (Crawley, 1997). 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). The African elephant is 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 (Conybeare 1991, Valeix, 2002). Damage on woody vegetation, particularly around waterholes, is under the spotlight (National Parks, unpublished data).

Water is a key resource that influences distribution and intensity of browsing by water-dependent herbivores in protected areas during the dry season. The introduction of artificial watering points in wildlife areas results in most animals becoming sedentary around artificial waterholes during the dry season when seasonal waterholes dries up (Thrash and Derry, 1999). Such aggregative response may modify the environment around waterholes (Laws, 1970, Bromwich, 1972) as elephant home range decreases (Owen-Smith, 1988). During and soon after the growing season, palatable fodder and water are abundant, and elephant disperse from permanent watering points. This hence increases the home range. The pattern of water utilization by elephant, however, does not vary much between seasonal and artificial watering points.

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 during the dry season. This, therefore, creates an elephant concentration gradient (Conybeare, 1991). Woody plant damage, diversity and structure may be different in each zone of elephant occupancy due to different levels of disturbance factor.

There is extensive development of artificial watering points in Hwange National Park. This has resulted in increased game populations, particularly elephant. The elephant population was estimated at approximately 45 000 in 2005 (Unpublished National Parks records). This is above the recommended carrying capacity for the park (Unpublished National Parks records). The park is faced with the dilemma of managing a species in urgent need of protection elsewhere yet so overabundant in the park. There has been a tremendous increase in elephant numbers within the Hwange National Park since 1986 when culling was suspended (Valeix, 2002). Option to consider culling as a means of controlling elephant populations in the park is being thwarted by the global conservation status of elephant (United Nations Environment Programme (UNEP)-World Conservation Monitoring Center (WCMC), 2005), ethical concerns, and lack of enough scientific information to influence decision making on culling.

1.2 Problem statement

Concentration of elephant on artificial watering points during the dry season has intensified damage of surrounding woody vegetation (Conybeare, 1991). Watering points are bound to create problems, such as overbrowsing by elephants (Bromwich, 1972). The recommended local density of 0.5 individuals per square kilometer in Hwange National Park is exceeded during the dry season. Water scarcity during the dry season has caused aggregation of elephant and other water-dependent species around artificial watering points in Hwange National Park. This has had the effect of destroying vegetation through herbivory and trampling. Conybeare (1991) indicated that elephants may affect recruitment of *Baikiaea plurijuga* close to artificial watering points in Hwange National Park (Conybeare, 1991).

Artificial watering points contain water all year round and elephants use them throughout the year. Woody vegetation in the vicinity of artificial watering points has less time to recover from elephant browsing. Natural watering points contain water only during the rainy season, and elephants utilize them part of the year. Woody vegetation around natural watering points resembles a sustainable system where woody vegetation could recover from elephant damage.

Although elephants are modifying woody vegetation around both artificial and seasonal watering points, it is likely that there is greater damage around artificial (pumped) watering points that contain water all year round than around natural watering points that contain water only during the wet season.

1.3 Justification

The impact of elephant on woody vegetation in relation to artificial watering points in Hwange National Park was last studied by Conybeare (1991). Results of that work indicated that vegetation plots closest to artificial watering points had lower mean tree and shrub densities than those further away. Conybeare (1991) recorded the highest elephant occupancy and heaviest woody vegetation damage within 1km radius of an artificial watering point, moderate elephant occupancy between 1 and 2km radius, and fairly low and uniform zone between 2 and 16km radius. The present work seeks to compare the extent of elephant damage on *Baikiaea plurijuga* dominated woody vegetation around artificial and natural waterholes. The pattern of elephant damage on juvenile and mature *Baikiaea* trees could be investigated with distance from watering points.

It should not be assumed that elephants are solely responsible for observed change in woody vegetation (Western and Van Praet 1973). Likewise, it should not be assumed that provision of artificially pumped water results in greater damage to woody vegetation than the damage around seasonal watering points. Trollope *et al* (1998) noted the limitations of visual observations that are not supported by data analysis. It is true that aggregative vegetation response to high concentrations of elephant around a key resource could possibly constitute an ecological problem that needs to be monitored. The impact of water provision as a management policy in Hwange National Park could be assessed under the present study.

The three elephant occupancy zones as described by Conybeare (1991) can be used to test the validity of the Intermediate Disturbance Hypothesis (Connell, 1978) around both seasonal and artificial watering points. Establishing the spatial effects of elephant impact on the diversity of woodlands around waterholes in Hwange National Park may assist in better understanding of the complexity of the impact of disturbance on woodland.

Baikiaea plurijuga is one of the least elephant favored species (Childes and Walker, 1987). The present study was, however, conducted in *Baikiaea plurijuga* dominated woodland because it is the most common vegetation type in Hwange National Park. Focusing on a single important species tells only part of the story (Timberlake and Childes, 2004). Assessment of damage on the basis of dominant vegetation type in the area gives a true reflection of woody vegetation status in relation to elephant numbers that can form a basis for decision making regarding elephant management policies in Hwange National Park.

Seasonal watering points act as a benchmark against which assessment on artificial watering points could be made. A comparative study could provide a basis for proper management of elephant around artificial watering points.

1.4 Aim of work

The major aim of the present work was to investigate the level of damage due to elephant browsing on the structure of *Baikiaea plurijuga* dominated woody vegetation around watering points in a protected wildlife area.

1.5 Specific objectives

1. To compare the extent of elephant damage on *B. plurijuga* plants around artificial and natural watering points
2. To determine changes in damage to *B. Plurijuga* with distance from watering points
3. To compare density, height, canopy cover and basal area of *B. plurijuga* between elephant occupancy zones of artificial and natural watering points
4. To determine changes in *B. plurijuga* population structure (density, height, canopy cover, basal

area) with distance from artificial and natural watering points

5. To determine the change in woody species diversity in elephant occupancy zones of watering points.

1.6 Research Questions

The work attempts to answer the following questions on how elephant concentration gradient, through herbivory, impacts on *Baikiaea plurijuga* population structure and woody species diversity around artificial and natural watering points. Artificial watering points (permanent water) are likely to encounter higher level of elephant damage on *B. plurijuga* than natural watering points (seasonal) due to longer residency time of elephants. Key questions in the work include:

1 Is there a significant difference in extent of damage on shrub and mature *Baikiaea plurijuga* plants between elephant occupancy zones of artificial and seasonal watering points?

2 Is there a significant relationship between damage on shrub and mature *Baikiaea plurijuga* with distance from watering points?

3 Is there significant difference in height, density and basal area of *B. plurijuga* between artificial and natural watering points in relation to elephant occupancy zones?

4 Is there a significant relationship between height, density and basal area of *Baikiaea plurijuga* and distance from watering points?

5 Do elephant occupancy zones have an impact on woody plant diversity around watering points?

1.7 Hypothesis

i. **Ho**: Elephant damage on shrub and mature *Baikiaea plurijuga* around artificial and natural watering points is similar

H_1: Elephant damage on shrub and mature *Baikiaea plurijuga* around artificial watering points is greater than damage around seasonal watering points

ii. **Ho**: There is no difference in height, density and basal area of *B. plurijuga* between artificial and natural watering points in relation to elephant occupancy zones.

H_1: There are differences in height, density and basal area of *B. plurijuga* between artificial and natural watering points in relation to elephant occupancy zones.

iii. **Ho**: *Baikiaea plurijuga* population structure (height, density and basal area) does not change with distance from the waterhole

H_1: *Baikiaea plurijuga* population structure changes with distance from the waterhole

1.8 Book structure

The book is constituted by six parts. The first part gives an introductory outline of the environmental determinants that could modify woody vegetation structure. The importance of doing the work is also reflected. The second part comprises of literature review on the impact of elephants on woody vegetation around watering points during limiting period of the dry season. The third part gives the study area where the current work was done. The fourth part describes materials and methods used for the work. Part 5 gives the presentation of results and part 6 gives the discussion and recommendations.

2.0 Literature Review

2.1 Policy and plan for elephant management in Zimbabwe

Elephants constitute an important component of Zimbabwe's wildlife and cultural heritage. The government of Zimbabwe aims to promote conservation of elephants, as part of biodiversity conservation, while ensuring their sustainable use and their contribution to national development (Anonymous, 1997). In order to attain policy goals, some of the management objectives include the maintenance of elephant numbers and densities below levels which will not compromise biodiversity. There is also need for maintenance of continued research and monitoring necessary for the conservation and management of elephants.

Management objectives can be met by defining the ecological carrying capacity or preferred elephant density for each National Park and carrying out periodic population reductions either through culling or translocations. This is done to keep the elephant population within the ecological carrying capacity or preferred densities for each National Park. There is also need to identify monitoring and research priorities at both national and regional levels and identifying key variables to monitor in line with research priorities for example changes in vegetation structure (Anonymous, 1997).

2.2 Elephant population trends

On a continental scale, the population of the African elephant dropped from about 1.3 million in 1981 to approximately 650 000 a decade later (Barbier *et al,* 1990). All regions of Africa except Southern Africa experienced a downward population trend between 1981 and 1995 (Said *et al*, 1995). Populations in southern Africa experience some fluctuations, and as such it is difficult to establish population trend. However, most of the population estimates are wild guesses and conservationists questioned population estimates (Barnes, 1999). Recent data on continental elephant population trends is scarce.

Southern Africa is estimated to have 300 000 elephants of the continent's estimated 400000-600 000 elephants, most of which is found in Botswana and Zimbabwe (http://www.smh.com.au/articles/2004/09/24/109596186299.html). Zimbabwe, Botswana, South Africa and Namibia show an upward population trend, whilst Angola, Zambia, Malawi and Mozambique show a downward population trend since the eighties (Said *et al*, 1995). In many countries, elephants exist in small, isolated populations that are restricted to parks, reserves and other protected areas (Douglas-Hamilton, 1987).

Elephant population in Zimbabwe is high due to effective management measures, concept of sustainable use and restricted international trade in ivory (Anonymous, 1997). The biggest threat to the survival of elephants in the country is loss of habitat and conflict with legitimate human interests (Anonymous, 1996). Tchamba and Mahamat (1992) indicated that although elephant population has been generally decreasing on a continental scale, the population has been increasing in certain localities. Elephant population in Hwange National Park, Zimbabwe, has increased markedly since the 1930s due to provision of water (Cumming, 1981). Valeix (2002) postulated that the elephant population in the park started to increase as early as the 1920s, with a population of approximately 2 000 in 1928.

During the dry season in the past, high animal mortality was recorded due to water scarcity (Valeix, 2002). The construction of artificial watering points increased elephant population in the park. Culling episodes were introduced to maintain the elephant population to 12 000 in the early 1980s (Anonymous, 1998). Elephant population was estimated at 15 000 by 1985 and culling was suspended in 1986 (Anonymous, 1998; Cumming 1981).

Aerial survey estimates indicated a dry season elephant population of approximately 25 000 for Hwange National Park in 1995 (Price, 1996). Elephant population increased to 30 000 in 1997, 32 000 in 1998 (Anonymous, 1998) and to 44 492 elephants by 2001 (National Parks aerial survey 2001). During the 1999 dry season, elephant density reached 5.34 individuals per square kilometers in Main

Camp area (Bourgarel and Fritz, 2000) and rose to 5.61 elephants per square kilometer by 2002 (Dunham and Mackie 2002). Elephant population for 2005 was estimated at around 45 000 individuals (Unpublished National Parks records). The figure is above the recommended carrying capacity of 7 280 – 14 560 elephants for the park.

2.4 Elephant feeding behavior

Effects of herbivory depend on growth form of plant, plant part removed, intensity, frequency and season of use, growth stage of plant, soil type and soil moisture conditions and time since the previous defoliation (Frost *et al*, 1986). Most feeding by elephants occurs below 2m, and as such, it competes directly with other herbivores sharing the same habitat and feeding on the same resource (Guy, 1976). Elephant feeding height is within the recruitment class (1-3m) and high damage is likely to fall within the class (Tchamba and Mahamat, 1992). Maximum height an elephant can feed is 6m (Croze, 1974). Trees with their greater proportion of canopy out of reach of elephants are knocked over.

Pushing over and uprooting of trees may improve food availability to elephants in the dry season (Jachmann and Bell, 1985). However, not all species favored by elephants are knocked over, but those which have shallow rooting system or weak stems (Guy, 1976). It should also be noted that elephants destroy woody vegetation not necessarily to feed but as a social display by males. Male elephant can uproot nine trees per day in the dry season or 4.5 trees per day throughout the year (Guy, 1976). Males may kill more trees than females (Conybeare, 1991).

Eltringham (1982) noted that an elephant has a wide range of food preferences and can resort to any plant species on the basis of availability. Forage selection is influenced by forage availability (Dublin, 1995) and pnenological stage of the plant (Styles and Skinner, 2000) among other factors. Elephants become selective browsers when intraspecific competition is low but tend to browse evenly among woody species when resources are limiting (Thrash and Derry, 1999). According to Guy (1976), elephants select a wide range of species, generally eating the species in quantities proportional to their occurrence within woodlands although some specific species are positively selected or avoided. In Hwange National Park, a record of 165 species was noted to have been eaten by elephants per year (Rushworth, 1973). Guy (1976) recorded a total of 22 species to have been eaten in one day by one elephant. Elephants do not selectively damage trees on the basis of chemical composition (Anderson, 1973).

By contrast, Jachmann and Bell (1985) found that there is a significant correlation between utilization of certain tree species by elephants and protein and sodium content. Woody plant destruction is usually selective according to species, and favored species tend to decline in abundance (Field, 1971). Owen-Smith (1988) characterize large herbivore dietary intake in terms of plant species eaten, plant part ingested and nutrient content of the ingested material. Conybeare (1991) indicated that elephants are selective in their feeding behavior, tending to prefer palatable species such as *Combretum collinum, Acacia ataxacantha* and *Dichrostachys cineria* than unpalatable species such as *Ochna pulchra* and *Baikiaea plurijuga* (Childes and Walker, 1987). Preferred species by elephants according to Owen-Smith (1988) include species of *Acacia, Azima, Baphia, Brachstegia, Combretum, Colophospermum, Terminalia* and *Uapaca.* Species composition of a particular site may modify the amount of elephant damage (Conybeare, 1991). Calenge *et al* (2002) indicated that elephants select trees to damage according to species and height.

Browsing by elephants is more prevalent in the dry season and grazing becomes rife in the wet season due to factors such as grass availability, quality and digestibility Guy (1976). Elephants obtain much of their needed protein during the dry months from browse (Laws, 1970). Bark stripping, breaking of stems and uprooting of woody species is common during the dry season (Owen-Smith, 1988). In the wet season, when browsing, an elephant strips leaves and break off branchlets to consume terminal twigs.

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2.5 Impact of elephant population density on woody vegetation around watering points

Components of woody vegetation structure are horizontal, vertical and quantitative structure (Mueller-Dombois and Ellenberg, 1974). Horizontal structure refers to the spatial distribution of species populations and individuals. Vertical structure refers to stratification of vegetation into layers. Quantitative structure refers to abundance of each species in the community (Mueller-Dombois and Ellenberg, 1974). The foraging habits of African elephant (*Loxodonta africana Blumenbach*) profoundly influence the structure and function of African woodland and savanna ecosystems (Caughley, 1976). Large elephant population densities accompany serious ecological problems due to the feeding habits of elephants (Anonymous, 1997).

Assessment of density of different height class individuals around water sources can be used to pinpoint the structural changes occurring in the woody vegetation around watering points (Brits *et al*, 2002). An ecological system of interactions between a watering point, its surrounding vegetation and the grazing animal is known as the 'piosphere' (Lange, 1969). Watering points have led to the development of a gradient of utilisation pressure which is greatest near watering point and decreases as a function of distance from it (Graetz and Ludwig, 1978). Van der Schijff (1959) identified five zones according to degree of utilisation by game. The first zone was trampled to dust and it stretched up to 91m from water. The second, third, fourth and fifth zones stretched to 1.6km, 5km, 8km and further than 8km from watering point respectively.

The second zone was grazed short and trampled. Moderate grazing was prevalent in the third utilisation zone (1.6-5km from water). Light and selective grazing was common in the fourth zone. Little or rare utilisation was identified beyond 8km during the dry season. Provision of more water sources has led to even utilisation of herbaceous vegetation, and only the first and second zones of Van der Schijff (1959) are recognized in Kruger National Park (Thrash *et al*, 1998, cited from Brits *et al*, 2002).

Changes in vegetation structure and biodiversity occur with distance from the watering points (Conybeare, 1991). At further distance from water, unaltered woodland and shrubland were recorded in Hwange National Park (Conybeare, 1991). The degree of damage declines with distance from water irrespective of how much vegetation there is (Bromwich, 1972). Concentration of elephants around artificial watering points in Hwange National Park, Zimbabwe, is a seasonal phenomenon. Elephants migrate from surrounding private farms and forestry areas and countries such as Botswana in search for water during the dry season. The movement of species of wildlife is affected by the development of artificial watering points.

Changes in water distribution cause a change in the temporal and spatial patterns of utilization of the vegetation (Thrash and Derry, 1999). Elephants strongly depend on surface water and they dominate at watering points, tending to monopolize water (Valeix, 2002). Water is one of the key resources in arid regions where wildlife keeping is a viable option. Resources which determine the size of animal population in limiting periods are referred to as key resources (Illius and O'connor, 2000).

The aggregative response by elephants around waterholes in the dry season results in increased browsing pressure and severe trampling around those areas (Thrash and Derry, 1999). High elephant numbers may influence the recruitment of *Baikiaea plurijuga* close to water (Conybeare, 1991). In areas with large elephant populations, the density and canopy cover of trees is directly proportional to distance from watering points (Thrash and Derry, 1999). Elephant browsing may open up the tree canopy (Eltringham, 1982).

Shrub density gradually increases with distance from water (Brits *et al*, 2002). Close to water, shrub and tree density is low due to the impact of herbivores (Conybeare, 1991). In Kruger National Park, Brits *et al* (2002) recorded low shrub density closer to water, and highest shrub density at approximately 2.8km from water. High shrub density beyond the highest shrub density zone represents the natural shrub density of an area (Brits *et al*, 2002). Tree density may not show much change with distance from watering point (Brits *et al*, 2002). Density of shrubs may also not be related to distance from water neither within shrubland nor within mixed woodland (Mosugelo *et al*, 2002).

During the wet season, elephants disperse from artificial watering points and browsing pressure and trampling effects spread to seasonal watering points. Seasonal watering points augment game pressure until June/July when they start to dry up. The effect of game on seasonal watering points may be one of utilization rather than destruction, and woody vegetation may be utilized evenly with distance from water (Bromwich, 1972). 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.

Childes and Walker (1987) investigated the dynamics of the woody vegetation in the Kalahari sand area of Hwange National Park outside the influence of waterholes, and considered that edaphic factors were the primary determinants of the vegetation structure, together with fire, and that elephants had only a minor effect. However, waterholes are invariably associated with high numbers of wild animals that normally exceeds the recommended carrying capacity. The high carrying capacity of the eastern Selous Game Reserve, Tanzania, is in part due to a network of permanent and seasonal waterholes (Rodgers, 1980).

Most browsers experience food shortages during the dry season when most of woody plants drop their leaves (Frost *et al*, 1986). However, the African elephant can be able to feed on small twigs, bark and roots of woody plants (Owen-Smith, 1988). Under severe drought conditions, wood, bark and roots may occupy 70-80% of elephant feeding time (Owen-Smith, 1988). Such adaptation can expose woody vegetation around waterholes at stake during the dry season.

The greatest damage of the habitat by elephants is in the vicinity of rivers and permanent watering points (Laws, 1970). Tree loss measured from aerial photographs was highest close to water in Gonarezhou National Park in Southern Zimbabwe (Tafangenyasha, 1997). Elephants are the primary agents of woody structure changes near surface water in the Kruger National Park (Du Toit, 1988). A change in woody vegetation structure is an eventual outcome of continued heavy defoliation.

At high local density, apart from other factors such as fire and natural mortality, elephants may reduce plant primary production (Bell, 1984). Heavy utilization of all or most species may depress plant biomass, hence primary production (Owen-Smith, 1988). For most semi-arid areas, the recommended density of 0.5 elephants per square kilometer ensures that equilibrium between rates of tree loss and regeneration can be attained (Martin *et al* 1992).

High elephant concentration may supress regeneration and maintains vegetation in the scrub phase (Childes and Walker, 1987). However, it should be noted that regeneration of woody vegetation around waterholes can also be affected by smaller herbivores (Hiscocks, 1999). Small herbivores such as kudu and impala may suppress regeneration of seedlings and shoot growth (Crawley, 1997). In East Africa, small antelope have an important impact on woodland regeneration, by suppressing seedling recruitment (Belsky, 1984).

In Hwange National Park, elephants spend about 33% of their time in *Baikiaea plurijuga* woodlands in the dry season (Conybeare, 1991). In the vicinity of watering points, elephants can remove 20% of *Baikiaea plurijuga* trees per annum, and at further distance away from water, few trees of *Baikiaea plurijuga* (2-3% per annum) can be removed (Conybeare, 1991). Frost is not an important agent of change in this vegetation type close to watering points (Conybeare, 1991). Low heat absorption/retention capacity of the Kalahari Sands result in a high incidence of frost mortality among woody plants (Dudley, 1999). A change in the soil properties of Kalahari sands close to water due to animal excreta deposition is the probable cause of low frost incidences (Dudley, 1999). Fire and frost perturbations are expected to decrease as a result of changes in local climate regimes (warmer winters and increased drought) predicted under global climate-warming models (Dudley, 1999).

Dudley (1999) found that elephant browsing is a significant factor in the structural dynamics of woodland habitats in Hwange National Park. This is contradictory to earlier studies by Childes and

Walker (1987) and Rushworth (1975). Tree species which appear particularly prone to mortality from elephant damage include *Acacia erioloba, Baikiaea plurijuga, Colophorspernum mopane* and *Burkia africana* (Dudley, 1999). The constitution and structure of the Kalahari sand community may shift with time in response to the influence of climate, fire, animals and man, but always within the basic limitation imposed by the moisture regime, soil moisture being the most single factor affecting the vegetation (Rushworth, 1975).

Elephants may create gaps giving room to the establishment of new plants and growth of suppressed ones (Oliver and Larson, 1990). Diversity is an outcome of disturbance, competition, resource partitioning and species immigration (Brown, 1988).

The Intermediate Disturbance Hypothesis is an ecological hypothesis which proposes that biodiversity is highest when disturbance is neither too rare nor too frequent (Connell, 1978). The notion that disturbance can increase biodiversity opposes the older idea that diversity is highest in undisturbed ecosystems. Disturbance is thought to have three principal components within which Connell (1978) contends that variation in magnitude correlates with variations in diversity. The gradual decrease in elephant occupancy with distance from water in the dry season (Conybeare, 1991) suggests that browsing pressure, a disturbance factor, is too heavy and frequent close to water and low and infrequent further away. One of the variable determinants of habitat diversity is distance from watering point due to spatial variation in herbivore utilization (Collinson, 1983). The huge number of animals in the tropics must be one of the potent causes of maintainance of richness of the flora (Burrows, 1990).

Since moderate disturbance may promote increased habitat heterogeneity, particularly in a homogenous environment, it is expected that highest biodiversity occurs in the zone of moderate elephant occupancy, which is 1km to 2km radius from the waterhole, according to Conybeare (1991). However, it should be noted that occupancy by elephants may not be linearly related to distance to water but can be very high in close proximity and then drop to a more uniform level for a distance of some kilometers (Conybeare, 1991).

2.6 Impact of fire on vegetation around watering points

There is a negative relationship between tree biomass and grass production, and as such, fuel loads in woodlands is generally low to support a fire or high fire intensities that can cause damage to trees (Chidumayo *et al*, 1996). Once a sufficient number of trees has reached the canopy, shading reduces grass production. A combination of sandy soil and a moderate rainfall results in a high subsoil: topsoil moisture ratio that favors woody species (Walker and Noy-Meir, 1982). Grass production is positively related to annual rainfall in areas receiving less than 1 000mm but is modified by woody plant cover and grazing intensity (Rutherford, 1981). Frost *et al* (1986) indicated that patchy grazing can cause patchy fires. Fire can suppress the growth and recruitment of saplings to the canopy (Bell, 1984). In savannas, plants that are more than 3m tall tend to survive most fires (Frost and Robertson, 1987)

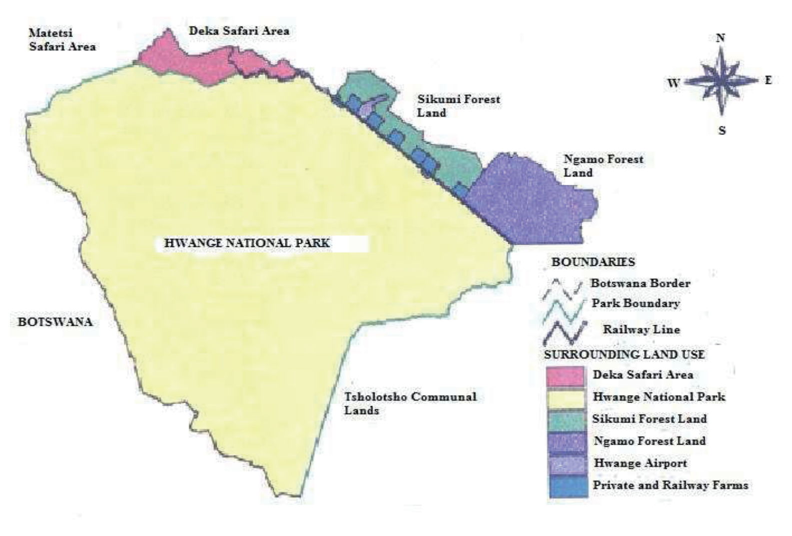
Fire frequency is usually low around watering points due to high browsing pressure and severe trampling by large herbivores, which reduces fuel loads. Gambiza *et al* (2000) found that fuel loads are lowest under heavy stocking rates and highest under light and moderate stocking. The zone adjacent to the watering point experiences a very heavy (mostly trampling) pressure and is often referred to as the 'sacrifice area', with reduced fire intensity (Thrash and Derry, 1999). Watering points are known and accepted as sacrifice areas (Bromwich, 1972). Browsing pressure decreases while fire occurrence increases with increasing distance from the watering point. In northern Chobe National Park, Botswana, elephant browsing was high and fire occurrence low within 2km from Chobe River and browsing was low and fire occurrence high beyond 7km from the river (Mosugelo *et al*, 2002).

Fire and herbivory are events that can interact, and the consequences are not always easy to predict (Frost *et al*, 1986). In many cases, it is not elephant alone that is responsible for habitat destruction, but a combination of elephant damage and other factors, particularly fire (Laws, 1970). In some areas, destruction of trees by fire is a combination of debarking and breakage by elephants, followed by grass fires that the damaged trees would normally no longer resist (Ford, 1966). However, frequency and intensity of fire or herbivory can be used as measures that can influence the outcome apart from other factors.

3.0 Study Area

3.1 Size and Location

Hwange National Park is located in the north-west of Zimbabwe, between 18º30' and 19º50'S, and 25º45' to 27º30'E. It is bordered by Botswana in the west, Matetsi and Deka Safari areas in the north, State Forest Land and farms in the northeast, and Tsholotsho Communal Land in the southeast. It is the biggest national park in Zimbabwe, occupying some 14 651 square km, (Childes and Walker 1987). Hwange National Park and the surrounding areas are presented in Figure 1.



Adapted from Hwange National Park Management Plan (1999-2003)

Figure 1: Hwange National Park and surrounding areas

Hwange National Park is zoned into northern wild area, central wild area and southern wilderness area for purposes of management. The Park comprises three major camps: Hwange Main Camp, Sinamatella Camp and Robins Camp, all located in the northern part of the park area. The present work 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 km.

3.2 History

Archeological evidence of stone-age artifacts such as stone tools and hand axes suggest that people inhabited Hwange National Park (Anonymous, 1998) several thousand years ago. The Bantu-speaking Kalundu people were the first to inhabit the Park between 400 and 500 AD. Other groups that followed were the Tonga and Leya from Zambia. The Dende, who were later known as the *Nambya*, joined the Leya in the Park during the 18th century. Chief Dende was their leader. He later changed his name to Sawanga, and finally to Wange, which is believed to be the origin of the current name for the park.

People of this era survived by hunting, gathering, fishing, rearing of cattle and growing of crops such as bulrush millet, wheat, sorghum and maize. The economic and social structure of the *Nambya* people was disrupted by Ndebele raids of the 1850s, tsetse fly infestation, introduction of fire arms, importation of European goods and intensive hunting from 1860 onwards. The first Europeans to inhabit the park in the 19th century were Selous and Tom Saddler. The two hunted in Linkwasha and Dopi areas, and in the hills in the north of the park in 1873 and 1875, respectively (Anonymous, 1998).

Most of the Park was, however, unknown until 1928 despite the existence of hunter-gatherers and pastoralists in the southern region of the park bordering Tsholotsho area. The park was proclaimed a Game Reserve in 1928 (Greaves, 1996), and in 1949, it was proclaimed a National Park under the National Parks Act Number 53 of 1949 (Valeix, 2002; Anonymous, 1998). The Park has been actively managed since 1930, with the primary objective of increasing populations of large herbivores for purposes of tourism and maintenance of biodiversity. To meet this objective, artificial watering points were introduced in 1935.

3.3 Geology, Soils and Topography

Hwange Main Camp is generally flat to slightly rolling, depending on the prominence of fossil aeolian dunes. Altitude ranges between 900 and 1100 m above sea level (Druley, 1999). According to Valeix (2002), mean altitude ranges from 1000 to 1100 m. Four broad geological types are found in Hwange National Park: Kalahari sands, Batoka basalt, karroo sediments and pre-cambrian rocks (Rogers, 1993). Greaves (1996) has commented on the existence of some beds of chalcedony and pipe sandstone at the base of Kalahari sands, with the sands overlying some rocks of the karroo and earlier systems.

Kalahari sands are considered to be late tertiary and probably mio-pliocene in age (Rushworth, 1975). Kalahari sand itself is pink or bluff coloured structureless Aeolian sand. The well rounded quartz grains have frosted surfaces. The Kalahari sand dune systems of central and southern Africa are built up from surface sediments of the Kalahari beds. These are extensive continental deposits which accumulated in a great internal basin (Childes and Walker, 1987). Kalahari sands occupy about 5% of the land area, largely confined to the western part of the country (Gambiza, 2001). Kalahari sand is the dominant soil type in Hwange National Park and covers two thirds of the Park (Greaves, 1996; Anonymous, 1998).

Redistribution of the original aeolian deposits through agents of wind and water has led to accumulation of some clays and silts in the inter-dune troughs and drainage lines, and of calcrete in fossil lake basin (Rogers, 1993). Kalahari sands can reach a depth of between 20 m and 300 m (Greaves, 1996). In Hwange National Park, Kalahari sands reach a depth of 60 m or more, and are dominated by *Baikiaea plurijuga* , T*erminalia sericea* and *Burkea africana* open woodlands or wooded grasslands. The area is sometimes covered by vast areas of a dense mixed shrub/thicket vegetation in which *Terminalia sericea, Baphia massaiensis, Combretum* species*, Erythrophylum africanum, Baikiaea plurijuga* (coppice)*, Bauhinia macrantha and Acacia flecckii* are conspicuous (Rushworth, 1975).

3.4 Climate

Mean annual rainfall for Hwange Main Camp is 650 mm (Dudley, 1999; Anonymous, 1998). Rainfall decreases towards the central and southern parts of the Park, and towards the border with Botswana. 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 Main Camp area ranges from 24ºC in June to 32ºC in October (hottest month of the year). July is the coldest month, with an average screen temperature of 4.6ºC at Main Camp. High temperatures during the dry season account for 50% water loss through evaporation (unpublished National Parks records).

Frost occurs in Hwange National Park during months of May to August, and temperatures drop to a minimum of -5ºC or lower during this period. Black frosts, with temperatures lower than -7ºC, occur approximately after 5 years (Anonymous, 1998). Frosts that result in widespread damage to woody vegetation have occurred historically at approximately 5-year intervals (Childes and Walker, 1987). There is little published information on frost occurrence and its effects on woody vegetation (Rushworth, 1975). Evidence is, however, found in some areas where frost zones or belts are typified by shrub dominated woodlands. In some areas, stems, branches or whole woody plants are often killed. At least some 'dwarf' *Baikiaea* areas are maintained by annual frosting (Rushworth, 1975).

3.5 Vegetation

Hwange National Park is classified as an area of mixed woodland and open savanna (Greaves, 1996). Kalahari sands appear to carry high woody species biomass, and grass is relatively sparse (Rushworth, 1975). Woodland occupies about 64%, shrubland 32% and grassland only 4% (Anonymous, 1998). A total of 255 species of trees and shrubs are recorded in the Park. These dominate large tracts of land, and approximately 202 grass species are recorded (Greaves, 1996). Vegetation is mainly controlled by soil type.

Deep soils of Kalahari sands support tree species with deep, extensive root systems (Greaves, 1996). Species that form large stands of woodland and open woodland include *Baikiaea plurijuga, Pterocarpus angolensis* and *Guibortia coleosperma* (Greaves, 1996).

The dominant vegetation type for Hwange Main Camp is *Baikiaea plurijuga* mixed woodland and shrubland, commonly associated with *Combretum* sp., *Acacia* sp. and *Terminalia sericea* (Valeix 2002). Appendix A gives a list of species found associated with *B. plurijuga* in the study site. Childes and Walker (1987) indicated that Main Camp is dominated by *Baikiaea* woodland and C*ombretum-Acacia* shrubland habitats, interspersed with patches of *Acacia erioloba* woodland and open savanna. Figure 2 shows vegetation map of Hwange Main Camp area and location of watering points.

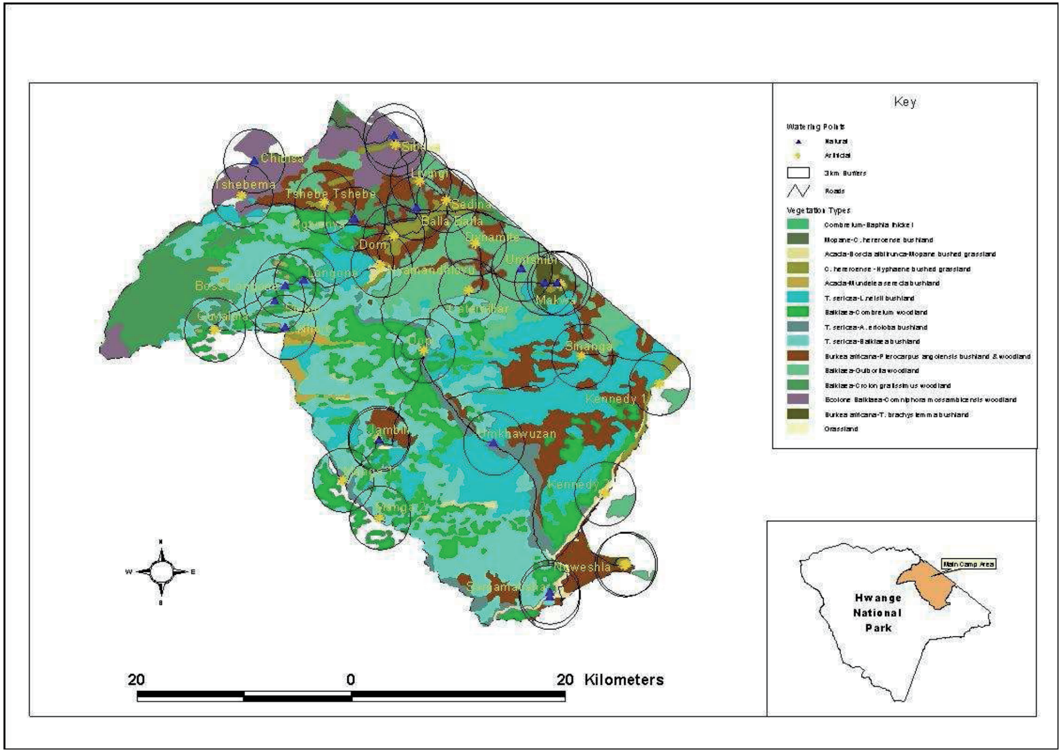


Figure 2: Vegetation map of Hwange Main Camp area and location of watering points

3.5.1 *Baikiaea plurijuga* distribution, geology and growth characteristics

Baikiaea plurijuga is also known as the Zambezi teak. *Baikiaea plurijuga* woodlands are dry savanna woodlands found primarily growing on Kalahari sands (Bradley and Dewees, 1993). The species covered 1 988 400 hectares in Zimbabwe in the early eighties (Judge, 1986). Parks and Wildlife controls 568 000 hectares, and the rest was shared among communal land, private land and Forestry Commission (Judge, 1986). *Baikiaea plurijuga* is exploited commercially for timber at an unsustainable rate (Judge, 1986). The origin of *Baikiaea plurijuga* is the Guinea-Congolian floral region. It spreads southward into the Zambezian region, following the Kalahari sand belt (Pierce, 1986). Hwange National Park is found within the Zambezi region.

Baikiaea plurijuga dominates and is well adapted to infertile deep sands of Kalahari formation (Childes and Walker, 1987) which supports well-grown woodlands, open woodlands and mixed shrub vegetation types (Vincent and Thomas, 1961). Moisture retention of Kalahari Sands in the lower horizons is an important aspect in the present distribution of *Baikiaea plurijuga. Baikiaea plurijuga* thrives under rainfall belt ranging from 600mm to 1080mm (Bradley and Dewees, 1993). The teak woodland is limited by available soil moisture, rooting depth and seasonality.

Baikiaea plurijuga regenerates from seed (Calvert, 1974). Regeneration of the species is poor (Pierce, 1986). Germinating seedlings are also prone to attack by rodents and large mammals (Rushworth, 1975). Animals such as buffalo and elephant sometimes limit the growth of the understorey through browsing, trampling and uprooting, hence may promote natural regeneration (Piearce, 1986). New stems may arise from rhizomes. The species is long rooted, and can reach a height of 20m. However, *Baikiaea plurijuga* is slow growing, and can reach 2.5mm in diameter per year (Calvert, 1974). Slow growing *Baikiaea plurijuga* may require 400 years to reach diameter at breast height of 38cm (Pierce, 1986). The species is fire and frost sensitive (Rushworth 1975, Calvert, 1974).

3.6 Fire

Natural fires occur in Hwange National Park. These are initiated by lightning. Areas of high anthropogenic fire frequency are along the railway line and the border with Botswana. Fire data presented by Rogers (1993) suggest that Hwange Main Camp area has low fire frequency in general. The greater proportion of Hwange Main Camp experiences a fire frequency ranging between one and four fires in every 23 years.

3.7 Water

A majority of the waterholes are natural, but contain water only during the rainy season and early dry season. There are more than 20 000 natural watering points that occur in Hwange National Park. Natural waterholes are shallow depressions that are filled by run-off during the rainy season (Van Wijngaarden, 1985). Weir (1965) attributed the origin of natural waterholes to zoogenous erosion by large mammals. Further evolution of these water holes may be critically influenced by these mammals. In Hwange National Park, natural water sources include pans, seeps and springs that occur in such large rivers as the Deka and Lukosi.

Due to drying of most natural waterholes during the dry season, and the subsequent high animal mortality, the Department of National Parks and Wildlife Management decided to sink boreholes in the Park (Valeix, 2002). The objective behind the development of artificial watering points was to enhance game population densities, thus enhancing tourism potential for the area. This would subsequently prevent migration of animals to areas outside the park (Anonymous, 1998).

First artificial watering points in Hwange National Park were sunk in 1935, and by 1973, about sixty-four boreholes were operational and under maintenance. By 1984, there were a total of seventy four drilled boreholes (Anonymous, 1998). Populations of game increased due to the provision of more permanent water. This resulted in deteriorating vegetation status, first noticed in some areas of the Park in 1947, and later gradually becoming more prevalent and widespread (Anonymous, 1998). The subsequent increase in elephant population exerted a competitive effect on other browsers, notably grazers and mixed feeders (Valeix, 2002). Elephant and ungulates mainly concentrate in the northern part of the Park, especially Main Camp, during the dry season. These high concentrations are driven by the search for water (Valeix, 2002).

3.8 Fauna

Hwange National Park represents one of the richest biodiversity areas in Africa, including a high abundance of fauna (Greaves, 1996; Valeix, 2002). The park boasts of a total of 105 mammalian species, inclusive of 19 large herbivores species and eight large carnivores species. The elephant makes up 70% of the total biomass of large mammals, (while the giraffe, buffalo and impala, make up 24%), and is the most common and widespread mammal in the park. The tsessebe and red hartebeest are rare species in the Park (Anonymous, 1998). Animal densities decrease towards the drier areas south of the park

The provision of water and control of hunting since 1928 have resulted in spectacular increase in game population (Greaves, 1996). Culling episodes occurred from 1963 to 1988, but elephant population generally increased despite culling (Anonymous, 1998). Hwange National Park is not an ecological island, as animals move to and from Botswana, Matetsi Safari Area, forest reserves and private land east of the railway line. Considerable changes in several large mammalian species occurred over 30 years. These have seen some populations of such species as buffalo generally decreasing since the 1969/71 survey (Anonymous, 1998).

Birds (residents and migrants) comprise about 410 species (Greaves, 1996). Large raptors and many species of migratory waterfowls breed in the area. Hwange National Park and Matetsi Safari Area combined have 37 species of snakes, 13 species of lizards, seven species of gecko, one chameleon species, three terrapin species, two tortoise species, five amphibians as well as the Nile crocodile (Blake, 1972; Broadley and Blake, 1979). Diversity of species is enhanced by the diversity of vegetation zones (Greaves, 1996).

4.0 Materials and Methods

4.1 Experimental design

4.1.1 Geographic Information System (GIS) methods for sample site selection

The stratified random sampling procedure was adopted. Geographic information system (Landres *et al*, 2001) was used to create three kilometer buffers around each of the watering points in the Hwange Main Camp management area. This was followed by an overlay of vegetation types on the three kilometer buffers using Rogers (1993) vegetation map for Hwange National Park (Figure 2). Watering points falling within vegetation types containing 50% or more *Baikiaea plurijuga* as dominant or co-dominant species were selected. This brings uniformity in type of vegetation sampled among artificial and natural watering points for comparison purpose.

An assessment of pumping history of the selected watering points was carried out. Waterholes were divided into natural (seasonal) and artificial classes. For the seasonal points selected, their proximity to artificial watering points was assessed. Natural watering points located within six kilometers of an artificial watering point were discarded as effects of browsing from artificial watering points would have an effect on results. Selected watering points had to be not less than five kilometers apart to avoid range degradation and homogenization of vegetation through coalescing of piospheres (Zambatis, 1980). Selected waterholes had to be above fifteen years in age.

4.1.2 Sampling procedure

Artificial watering points of similar elephant concentration levels were selected for sampling in the study site. Confidence limits were computed from dry season twenty four-hour waterhole counts over a sixteen year period (baseline data from Wildlife and Environment Zimbabwe and National Parks). Table 1 below shows the elephant census mean (16-year period) for each artificial watering point sampled.

Table 1: 24-hour waterhole elephant census mean for artificial watering points in Hwange Main Camp area (16-year average-1990-2005)

Name of Artificial Watering Point	***16-year elephant census mean***	***Standard Deviation***	***Standard Error***	***-95% Confident Limit***	***+95% Confident Limit***
Caterpillar	358	238.4566	59.61414	231.8730	486.0020
Dopi	322	179.1690	44.79225	226.7776	417.7224
Guvalala	311	148.5756	37.14389	232.6422	390.9828
Manga 1	309	162.1530	40.53825	222.5948	395.4052

The overlapping nature of confidence limits (table 1) was the basis for similarity in elephant concentration among artificial watering points. Seasonal watering points that satisfied the buffering, distance and age criteria were assumed to be less elephant impacted sites as they are dry for part of the year.

The development of sampling technique was after Brits *et al* (2002). At each selected waterhole, a 3km 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. Quadrats measuring 20m x 20m were systematically placed at 500m, 1km, 1.5km, 2km, 2.5km and 3km along each baseline transect from the watering point. This gave a total of six quadrats at each waterhole.

The area immediately surrounding the waterhole to a distance of approximately 100m was disregarded as far as the assessment of trend was concerned as any observed damage was due to animal milling around, waiting to drink (Bromwich, 1972). Each point was used as the center of a quadrat. Where bare ground or different vegetation type was encountered, direction of movement deviated 20m left or right at right angle. This was decided on the basis of tossing a coin. Sites of non-*Baikiaea plurijuga* dominated vegetation type were excluded from the assessment. Second or third baseline transects at each particular watering point were chosen randomly if there was missing point.

Sampling was done within three zones of elephant occupancy around a watering point according to Conybeare (1991). Four artificial and four seasonal watering points were sampled to make a total of forty eight quadrats. Woody vegetation in the quadrats along baseline transects was examined for any damage by elephant, as guided by damage classification (Bromwich, 1972). The damage scoring was determined by the form of damage and intensity. Other variables measured included density of woody species, height, girth and canopy cover.

It was assumed that all artificial watering points used in the study were similar in terms of environmental variability among themselves. Likewise, similarity was also assumed for all natural watering points in all aspects of the environment. This assumption was due to the uniformity of environmental factors in the study area such as rainfall, temperature, soil type, topography, elephant concentration among watering points and vegetation type through stratification.

4.2 Assessment of woody vegetation damage and measurement of variables

4.2.1 Woody vegetation damage

The current work focused on the level of elephant damage on *B. plurijuga* in different size-classes of the population in relation to distance from artificial and natural watering points. Overall damage to woody vegetation in *B. plurijuga* dominated vegetation plots (quadrats) was also recorded. Mapaure and Mhlanga (1998) defined elephant damage as any noticeable form of vegetation utilization by elephant. Damage by fire, frost, diseases and wind was not considered in the study. Height, density, basal area and canopy cover were used to define *B. plurijuga* population structure.

Measurements were made on all trees and shrubs 1m or more tall. Trees are considered as woody plants above 3m in height and with basal diameter of 6cm or more (Anderson and Walker, 1974). The height criterion was used to separate shrubs and trees. Any woody species falling under this size were regarded as shrubs. The height criterion was used to separate shrubs and trees.

Form of elephant damage could be broken stems, broken branches, bark stripping and scarring, pushed trees and uprooted trees or shrubs (Mapaure and Mhlanga, 1998; Bromwich, 1972). Converted trees were also considered as shrubs in accordance with Anderson and Walker (1974). All woody plants were assessed for height, and damage was calculated using a standard formula (Bromwich 1972). Degree of damage on woody vegetation was subjectively estimated in the assessment of damage. Calculation of overall damage was done using a formula adapted from Bromwich (1972).

The following measures that reflect likely elephant impacts could be assessed: seedling that are <1m in height, juvenile trees, that are 1-3m in height and mature trees that are >3m in height (Okula and Sise, 1986). Shrubs (<1m in height) were not included in the measurements as shrub browsing is not confined to elephant alone, but includes such other browsers as kudu (Hiscocks 1999). Assessment of elephant damage was therefore confined to juvenile (1-3m) and mature (>3m) trees. Observed damage on *B. plurijuga,* which did not appear to be attributable directly to elephants was not considered. For each woody plant in each height category, damage was scored using damage indexes formulated by Bromwich (1972) as indicated in Table 2.

Table 2: Damage classes on percentage basis (Bromwich, 1972)

Class	**Damage index**
Light browsing	10% of available plant
Moderate light	11-25%
Moderate	26-50%
Heavy	51-75%
Extremely heavy	76-99%

4.2.1.1 Damage calculations

Overall Percentage damage to woody vegetation= Sum of damage ratings/maximum possible damage x 100

Where, Damage rating = Mid-point of damage class (index) x height of a woody plant species.

Maximum possible damage of a site = sum of height x 100

Mid-points for which damage is determined are 5%, 18%, 38%, 63% and 88%. All are derived from percentage damage indices (Table 2).

4.2.2 Tree and Shrub density

The density of trees and shrubs would be given by the number of trees or shrubs per unit area of quadrat, which can be expressed as trees/shrubs per hectare. Multi-stemmed species were listed as one tree. Density was used as a measure of abundance (Muller-Dombois and Ellenberg, 1974).

4.2.3 Height

Tree height was measured by means of a graduated height stick. Height of plants stratified the vertical components of *B. plurijuga* into layers of shrubs and trees. Height measurement is considered as of paramount importance in assessing damage (Mueller-Dombois and Ellenberg, 1974) as it allows determination of height class most vulnerable to elephant damage.

4.2.4 Girth

Circumference was measured at breast height in order to calculate basal diameter. Basal diameter measures the cross-sectional area (basal area) of plant stems at breast height (1.2m) per unit area of ground. Basal area gives a direct measure of dominance of a given plant species or woody vegetation size class per unit ground area (Husch, Miller and Beers**.** 1993). For multi-stemmed plants, mean girth of separate stems was used.

$BA= C^2/(4\pi)$

Where C=Circumference (girth)

4.2.5 Canopy Cover

Canopy cover is defined as the percentage of sampled area under the canopy of a given species.

Canopy cover of woody vegetation was calculated using the line intercept method (Canfield, 1941). The length of the line in each quadrat was 20m. The line divides the quadrat into two and was perpendicular to the direction of baseline transect. Cover of individual species was easily obtained by collecting intercept data on a woody species basis. Canopy cover is an indirect measure of productivity. The method though is time consuming, particularly in dense vegetation or when intercept distances are difficult to define because of gaps or irregular edges within the canopy (Canfield, 1941).

4.3 Data Analysis

Descriptive statistics were used to explain trends in the data set. Woody species diversity was calculated using Shannon Weiner function (details given on subsection 4.3.1.3). Mann Whitney tests using STATISTICA version 6 were used to test for significant difference for each damage variable and canopy cover assessed between independent groups from artificial and seasonal watering points in three distance classes (elephant occupancy zones), that is ≤1km (high elephant occupancy zone), >1-2km (moderate elephant occupancy zone) and >2km from water (low elephant occupancy zone), and in height classes, 1-3m (juvenile trees/shrubs) and >3m (mature trees).

One-way analysis of variance was computed for height, density and basal area of *B. plurijuga* between elephant occupancy zones of artificial and natural watering points (STATISTICA Version 6). Canopy cover and basal area could be used as measures of dominance (Muller-Dombois and Ellenberg, 1974). The two can be used interchangeably depending on the focus of study. Canopy cover and basal area were analyzed separately in order to investigate the influence of elephants in the creation of gaps. Data were tested for normality to meet the assumptions for analysis of variance (Sokal and Rohlf, 1995).

Discriminant analysis (DA), a multivariate analysis technique, was used to explore the relationship of quadrats in elephant occupancy zones of both artificial and natural watering points in relation to damage on *B. plurijuga*. Log transformation was done for damage percentages used during Discriminant analysis. Discriminant analysis is a single technique that describes the difference among two or more well-defined groups. It also predicts the likelihood that an entity of unknown origin will belong to a particular group based on a suite of discriminating characteristics (McGarigal *et al*, 2000). The choice of initial grouping reflects personal preference rather than any difference in statistical procedure (MacGarigal *et al*, 2000).

Simple linear regression analysis was done to establish the relationship between measured variables and distance from both artificial watering point (AWP) and natural watering point (NWP) (STATISTICA version 6).

Variables and indices used in the study were; overall woody damage, overall damage to *Baikiaea plurijuga*, damage to *Baikiaea plurijuga* recruits (1-3m), damage to mature *Baikiaea plurijuga* (>3m), proportion of *Baikiaea plurijuga* plants damaged, density of *Baikiaea plurijuga* shrubs, density of *Baikiaea plurijuga* trees, mean height *Baikiaea plurijuga* shrubs, mean height *Baikiaea plurijuga* trees, mean basal area *Baikiaea plurijuga* shrubs, mean basal area *Baikiaea plurijuga* trees, canopy cover, woody species diversity, species richness and species evenness.

4.3.1 Measures of diversity

A non-parametric measure of species diversity for each waterhole was determined by Shannon Weiner index (Krebs, 1999). Species evenness was determined according to Simpson’s method (Renolds and Ludwig, 1988), and species richness recorded as the total number of species in a community (Krebs, 1999).

4.3.1.1 Species richness

An inventory technique was used to record woody species in all quadrats. Species richness can be defined as the total number of species in a community (Krebs 1999). Species richness provides a basis for monitoring effects of physical impacts on vegetation (Spellberg 1991). Species inventories for particular habitats are frequently required for purposes of conservation management (Underwood 1997). Concentration of elephants on woody vegetation around waterholes is assumed to have an effect on species richness.

4.3.1.2 Species evenness

Species evenness refers to the way in which individuals are distributed among samples (Spellberg 1991). Measurement of evenness is very important because heterogeneity is a function of species richness and evenness (Krebs 1999). To achieve measurement of evenness, the Simpson's index of evenness was used (Krebs 1999)

$$\frac{E_i}{d} = \frac{\left(\frac{1}{\breve{D}}\right)}{S}$$

Where $\frac{E_i}{d}$ = Simpson's measure of evenness

$\breve{D}$ = Simpson's index $= \sum p_{i^2}$

S = Number of species in the sample

4.3.1.3 Species Diversity

Diversity is synonymous to heterogeneity because it incorporates both species richness and evenness into a single value (Ludwig and Reynolds 1988). Diversity index alone is difficult to interpret as so much valuable information about the relative importance of species richness and evenness is not reflected by the single statistic (Townsend *et al* 2003). The index, however, attempts to describe a complex community structure and interpretation of the index could be fairly possible by calculating species richness and evenness separately. The Shannon Weiner function was used to calculate the diversity index of sampling units at each sampling site. The index was calculated using the following formula (Townsend *et al* 2003).

$$H^{'} = -\sum_{i=1}^{n} p_i \ln p_i$$

Where $H^{'}$ = Shannon Weiner diversity index
p_i = Proportion of individuals of species i in the community

Woody species diversity along an elephant herbivory gradient (elephant occupancy zones) was used to show the validity of the Intermediate Disturbance Hypothesis. Intensity and distribution of disturbance in the form of elephant browsing was compared between artificial and seasonal watering points. It was assumed that elephant disturbance was highest closer to water and the resultant high disturbance was likely to result in low species diversity. Woody species richness was expected to increase at moderate disturbance, and to decrease at lower concentration at some specified distances from the watering point.

5.0 RESULTS

5.1 Assessment of elephant damage on *B. plurijuga* around watering points

5.1.1 Levels of damage to recruiting *B. plurijuga* plants in high, medium and low elephant occupancy zones around artificial and natural watering points.

Mann Whitney comparison test for significance showed significant difference (P<0.05) in damage to *B. plurijuga* recruits between artificial and natural watering point in high elephant occupancy zone. There were no significant differences (P>0.05) in damage to *B. plurijuga* recruits between artificial and natural watering points in moderate and low elephant occupancy zone. Table 5.1 shows damage to *B. plurijuga* recruits in elephant occupancy zones of artificial and natural watering points (Combined quadrats, n=8).

Table 5.1: Damage (%) to recruiting *B. plurijuga* plants in high, medium and low elephant occupancy zones around artificial and natural watering points.

	Elephant occupancy zone		
Type of watering point	**High**	**Moderate**	**Low**
Natural	11.5	10	8
Artificial	26.5	10	9.75
p-level	0.0053	0.92	0.15

P significant at 0.05

5.1.2 Levels of damage to mature *B. plurijuga* plants in high, moderate and low elephant occupancy zones around artificial and natural watering points.

Mann Whitney comparison test for significance showed no significant differences on damage to mature *B. plurijuga* between artificial and natural watering points in high, moderate and low elephant zones of occupancy. Table 5.2 shows damage level to mature *B. plurijuga* in elephant occupancy zones of artificial and natural watering points (combined quadrats, n=8).

Table 5.2: Levels of damage (%) to mature B. plurijuga plants in high, medium and low elephant occupancy zones around artificial and natural watering points.

	Elephant occupancy		
Type of watering point	**High**	**Moderate**	**Low**
Natural	14	9	8
Artificial	18	14	8
p-level	0.32	0.057	0.79

5.1.3 Levels of damage to overall *B. plurijuga* plants in high, medium and low elephant occupancy zones around artificial and natural watering points.

Mann Whitney comparison test for significance showed no significant difference (P>0.05) in overall damage to *B. plurijuga* between artificial and natural watering points in high, moderate and low elephant zones of occupancy. Table 5.3 shows levels of damage to overall *B. plurijuga* plants in elephant occupancy zones of artificial and natural watering points (Combined quadrats).

Table 5.3 Levels of damage (%) to overall *B. plurijuga* plants in high, medium and low elephant occupancy zones around artificial and natural watering points.

	Elephant occupancy		
Type of watering point	**High**	**Moderate**	**Low**
Natural	14	10	8
Artificial	21	12	8
p-level	0.17	0.20	0.63

5.1.4 Proportion of *B. plurijuga* plants damaged in high, medium and low elephant occupancy zones around artificial and natural watering points.

Mann Whitney comparison test for significance showed a significant difference ($P<0.05$) in proportion of *B. plurijuga* plants damaged between artificial and natural watering points in high elephant occupancy zone. There were no significant differences in proportion of *B. plurijuga* plants damaged between artificial and natural watering points in moderate and low elephant occupancy zones. Table 5.4 shows damage levels for proportion of *B. plurijuga* plants in elephant occupancy zones of artificial and natural watering points.

Table 5.4 Proportion of *B. plurijuga* plants damaged in high, medium and low elephant occupancy zones around artificial and natural watering points (Combined quadrats).

	Elephant occupancy		
Type of watering point	**High**	**Moderate**	**Low**
Natural	19	15	14
Artificial	39	19	13
p-level	0.035	0.79	0.92

5.1.5 Levels of damage to overall woody vegetation in high, medium and low elephant occupancy zones around artificial and natural watering points.

Mann Whitney comparison tests for significance showed significant difference ($P<0.05$) in damage to overall woody vegetation between artificial and natural watering points in high elephant occupancy zone. There were no significant differences ($P>0.05$) in damage to overall vegetation between artificial and natural watering points in moderate and low elephant occupancy zone. Table 5.5 shows overall damage to woody vegetation in high, moderate and low elephant occupancy zones of watering points.

Table 5.5. Levels of damage (%) to overall woody vegetation in high, medium and low elephant occupancy zones around artificial and natural watering points (Combined quadrats).

	Elephant occupancy		
Type of watering point	**High**	**Moderate**	**Low**
Natural	18	13	10
Artificial	23	15	11
p-level	0.051	0.26	0.26

5.2 Relationship between damage to *Baikiaea plurijuga* plants and distance from watering points

5.2.1 Relationship between damage on recruiting *Baikiaea plurijuga* with distance from watering points

There was a significant ($P<0.05$), stronger negative linear relationship between damage to *B. plurijuga* recruits and distance from artificial watering point. Damage to *B. plurijuga* recruits decreased with distance from artificial watering points. Figure 5.1 shows relationship between damage to recruits and distance from artificial watering points.

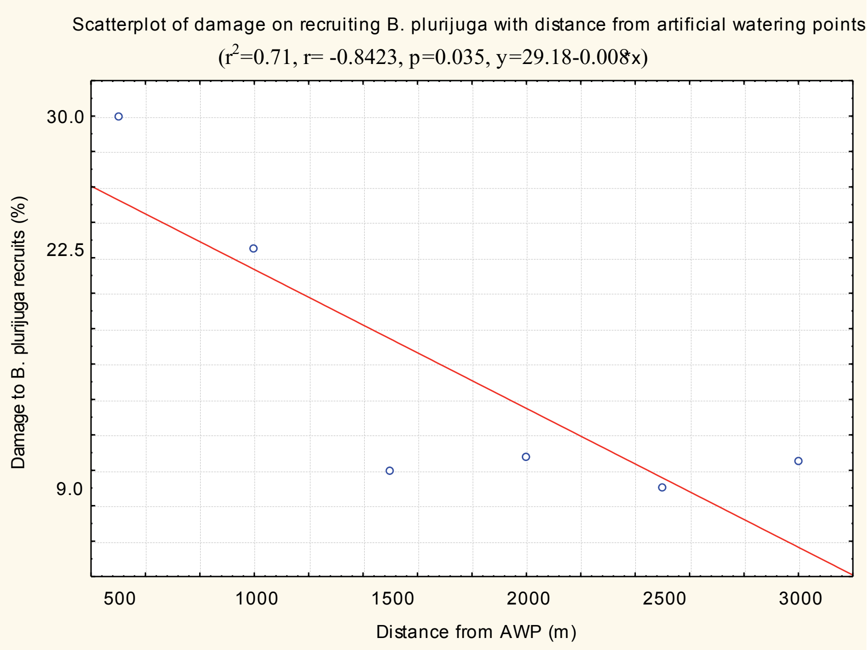


Figure 5.1 Relationship between damage on recruiting *Baikiaea plurijuga* with distance from artificial watering points.

There was no significant linear relationship between distance from natural watering point and damage to *B.plurijuga* recruits ($r^2 = 0.22$; r = -0.47, p = 0.35; y = 12.03 - 0.0013*x).

5.2.2 Relationship between damage on mature *Baikiaea plurijuga* with distance from watering points

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* decreases with distance from artificial watering points. Figure 5.2 shows the relationship between damage to mature *B. plurijuga* and distance from artificial watering point.

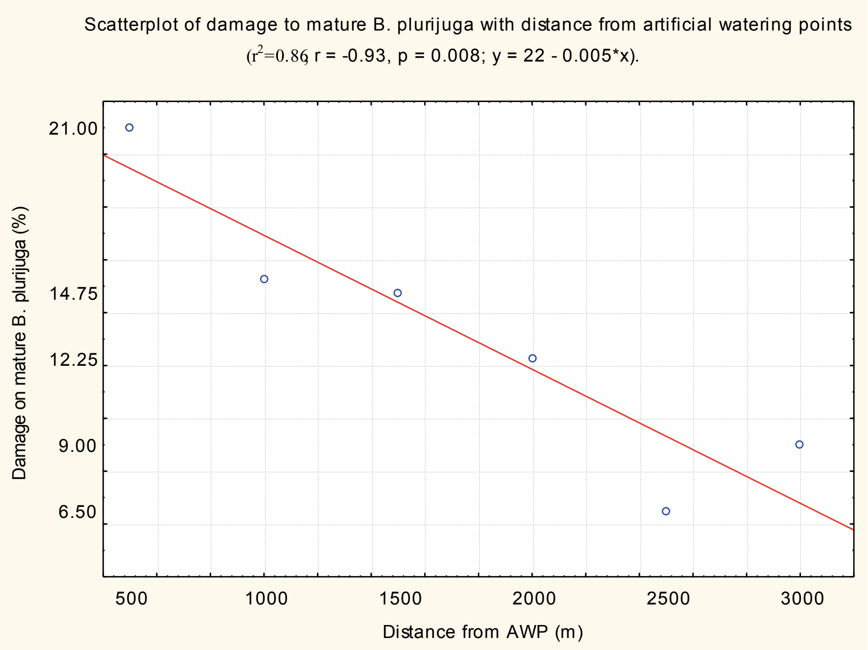


Figure 5.2 Relationship between damage on mature *Baikiaea plurijuga* with distance from artificial watering points

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* decreases with increasing distance from natural watering point. Figure 5.3 shows relationship between damage to mature *B. plurijuga* and distance from natural watering point.

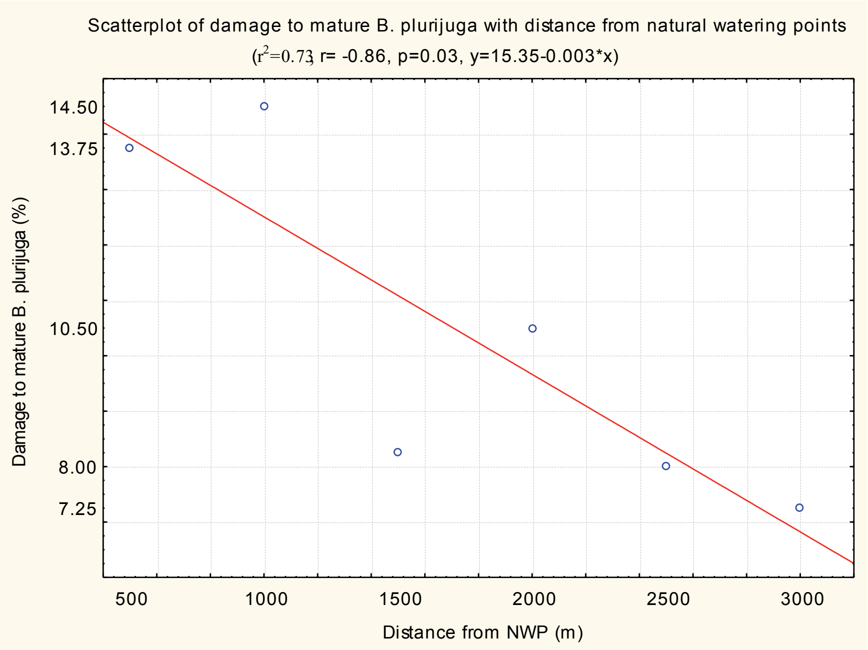


Figure 5.3 Relationship between damage on mature *Baikiaea plurijuga* with distance from natural watering points

5.2.3 Relationship between proportion of B. plurijuga plants damaged (%) and distance from watering points

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. Figure 5.4 shows relationship between proportion of *B. plurijuga* plants damaged and distance from artificial watering point.

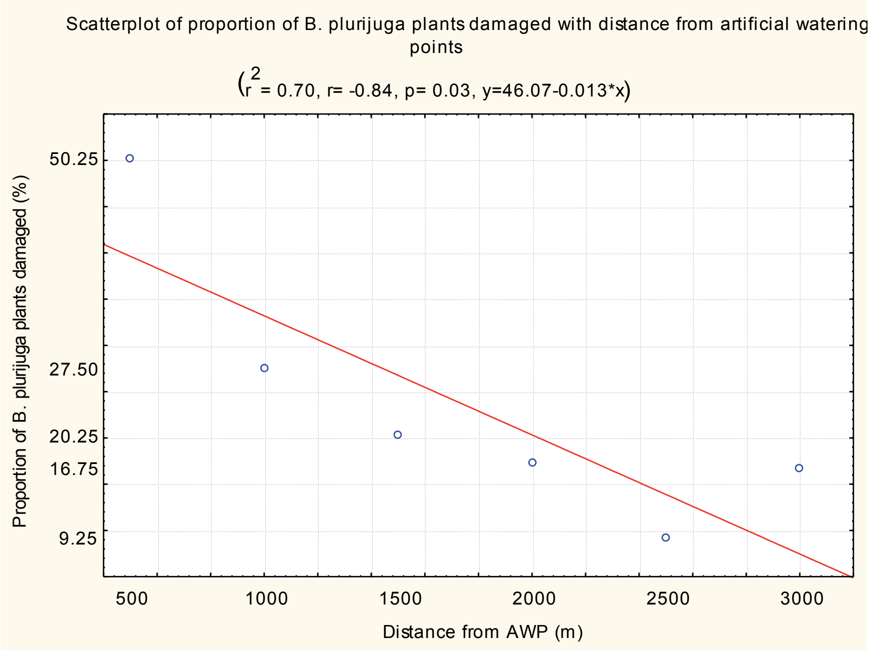


Figure 5.4 Relationship between proportion of *B. plurijuga* plants damaged and distance from artificial watering points

There was no significant linear relationship between proportions of *B. plurijuga* damaged (%) and distance from natural watering point. ($r^2 = 0.11$; $r = -0.33$, $p = 0.53$; $y = 18.68 - 0.0014*x$).

5.2.4 Relationship between damage to overall woody vegetation and distance from watering points

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. Figure 5.5 shows relationship between overall woody vegetation damage and distance from artificial watering point.

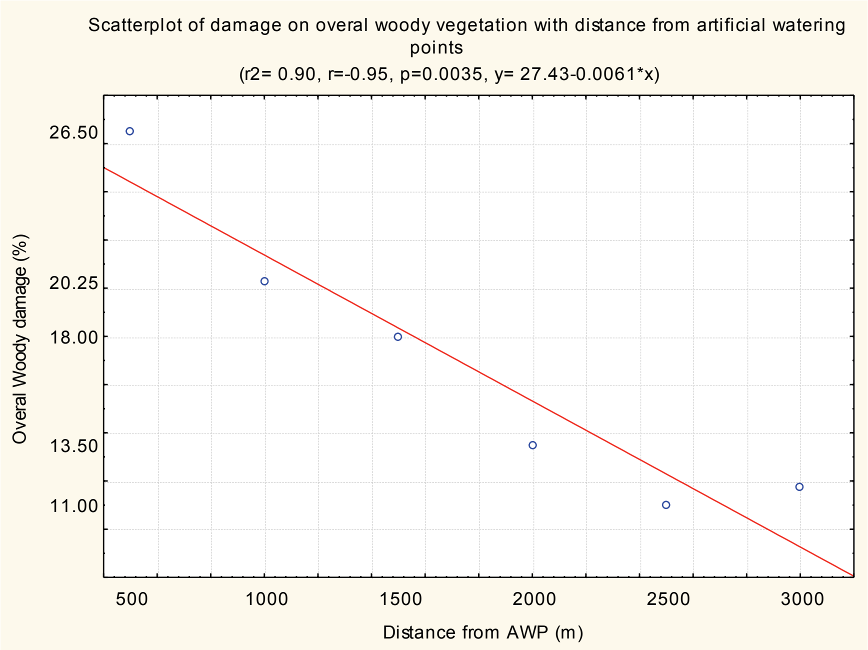


Figure 5.5 Relationship between damage on overall woody vegetation with distance from artificial watering points

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. Figure 5.6 shows relationship between overall woody vegetation damage and distance from natural watering point.

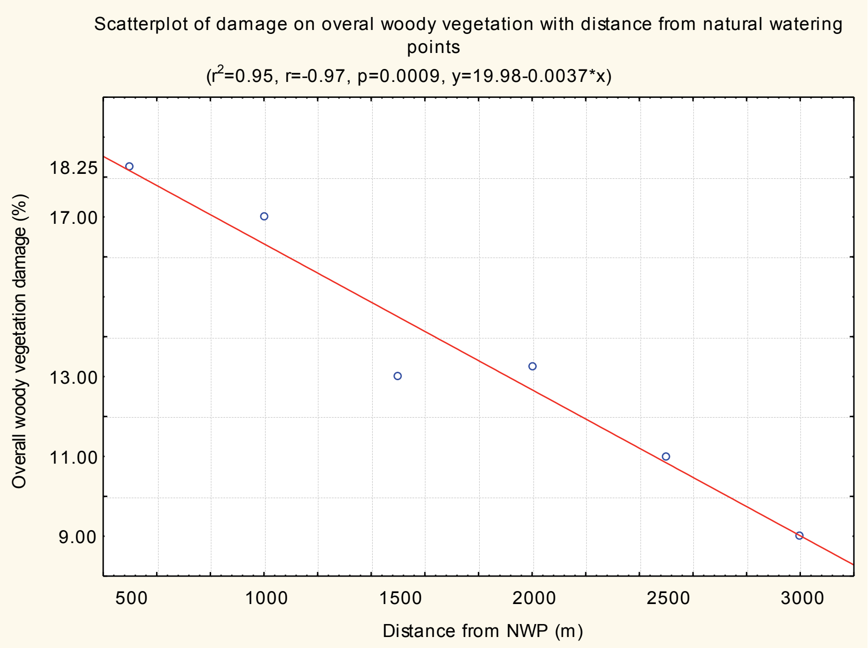


Figure 5.6 Relationship between damage on overall woody vegetation with distance from natural watering points

5.3 Differences in structural components of *B. plurijuga* between artificial and natural watering points in relation to elephant occupancy zones.

Mann Whitney comparison test for significance showed significant difference ($P<0.05$) between canopy cover (%) of artificial and natural watering points in high elephant occupancy zone. There were no significant differences in canopy cover (%) between artificial and natural watering points in moderate and low elephant occupancy zone. Table 5.6 shows canopy cover (%) in elephant occupancy zones of artificial and natural watering points.

Table 5.6: Canopy cover (%) of *B. plurijuga* plants in high, medium and low elephant occupancy zones around artificial and natural watering points (Combined quadrats, n=8).

	Elephant occupancy		
Type of watering point	**High**	**Moderate**	**Low**
Natural	50	78.65	83.68
Artificial	31.5	60	93.75
p-level	0.031	0.17	0.29

P significant at 0.05

Analysis of variance showed significant difference ($F_{1,\ 14}=8.48$, $P<0.05$) in mean basal area of *B. plurijuga* shrubs (recruits) between artificial and natural watering points in high elephant occupancy zone. There were no significant difference ($P>0.05$) in mean basal area of *B. plurijuga* trees between artificial and natural watering points in moderate and low elephant occupancy zones. Table 5.7 shows mean basal area of *B. plurijuga* shrubs in elephant occupancy zones of artificial and natural watering points.

Table 5.7: Mean basal area of *B. plurijuga* shrubs (mean basal area ± standard error) in high, medium and low elephant occupancy zones around artificial and natural watering points.

	Elephant occupancy		
Type of watering point	**High**	**Moderate**	**Low**
Natural	0.017 ± 0.0041	0.0190 ± 0.0035	0.0317 ± 0.0066
Artificial	0.033 ± 0.0034	0.0174 ± 0.0025	0.0189 ± 0.0035
F-value ($df_{1,14}$)	8.48	0.14	2.96
p-level	0.011	0.71	0.11

P significant at 0.05

Analysis of variance for other components of structure such as mean height *B. plurijuga* shrubs and trees, mean density *B. plurijuga* shrubs and trees and mean basal area *B. plurijuga* trees did not show significant differences (P>0.05) between artificial and natural watering points in relation to elephant occupancy zones (see appendix 3).

5.4. Discriminant analysis of elephant occupancy zones

Discriminant analysis described 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 *B. plurijuga* plants damaged) for both artificial watering points (AWP) and natural watering points (NWP). Pre-specified distance groups for each type of waterhole (artificial/natural) were three i.e. high elephant occupancy zone (≤1km from water), moderate elephant occupancy zone (>1-2km from water) and low elephant occupancy zone (>2km from water). New groups based on dissimilarity in extent of damage to *Baikiaea plurijuga* in elephant occupancy zones were formed (Figure 5.7).

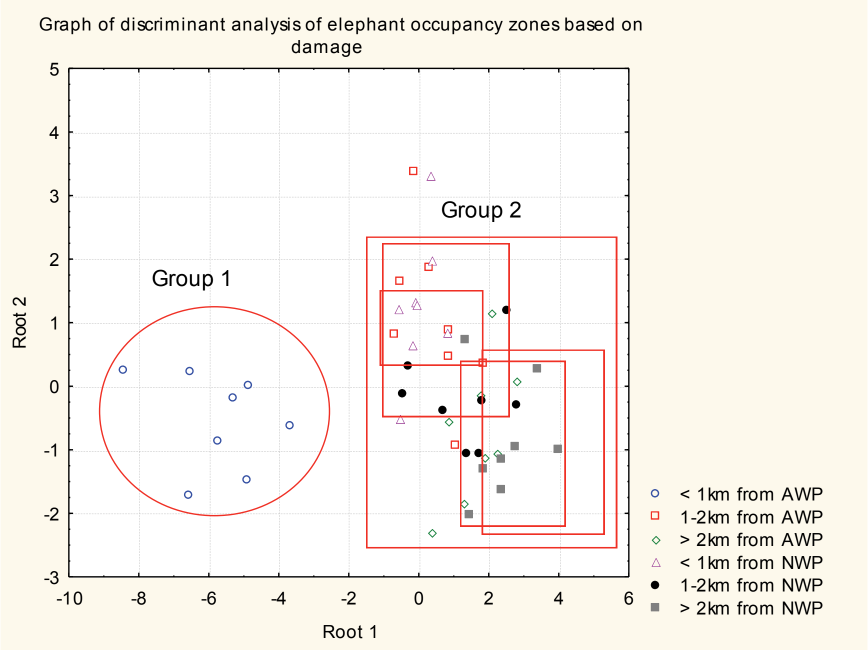


Figure 5.7: Grouping of quadrats in distance classes based on damage dissimilarity

Quadrats in high elephant occupancy zone (≤1km from water) were able to discriminate from the other groups by 100% (Group 1). The classification matrix (Appendix 4) confirms that some cases were misclassified from their original groups. Fifty percent of cases (quadrats) were misclassified from group >1-2km of AWP, 25% misclassified from group >2km of AWP, 13% misclassified from group ≤1km of NWP, 75% misclassified from group >1-2km of NWP and 13% misclassified from group >2km of NWP. There is no distinct pattern in the grouping of quadrats in groups (Group 2; Figure 5.7).

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

Components of structure considered in the present work 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 5.8 shows changes in shrub density with distance from artificial and natural watering point.

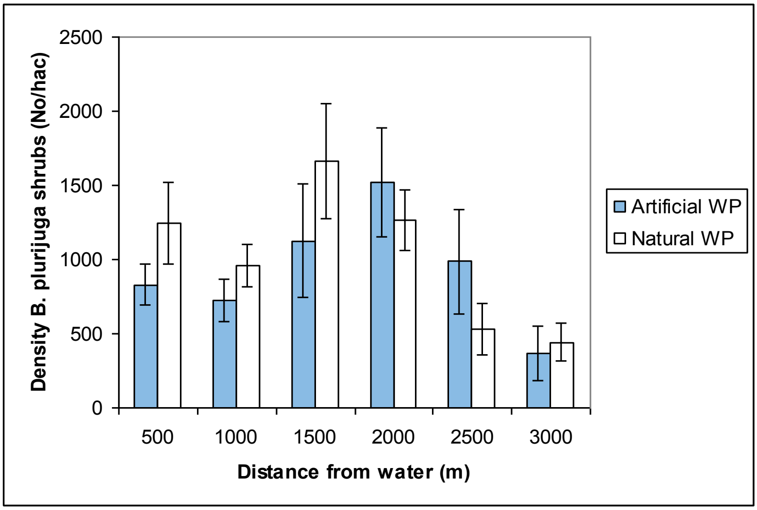


Figure 5.8: Mean density of *Baikiaea Plurijuga* shrubs with distance from artificial and natural watering points

There was no significant linear relationship between mean shrub density and distance from both artificial and natural watering point (P>0.05) (Appendix 5). Density of shrubs was relatively low within 1km radius from watering points. Shrub density increased with a further increase in distance from artificial watering point with highest density of 1 525 shrubs per hectare reached at 2km from water. Shrub density decreased beyond 2km from artificial watering point. An increase in shrub density was observed with a further increase in distance from natural watering point with the highest density of 1 687 shrubs per hectare reached at 1.5km from watering point. Shrub density decreased beyond 1.5km from natural watering point. *B. plurijuga* tree density was low closer to water on both artificial and natural watering points. There was a gradual increase in density with a maximum tree density of 1 887 per hectare reached at 2.5km from AWP and maximum tree density of 1 162 per hectare reached at 1.5km from natural watering point.

Tree density of *B. plurijuga* generally increased with an increase in distance from artificial watering point up to 2.5km. Tree density decreased beyond 2.5km from artificial watering point. Tree density of *B. plurijuga* gradually increased with an increase in distance from natural watering point. Figure 5.9 shows density of trees with distance from artificial and natural watering points.

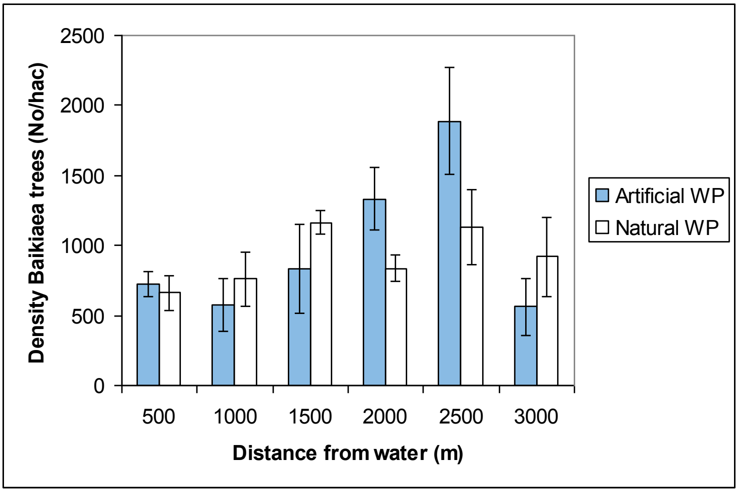


Figure 5.9: Mean density of *B. plurijuga* trees with distance from artificial and natural watering points.

There was no significant linear relationship (P>0.05) between density of *B. plurijuga* trees and distance from both artificial and natural watering points (Appendix 5).

Mean height of *B. plurijuga* shrubs did not vary much with distance from watering points.

Figure 5.10 shows mean height of *B. plurijuga* with distance from artificial and natural watering points.

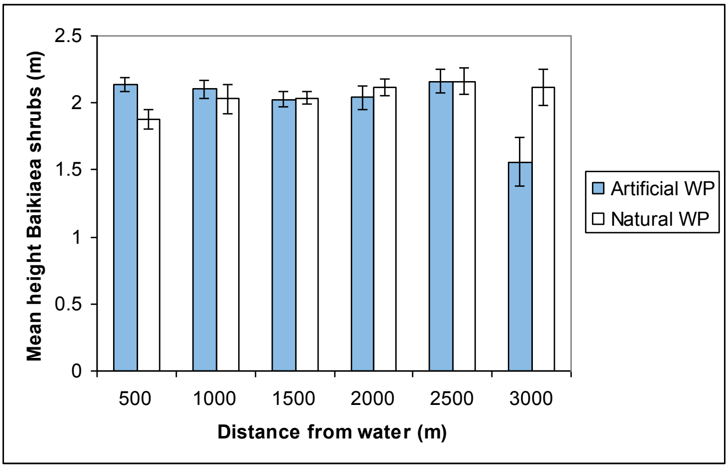


Figure 5.10: Mean height of *B. plurijuga* with distance from artificial and natural watering point.

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), positive linear relationship (P>0.05) between mean height of *B. plurijuga* shrubs and distance from natural watering point. Figure 5.11 shows linear relationship between mean height of *B. plurijuga* shrubs and distance from natural watering point.

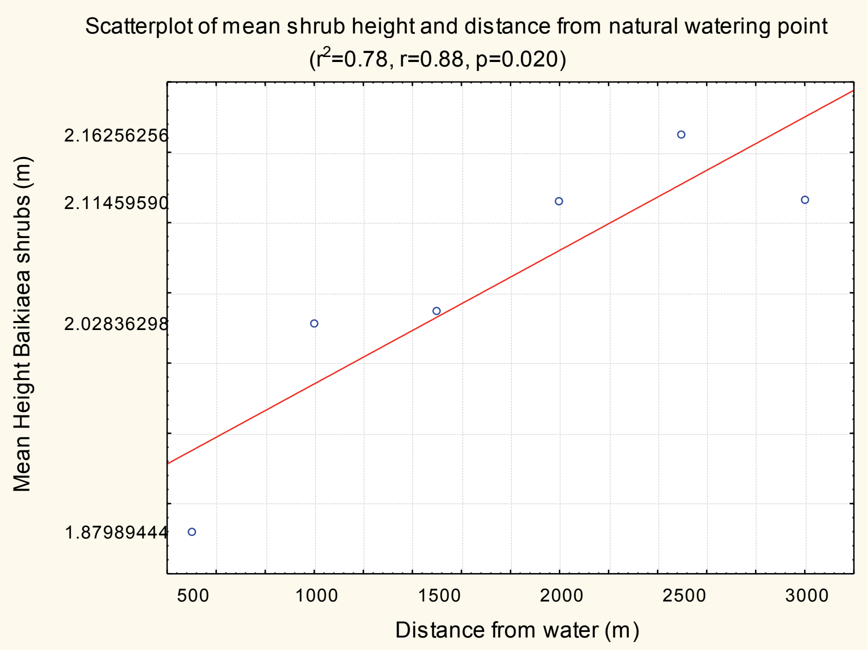


Figure 5.11: **Relationship between mean shrub height and distance from natural watering point.**

Mean height of *Baikiaea plurijuga* trees is around an average of 5m within 2.5km radius from artificial and natural watering point. Mean height of *B. plurijuga* trees increases beyond 2.5km from both artificial and natural watering point. Figure 5.12 shows mean height of *B. plurijuga* trees with distance from artificial and natural watering point

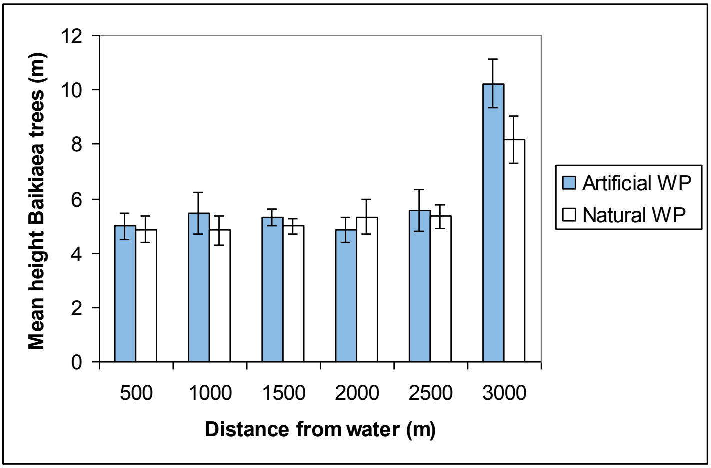


Figure 5.12: Mean height of *B. plurijuga* trees with distance from artificial and natural watering point.

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* shows a strong and positive significant linear relationship ($P<0.05$) with distance from both artificial and natural watering points (Appendix 5). Figure 5.13 shows canopy cover changes with distance from watering points.

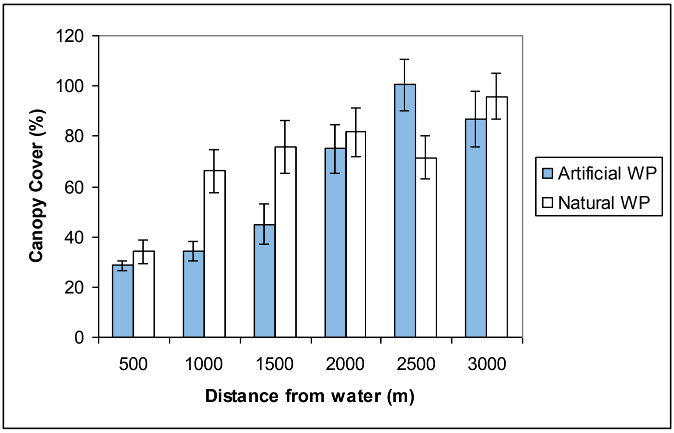


Figure 5.13: Canopy cover changes with distance from artificial and natural watering points

There is a general increase in canopy cover with increasing distance from watering points with maximum canopy cover of 100% and 96% reached at 2.5km and 3km from artificial and natural watering points respectively. Mean basal area of *B. plurijuga* shrubs is higher close to artificial watering points than further away. Mean basal area of *B. plurijuga* shrubs is lower closer to water and gradually increases 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. Figure 5.14 shows mean basal area of *B. plurijuga* shrubs with distance from artificial and natural watering point.

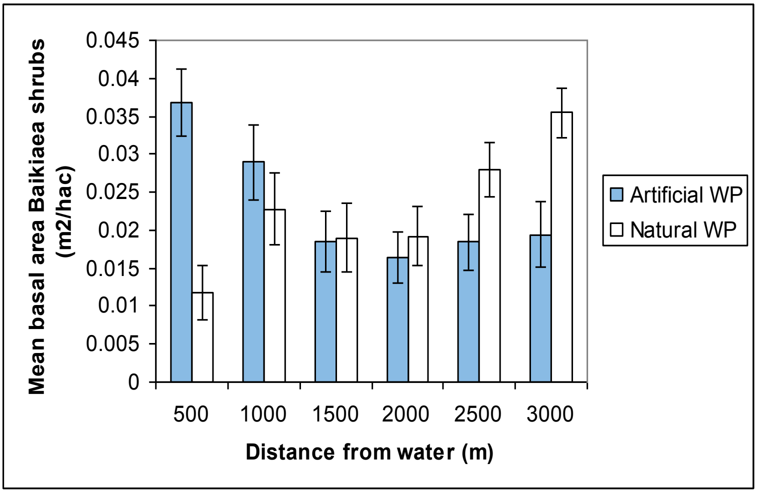


Figure 5.14: Mean basal area (+/- se) of *Baikiaea plurijuga* shrubs with distance from artificial and natural watering point

Mean basal area of *B. plurijuga* trees is generally low closer to watering points. A further increase in distance beyond 2.5km from waterholes results in a high increase in mean basal area of *B. plurijuga.* Maximum mean basal area of *B. plurijuga* trees reached at 3km radius of AWP was 1.42 m^2 per hectare and that for NWP was 0.61 m^2 per hectare. 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 (Appendix 5). Figure 5.15 shows mean basal area of *B. plurijuga* trees with distance from artificial and natural watering points.

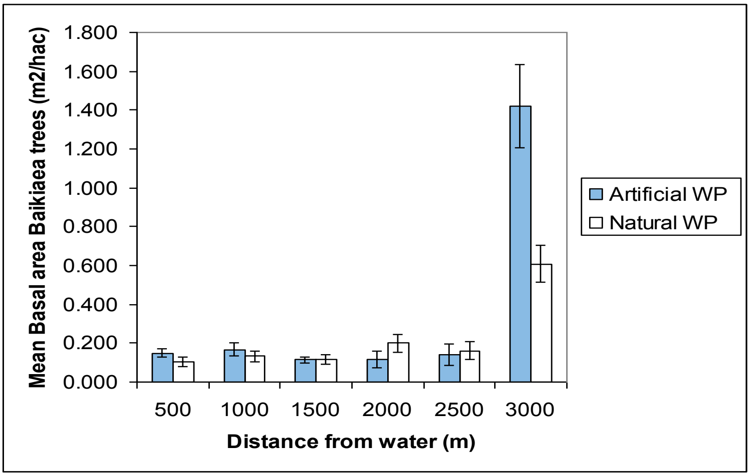


Figure 5.15: Mean basal area *B. plurijuga* trees with distance from artificial and natural watering points.

5.6 Diversity, species richness and species evenness in elephant occupancy zones

Diversity was highest closer to AWP and NWP and decreases as a function of distance. Figure 5.16 shows diversity with distance from watering points.

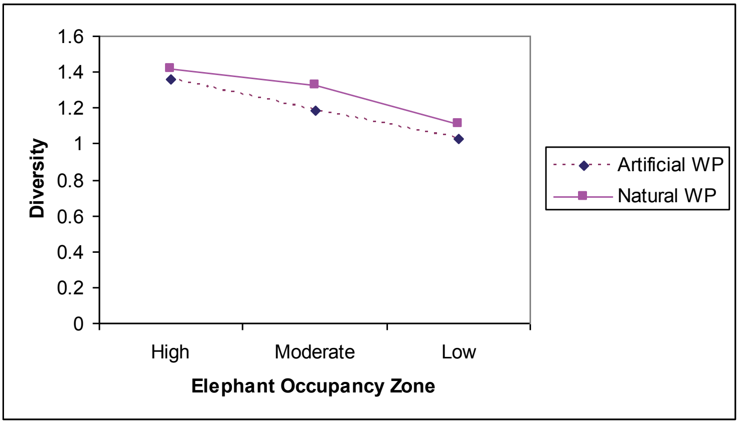


Figure 5.16: Diversity in elephant occupancy zones

Species richness was lowest in high elephant occupancy zones of both AWP and NWP, There was an increase in species richness in moderate elephant occupancy zone and relatively lower species richness in low elephant occupancy zones of AWP and NWP. Woody species evenness shows a general upward trend with distance from water. Table 5.8 shows woody species richness and evenness in elephant occupancy zones.

Table 5.8: Species richness and evenness in elephant occupancy zones

		Artificial Watering Points *Elephant Occupancy Zones*			*Natural Watering Points* *Elephant Occupancy Zones*		
		High	**Moderate**	**Low**	**High**	**Moderate**	**Low**
Evenness	**Mean**	0.38	0.34	0.41	0.29	0.32	0.37
	Standard error	0.13	0.14	0.18	0.076	0.11	0.25
Species Richness		23	26	24	22	25	23

6.0 Discussion

6.1 Evaluation of methods

The methods used to measure damage, height, density, basal area and canopy cover were generally satisfactory. The required information of the extent of elephant damage on *B. plurijuga* dominated woody vegetation around natural and artificial watering point was obtained. Although damage estimation was subjective, possible gross underestimation or overestimation of damage was taken into account by consulting a wildlife expert during reconnaissance. The method for calculating damage was efficient because it is not highly affected by the number of plants in a plot. Forms of damage such as bark stripping, breaking of stems, breaking of branches, pushing and uprooting of trees determine the level of damage during the estimation of damage in the field. Damage scoring considered height of woody species because most browsing by elephants occurs below 2m (Guy, 1976).

The line intercept method used in the determination of canopy cover had a few limitations in cases of overlapping tree or shrub canopies. This resulted in canopy covers more than 100% in some few plots further away from watering points. Density estimation of shrubs was time consuming where there was resprouting. Possible errors of inflating density of shrubs were avoided by considering multi-stemmed plants as one tree or shrub. Overestimation of shrub density was unavoidable in some instances when it was difficult to identify rhizomes on the ground. The estimation of height using the height stick was satisfactory, though height of plants more than 7m was estimated.

Comparison of extent of elephant damage on *B. plurijuga* between artificial and natural watering points considered replication at watering point level. Variability of the environments was minimized by stratifying watering points according to vegetation type using GIS technique, soil type and climate. Natural variations that occur in nature did not, however, affect overall results since the main aim was to determine the mean overall elephant damage around artificial watering points as compared to natural watering points.

Muller and-Dombois and Ellenberg (1974) noted that subdivisions of ecological parameters can be discovered by objective methods only through an extremely dense network of samples, which is impractical for most purposes. Natural variations in soil moisture and nutrient status of Kalahari sands and interaction of elephants with other environmental factors were not considered due to time constraints. Nonetheless, some patterns have emerged which should form a baseline study for more vegetation monitoring in Hwange National Park.

6.2 Extent of damage to *Baikiaea plurijuga* around artificial and natural watering points

The deteriorating vegetation status due to creation of artificial watering points have been described by various scholars (Anonymous, 1998, Brits *et* al, 2002, Van Der Schijff, 1957, Graetz and Ludwig, 1978, Thrash and Derry, 1999, Bromwich, 1972, Conybeare, 1991, Hiscocks, 1999, Laws, 1970, Tafangenyasha, 1997, Trollope *et al*, 1998, Van Wijngaarden, 1985, Van Wyk and Fairall, 1969, Lange, 1969). Very few studies compared the impact of elephants on woody vegetation around artificial and natural watering points (Bromwich, 1972). Very few studies also investigated the utilization of *B. plurijuga* by elephants in relation to watering points (Conybeare, 1991).

There is evidence from the present work that elephant browsing and trampling cause a significant impact on the survival of *Baikiaea plurijuga* recruits within 1km radius from artificial watering point. The relatively low damage to *B. plurijuga* recruits within 1km radius of natural watering points could be related to light utilization of vegetation during the dry season. The similarity in damage to *B.* plurijuga between 1-3km radius of artificial watering point and <1-3km radius of natural watering points could possibly be due to similarity in the utilization of *B. plurijuga* by elephants.

Results comply with Conybeare (1991) prediction that high elephant population in the Hwange National Park could possibly affect recruitment of *B. plurijuga* closer to artificial watering points. Brits *et al* (2002) also found that trampling effect due to increased herbivore numbers around watering points has a negative impact on the survival of seedlings of all woody plants. Large herbivores have relatively shorter legs and take relatively shorter steps than smaller herbivores, and so trample a greater area of ground per unit distance traveled (Cumming and Cumming, 2003).

Previous studies in Hwange National Park concluded that elephants had minor or insignificant influence in the structural dynamics of *B. plurijuga* population (Rushworth, 1975, Childes and Walker, 1985). These studies concluded that frost is an important factor that interacts with fire to influence changes in *B. plurijuga* population structure. Preceding studies by Conybeare (1991) and Dudley (1999) contradicted the findings that elephants had minor impact in the structural dynamics of Kalahari Sand vegetation. Dudley (1999) investigated the interactive effects of elephants, fire and frost and found that elephant browsing functions as both a direct and indirect variable in the mortality of woody plants within Hwange National Park. There was higher interaction between elephant damage, fire and frost than any of the interaction that excludes elephant damage (Dudley, 1999). Conybeare (1991) investigated the impact of elephants on the woody vegetation in the major habitats of the Kalahari sand areas of Hwange National Park in relation to artificial watering points. He concluded that vegetation change around artificial watering point was primarily due to elephants. Damage to *B. plurijuga* recruits (26.25%) and to *B.* plurijuga trees (18%) in high elephant occupancy zone (≤1km from water) of artificial watering point found in the present work supports Dudley (1999) findings. Dudley (1999) recorded damage frequencies of 50% and 18% for *B. plurijuga* shrubs and trees respectively.

Evidence from Southern African semi-arid savannas suggests that high elephant densities in nature reserves cause the overutilisation of woodlands (Ben-Shahar, 1996). The high density of elephants around watering points during limiting periods of the dry season in arid regions is not an exception. The associated ‘elephant problem’ is a typical paradigm whereby an increase in elephant numbers is followed by a decline in woody vegetation due to overbrowsing (Van Wyk and Fairall, 1969). The effect of fire is indeed a contributory interactive factor in the structural dynamics of savanna woodlands (Childes and Walker, 1987, Rushworth, 1975), but close to water, woody plants are probably influenced more by browsing than by fire (Brits *et al*, 2002).

The significant reduction in damage to mature *B. plurijuga* with distance from artificial and natural watering point could be ascribed to plant size and the feeding pattern of elephants further away from watering points. Firstly, the increase in plant size (height and basal area) with increasing distance from water reduces damage to plants. Plant mortality decreases exponentially as plant size increases (Gambiza, 2001). Secondly, *Baikiaea. plurijuga* may not be highly selected by elephants at further distance from the watering point. Unaltered woodlands were discovered by Conybeare (1991) at further distance from water. The increase in damage to mature *B. plurijuga* trees with distance towards watering point suggests that the abundance of preferred foods may be too low to allow the animals to restrict their feeding to the most preferred species (Owen-Smith, 1988). Elephants have catholic diets, but are nonetheless selective in their feeding habits according to site and season (Guy, 1976). Elephants become generalists when conditions are limiting (Westoby, 1978; Eltringham, 1982).

The increase in damage to mature *B. plurijuga* and overall woody vegetation damage towards natural watering point is related to the utilization of woody vegetation by elephants during the wet season when elephants browsing spreads to natural watering points.

6.2.1 Elephant occupancy zones

Elephant occupancy may not relate proportionally to the damage that could occur. The misclassification of quadrats from their pre-specified groups (elephant occupancy zones) during discriminant analysis results in overlapping of some quadrats in moderate and low elephant occupancy zone of artificial watering point. Overlapping of quadrats was due to sharing of common properties among quadrats in terms of elephant damage to *Baikiaea plurijuga* and overall woody vegetation damage

Conybeare (1991) noted that elephant occupancy may not be linearly related to distance from artificial watering point. He indicated that elephant occupancy can be very high in close proximity and then drop to a more uniform level for a distance of some kilometers. The high zone of elephant occupancy (>1km from water) around artificial watering points, which is associated with heavy destruction of woody vegetation (Conybeare, 1991), confirmed with the results of present work. Effect of large herbivore populations on recruitment around watering points has been documented in Kruger National Park (Thrash and Derry, 1999). Low shrub density was common closer to water due to high utilization pressure (Hiscocks, 1999).

Elephant occupancy with distance from artificial watering points, though not linearly related with damage in some instances, constituted an elephant herbivory gradient as described by Graetz and Ludwig (1978). This was revealed as there was a significant relationship between damage to *B. plurijuga* on recruits and trees and distance from AWP. Elephant occupancy zones of natural watering points may not be discernable as the damage gradient with distance from water was minimal. Damage on *Baikiaea plurijuga* recruits and proportion of *B. plurijuga* plants damaged did not change significantly with distance from natural watering point.

There might be two reasons for minimal damage to *B. plurijuga* recruits with distance towards natural watering point. Firstly, it could have been due to shorter browsing period and utilization of water during the wet season. Artificial and natural watering points share elephant population during the wet season when natural watering points contain water. Occurrence of elephants around natural watering points during the dry season, when they are dry, is mostly due to chance events. Bromwich (1972) found that the effect of game on natural watering point in Gonarezhou National Park may be one of utilization rather than destruction, and woody vegetation may be utilized evenly with distance from water. Secondly, there might be no relationship between elephant occupancy and damage to woody vegetation. Anderson (1973) found that in certain vegetation types, damage in areas of low elephant density may be proportionately more than damage in areas with high elephant densities.

Discriminant analysis confirmed that artificial watering points elicit distinct difference with natural watering points in damage to *B. plurijuga* plants within ≤1km radius from water. Elephant damage to *B. plurijuga* in zones of elephant occupancy around natural watering points (≤1km, >1-2km, >2km) was similar to damage that occur within >1-3km radius of artificial watering points. In Gonarezhou National Park, the construction of a new artificial waterhole resulted in higher tree loss and damage to woody vegetation by elephants closer to water as compared to damage on a natural watering point (Bromwich, 1972).

Natural watering points resemble a sustainable system, where there is equilibrium between rate of tree loss and rate of tree replacement. Mutualistic relationships between elephants and woodlands in terms of herbivore-plant density isocline could be described based on an equilibrium state (Craig, 1989). In the simplest terms, a system in “equilibrium,” when disturbed will return to its condition prior to the disturbance (Caughley, 1976). By implication, an “equilibrium” system contains self-correcting and self-repairing mechanisms. Historically, if elephants did destroy their habitats completely, they would leave the habitat and not return for many years, by which time the vegetation would recover (Walker, 1979). Although emigration is no longer feasible because of migration space constraint, natural watering points are characterized by relatively light vegetation utilization by elephants during the dry season when water is limiting, and confined only to artificial watering points.

Artificial watering points are bound to create problems such as over browsing by elephants. Considering the high concentration of elephants around artificial watering points, which is long and uninterrupted, a state of disequilibrium between rate of tree loss and tree replacement could occur. Artificial watering points cause indigenous large herbivores to become sedentary and results in year-round grazing and browsing of rangelands with an increase in utilization pressure (Brits *et* al, 2002). Elephants in Northern Botswana converge around water sources and reach densities of 8-10 per square kilometer particularly towards the end of the dry season (Craig, 1990). Heavy browsing of shrubs and trees by elephants particularly near permanent water is a major cause for concern (Ben-Shahar, 1993).

6.3 Structural Changes of *B. plurijuga* with distance from water

There was no significant linear relationship between shrub and tree density of *B. plurijuga* and distance from water. Results of present work contradicted with findings by Brits *et al* (2002) who found a significant, though weak linear relationship between tree and shrub density and distance from watering point. The differences could be ascribed to differences in vegetation types in the two study areas. Brits *et* al (2002) conducted work in *Scerocarya birrea-Acacia nigrescens* tree savanna woodland. Elephants utilize *Acacia species* and *Baikiaea species* in a different manner (see literature review sub-section 2.4).

There were some changes, however, with distance from water but the relationship was non-linear. Tree and shrub density was low close to water and generally increased as a function of distance. Tafangenyasha (1997) also reported low tree density closer to watering points than further away in a study conducted in Gonarezhou National Park. Elephant damage can take the form of reduction in tree density or decrease in shrub density close to water (Ben-Shahar, 1996). Canopy cover shows a significant increase with distance from both artificial and natural watering points. The concentration of elephants around watering points exposes vegetation in the vicinity to threat (Thrash and Derry, 1999). Ringrose *et al* (1996), found that woody plant density and cover increases as elephant numbers decreases, reflecting that elephant concentration do influence the extent of woody vegetation damage in ecosystems.

Baikiaea plurijuga woodlands around artificial watering points and natural watering points show 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 an increase in distance from artificial and natural watering point could partly be explained due to the reduction in damage to mature *B. plurijuga*. Mature *B.plurijuga* dominates further away from watering points. The long rooted nature of *B. plurijuga* does not favor uprooting of trees by elephants. Root system of a plant influence uprooting by elephants (Guy, 1976). Changes in canopy cover with distance from artificial watering point contradict with Conybeare (1991), who found no significant linear relationship with distance from watering point. Brits *et al* (2002) found that few individuals, but with larger canopies, are found closer to watering point and more individuals with smaller canopies further from the watering point. Several scholars associated canopy cover with plant height (Muller-Dombois and Ellenberg, 1974, Whittaker, 1970). Large trees constitute the greater proportion of canopy (Muller-Dombois and Ellenberg, 1974). The forest trees, with their upper foliage in full sunlight, form the canopy or uppermost level (Whittaker, 1970). A forest tree may gain advantage by reaching the canopy, where abundant light support photosynthesis. Smaller and fewer plants found closer to watering points and the increase in tree dominance with increasing distance from water supports an increase in canopy cover. Trees spend much of the energy of photosynthesis in growth of the woody tissue of stem and branches to support the foliage in the canopy (Whittaker, 1970). This partly explains the gradual increase in basal area of *B. plurijuga* trees with distance from watering points.

Small canopy trees found closer to watering points in the current work comply with Thrash (1991) findings in Kruger National Park. The distinct aggregative response by elephants around permanent watering points results in the opening of tree canopy (Thrash, 1991). In Kruger National Park, the density and canopy cover of *Combretum apiculatum* plants and the survival of all groups of woody plants were affected by the construction of the dam (Thrash *et al* 1991). Water as a key resource in arid regions is the driving force in the dynamics of ecosystems (Illius and O'connor, 2000). Basal area and canopy cover could be used as estimates of biomass (Ben-Shahar, 1996). Elephants over-utilize woody vegetation when they remove more biomass than plants could produce (Ben-

Shahar, 1996).

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

6.4 Diversity in relation to artificial and natural watering points

Diversity was higher closer to water due to biotic factors. Thrash (1991) reported no effect on the composition of woody community and species richness after construction of a dam. *B. plurijuga* is not particularly species rich, hence disturbance regimes by herbivores plays a part in increasing diversity. The decrease in diversity as a function of distance does not support the intermediate disturbance hypothesis. Relatively higher diversity associated with increased disturbance closer to watering points supports the theory of invasibility by Davies *et al* (2000). Davies et al. (2000) suggest that communities are more invasible when resources surge and temporarily go unused, providing an opportunity for invaders to capitalize on free resources.

Herbivores, apart from removing dominance of certain species, play a crucial role in the recycling of nutrients through their excretion products (Botkin *et al*, 1981). Elephants by opening up tree canopy, they create gaps in the ecosystem. This is characteristic of undisturbed site. A pool of unused resources may promote the invasion of new species (Davies *et al,* 2000). In areas with highly leached soils, such as Hwange National Park, herbivores maintain a continuous replenishment of nutrients on the soil surface for plant nourishment.

Dominant species have been reported to reduce species diversity thereby supporting the assumption that species richness increases when dominants are removed (Bengtsson et al, 1994). Cumming *et al* (1997) reported that elephants destroy trees and in the process open up woodlands, thus transforming habitats and altering animal and plant species composition. Low diversity found in *B. plurijuga* dominated sites at low elephant disturbance confirms the findings by Gambiza (2001) who reported that *Baikiaea plurijuga* woodlands are species poor. Some species are able to survive by solving the problem of competition with other species through niche differentiation (Whittaker, 1970). That is the reason why *Baikiaea plurijuga* is more adapted to infertile Kalahari Sands than other species (Judge, 1986). Evolution characterized the selection for survival in relation to problems of physical environment.

Natural watering points are associated with a higher diversity than artificial watering points due to relatively light vegetation utilization during the dry season. Areas threatened by elephant overpopulation during the dry season are not diversified (Tchamba and Mahamat, 1992). Higher diversity around natural watering points supports the equilibrium theory as described by Caughley (1976). For a species population in a climax to be stable, there must be a balance between natality and mortality. Ideally such balances of natality and mortality would, over longer periods at least, characterize all the species populations of the climax community. This constancy in a system is known as a dynamic equilibrium or steady state (Whittaker, 1970).

Species-diversity increases from the simple communities of early succession to the richer communities of late succession. The community that ends a succession is termed a climax. Central to the concept of climax is the community's relative stability under given climatic conditions. Climax implies a steady state condition in a natural community (Whittaker, 1970). Higher stability is associated with artificial watering points than natural watering points. This could partly be linked to the higher level of disturbance that breaks dominance of *B. plurijuga*, thus allowing more competitors tolerant to herbivory to establish themselves. Species richness was relatively higher at artificial watering point than natural watering point. The differences were partly due to the influence of rare species such as *Sclerocaya berria, Strychnos madagascariensis, Vangueria infausta* and *Viterx pyos*. Ideally species richness was similar between artificial and natural watering points.

6.5 Conclusion

The work demonstrated that the impact of elephants on *Baikiaea plurijuga* dominated woodlands due to provision of water in Hwange National Park is largely on its recruitment. Distance from watering points creates an herbivory gradient of woody vegetation utilization that is characterized by changes in some components of *Baikiaea plurijuga* structure. The zones of elephant occupancy with distance from watering points, however, did not reflect much on the gradients of woody vegetation utilization by elephants in *B. plurijuga* dominated woodlands.

Damage to shrubs, mature *B. plurijuga* and overall woody vegetation decreases linearly with distance from artificial watering points. There was no significant linear relationship between damage to *B. plurijuga* recruits and distance from natural watering points. Though damage to ***B. plurijuga*** recruits did not change significantly with distance from natural watering point, the gradient of vegetation utilization due to elephants was reflected by a significant decrease in damage to mature *B. plurijuga* and overall woody vegetation damage.

Components of *Baikiaea plurijuga* population structure (density, height, basal area) did not differ between artificial and natural watering points. Canopy cover within ≤1km radius from artificial watering point is lower than canopy cover around natural watering points. This reflected high elephant damage to *B. plurijuga* (canopy and sub-canopy) around artificial watering points than around natural watering points.

Canopy cover, mean basal area of shrubs and mean height of *B. plurijuga* increases with distance from natural watering points. *B. plurijuga* shrub density, tree density, mean height of trees and mean basal area of trees did not change linearly with distance from natural watering points. Canopy cover increases with distance from artificial watering points. There were no linear changes in height, density and mean basal area of *B. plurijuga* with distance from artificial watering points. Assessment of relationships may not be adequately described by a linear relationship because changes occurred but not in a non-linear fashion.

Woody species diversity in *B. plurijuga* dominated woodlands is higher around natural watering points than around artificial watering points. Diversity is higher closer to watering points, where browsing is higher and decreases as a function of increasing distance from water, which is associated with decreasing vegetation utilisation. Natural watering points provides a sustainable system where light vegetation utilization during the dry season promotes recovery and establishment of *B. plurijuga* recruits. The high browsing and trampling pressure associated with artificial watering points elicit damage difference with natural watering points within ≤1km radius from water.

6.6 Recommendations

There is need for continued research to investigate the impact of herbivores around watering points on ***B. plurijuga*** regeneration. Herbivores play a pivotal role in seed dispersal (Crawley, 1997) and seed germination (Calvert, 1974). Herbivores can affect the establishment of seedlings (Pierce, 1986,) and can consume seedlings (Skarpe, 1990). Little work has been done on the effects of the timing and intensity of herbivory on regeneration and growth of Zambezi teak forest (Gambiza, 2001). If higher damage on *B. plurijuga* recruits is compensated by a higher regeneration, then elephant damage is not critical.

Contradiction among scientific scholars on the effects of herbivores on *Baikiaea* plurijuga suggests that the effects of herbivores on teak are therefore unclear (Gambiza, 2001). More quantitative data needs to be collected to establish whether the results are consistent with those of present work, Conybeare (1991) and Dudley (1999). Future work should also look at competition. Competition can influence plant fitness, abundance, distribution and species composition (Bengtsson *et al*, 1994).

The present work was undertaken to determine the overall levels of elephant damage on *B. plurijuga* woodland between artificial and natural watering points. There was insufficient data to recommend management policies on individual watering points. There is enough evidence, however to support the fact that artificial watering points should be subjected to a rotation scheme that ensures an equilibrium state in the utilisation of *B. plurijuga*. The rotation programme would promote higher diversity and a reduction in damage to *B. plurijuga* recruits. Higher diversity was found on *B. plurijuga* dominated woodland around natural watering points.

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APPPENDICES

Appendix 1: List of woody species common in Baikiaea plurijuga dominated habitats in Hwange Main Camp area

Acacia ataxacantha
Acacia erioloba
Acacia fleckii
Acacia Luediritz
Acacia nilotica
Baikiaea plurijuga
Baphia massaencis
Berchemia discolor
Bouhnia petersiana
Brachystegia spiciformis
Burkea africana
Combretum apiculatum
Combretum celastroides
Combretum collinum
Combretum fragrans
Combretum gratissimus
Combretumh hereroense
Combretum zyheri
Commiphora angolensis
Commiphora pyracatoides
Commiphora mozambicensis
Croton gratissimus
Croton megalobotryes
Croton psuedopuchelus
Dichrostachys cineria
Erythrophylum africana
Euclea divinorum
Euphorbia coperi
Erythroxylum zambesiacum
Giuoportia coleosperma
Grewia aveliana
Grewia flavensis
Guiobortia coleospermum
Lonchocarpus nellsii
Merkamia zanzibarica
Mundulea sericea
Ochna cinabarina
Ochna pulchra
Peltophorum africanum
Psudolachnostylis maprounefolia
Sclerocaya berria

Strychnos madagascariensis
Terminalia Sericea
Vangueria infausta
Viterx pyos

Appendix 2: Mann Whitney comparison significance tests of damage in elephant occupancy zones between artificial and natural watering points.

Mann-Whitney U Test By variable Distance from Water
Significance at p <.05000

High elephant occupancy zone of AWP vs high elephant occupancy zone of NWP

Variable	Rank Sum	Rank Sum	U	Z	p-level
Overall Woody vegetation damage	86.50000	49.50000	13.5000	1.95151	0.05099
Overall Damage B. plurijuga	81.00000	55.00000	19.0000	1.37645	0.16868
Damage B. plurijuga recruits	94.50000	41.50000	5.50000	2.78715	0.00531
Damage mature B. plurijuga	77.50000	58.50000	22.5000	1.00138	0.31664
% B. plurijuga plants Damaged	88.00000	48.00000	12.0000	2.10351	0.03542
Canopy Cover (%)	47.50000	88.50000	11.5000	-2.1529	0.03132

P<0.05= Damage *B. plurijuga* recruits, % Baikiaea plants damaged, overall woody damage and canopy cover

Moderate elephant occupancy zone of AWP vs moderate elephant occupancy zone of NWP

Variable	Rank Sum	Rank Sum	U	Z	p-level
Overall Woody vegetation damage	78.50000	57.50000	21.5000	1.1167	0.26409
Overall Damage B. plurijuga	80.00000	56.00000	20.0000	1.2850	0.19877
Damage B. plurijuga recruits	69.00000	67.00000	31.0000	0.1061	0.91548
Damage mature B. plurijuga	86.00000	50.00000	14.0000	1.8973	0.05778
% B. plurijuga plants Damaged	70.50000	65.50000	29.5000	0.2631	0.79244
Canopy Cover (%)	55.00000	81.00000	19.0000	-1.365	0.17216

No significant Differences all variables

Low elephant occupancy zone of AWP vs low elephant occupancy zone of NWP

Variable	Rank Sum	Rank Sum	U	Z	p-level
Overall Woody vegetation damage	78.50000	57.50000	21.5000	1.1244	0.26083
Overall Damage B. plurijuga	72.50000	63.50000	27.5000	0.4826	0.62935
Damage B. plurijuga recruits	81.50000	54.50000	18.5000	1.4423	0.14919
Damage mature B. plurijuga	65.50000	70.50000	29.5000	0.2683	0.78844
% B. plurijuga plants Damaged	69.00000	67.00000	31.0000	0.1051	0.91623
Canopy Cover (%)	78.00000	58.00000	22.0000	1.0502	0.29362

No significant Difference all variables

Appendix 3: One-way analysis of variance for height, density and basal area of B. plurijuga in elephant occupancy zones.

Analysis of variance (high elephant occupancy zone of AWP and high elephant occupancy zone of natural watering point

Dependent variable	SS Model	Df Model	MS Model	SS Resid	Df Resid	MS Resid	F	p
Density Baikiaea shrubs	48400	1	48400	50276	14	35912	0.1347	0.7190
Density Baikiaea trees	15625	1	15625	10525	14	75178	0.2078	0.6554
Mean Height Baikiaea shrubs	0.11	1	0.11	0	14	0.0	4.4012	0.0545
Mean Height Baikiaea trees	0.55	1	0.55	16	14	1.2	0.4689	0.5046
Mean Basal area Baikiaea shrubs	0.00	1	0.00	0	14	0.0	8.4780	0.0113
Mean Basal area Baikiaea trees	0.01	1	0.01	0	14	0.0	2.5225	0.1345

Analysis of variance (moderate elephant occupancy zone of AWP and moderate elephant occupancy zone of natural watering point)

Dependent variable	SS Model	Df Model	MS Model	SS Resid	Df Resid	MS Resid	F	p
Density Baikiaea shrubs	12432	1	12432	1730535	14	12360	0.0100	0.921538
Density Baikiaea trees	28476	1	28476	2639922	14	18856	0.1510	0.703412
Mean Height Baikiaea shrubs	0.01	1	0.01	0	14	0	0.4894	0.495615
Mean Height Baikiaea trees	0.03	1	0.03	10	14	1	0.0348	0.854569
Mean Basal area Baikiaea shrubs	0.00	1	0.00	0	14	0	0.1442	0.709773
Mean Basal area Baikiaea trees	0.01	1	0.01	0	14	0	1.2276	0.286535

Analysis of variance (low elephant occupancy zone of AWP and low elephant occupancy zone of natural watering point)

Dependent variable	SS Model	Df Model	MS Model	SS Resid	Df Resid	MS Resid	F	p
Density Baikiaea shrubs	11289	1	11289.	6250234	14	44644	0.02528	0.8759
Density Baikiaea trees	16000	1	16000	1361500	14	97250	0.16452	0.6911
Mean Height Baikiaea shrubs	0.3	1	0.3	2	14	0.1	2.84295	0.1139
Mean Height Baikiaea trees	3.9	1	3.9	121	14	8.7	0.44677	0.5147
Mean Basal area Baikiaea shrubs	0.0	1	0.0	0	14	0.0	2.96151	0.1072
Mean Basal area Baikiaea trees	0.6	1	0.6	11	14	0.8	0.83470	0.3763

Appendix 4: (a) Classification Matrix: Rows: Observed classifications, Columns: Predicted classifications

Group	Percent	≤ 1km from AWP	>1-2km from AWP	> 2km from AWP	≤ 1km from NWP	>1-2km from NWP	> 2km from NWP
≤ 1km from AWP	100.00	8	0	0	0	0	0
>1-2km from AWP	50.000	0	4	1	1	2	0
> 2km from AWP	75.000	0	0	6	0	2	0
≤ 1km from NWP	87.500	0	1	0	7	0	0
>1-2km from NWP	25.000	0	0	2	2	2	2
> 2km from NWP	87.500	0	0	0	0	1	7
Total	70.833	8	5	9	10	7	9

Appendix 4 (b) Factor Structure Matrix: Correlations Variables - Canonical Roots (Pooled-within-groups correlations)

Variable	Root 1	Root 2	Root 3	Root 4	Root 5
Overall Woody damage	-0.570383	0.581360	0.307111	0.054189	0.489317
Overall Damage Baikiaea	-0.572049	0.329563	0.409847	0.553303	-0.300050
Damage Baikiaea recruits	-0.882001	-0.407410	0.126723	-0.071193	-0.186989
Damage mature Baikiaea	-0.387454	0.586452	-0.13710	0.547223	-0.433247

Appendix 5: Simple linear regression analysis of structural variables and distance from watering points

Linear regression analysis of *B. plurijuga* structural variables and distance from artificial watering points in Main Camp area of Hwange National Park

Variable	*r^2*	*r*	*P*
Density Baikiaea shrubs	$r^2 = 0.0237$	r = -0.1540	p = 0.7708
Density Baikiaea trees	$r^2 = 0.1365$	r = 0.3695	p = 0.4710
Canopy Cover	$r^2 = 0.8706$	r = 0.9331	p = 0.0066
Mean Height Baikiaea shrubs	$r^2 = 0.4133$	r = -0.6429	p = 0.1685
Mean Height Baikiaea trees	$r^2 = 0.4586$	r = 0.6772	p = 0.1395
Mean Basal area Baikiaea shrubs	$r^2 = 0.6427$	r = -0.8017	p = 0.0551
Mean Basal area Baikiaea trees	$r^2 = 0.4102$	r = 0.6405	p = 0.1706

Linear regression analysis of structural variables and distance from natural watering points in Main Camp area of Hwange National Park

Variable	*r^2*	*r*	*P*
Density Baikiaea shrubs	: $r^2 = 0.5312$	r = -0.7288	p = 0.1003
Density Baikiaea trees	: $r^2 = 0.3023$	r = 0.5498	p = 0.2584
Canopy Cover	: $r^2 = 0.7313$	r = 0.8552	p = 0.0299
Mean Height Baikiaea shrubs	: $r^2 = 0.7806$	r = 0.8835	p = 0.0196
Mean Height Baikiaea trees	$r^2 = 0.5706$	r = 0.7554	p = 0.0824
Mean Basal area Baikiaea shrubs	: $r^2 = 0.7660$	r = 0.8752	p = 0.0224
Mean Basal area Baikiaea trees	$r^2 = 0.5565$	r = 0.746	p = 0.0886

Appendix 6: Field data sheet

WOODY PLANTS INVENTORY (TREES/SHRUBS)

Site: ____ **Transect Dimensions:** _______________
Location: ____
Date: ____ **Observer:** __________________________
Transect No.: ____________________________________ **Area (sq. m):** _______________________

SU No	Species		Girth	Height	Damage Code					Notes
	Tree	Shrub			1	2	3	4	5	