Spatial variation in vegetation and soils around artificial watering points in Hwange National Park

By

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Tropical Resources Ecology

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May 2013

ABSTRACT

Piospheres are examples of the spatial impacts animals have on their environment. They tend to develop around artificial watering points, particularly in the dry season. The present study sought to assess impactof disturbance on plant species and soils across a disturbance gradient at watering points in the Main Camp of Hwange National Park.

The study was conducted around four artificial watering points (two seasonal watering points and two perennial watering points). A stratified sampling design was adopted, with woody vegetation plots systematically placed at 150 m intervals along 2 550 m long transects. Assessments of non-woody plants and soils were conducted in plots laid at 50 m interval along 2 500 m long transects.

Results indicated that woody species height and basal area increased with increasing distance from watering points. Shrub species richness was highest in moderately utilised zones and woody species diversity was lowest closest to the watering points. Non-woody species cover, richness and abundance increased towards the watering points. There was no consistent relationship between distance from water and non-woody species diversity. Concentrations of nutrients were highest in the vicinity of watering points. Soil moisture was lowest close to watering points and highest in the moderate occupancy zone. Soil pH was highest close to watering points. Onlyphosphorus was significantly different between seasonal watering points and perennial watering points. No significant differences were observed between seasonal watering points and perennial watering points in terms of vegetation attributes. Results indicate the existence of spatial variation in woody vegetation structure, non-woody vegetation cover and soil nutrient status and pH around artificial watering points which is associated with an animal disturbance gradient in Hwange National Park.

ACKNOWLEDGEMENTS

This study would not have been possible without efforts from Prof. S. Kativu for his invaluable supervision, Prof. C. H. D. Magadza for assistance on data analysis. Sincere acknowledgements are extended to Mr G. Matipano and Hwange National Park scientific services staff, in particular Hwange Main Camp for assisting with field work. Special thanks go to Edwin Makuwe, Simeon Mudhimba, Trust Dube, Leomba Mathe and Moreblessing Pekiwa who assisted in data collection.

Heartfelt appreciation goes to my husband Afios Mseva for his unwavering support and encouragement. A lot of appreciation goes to Mr and Mrs A. T. Mseva for providing me a home during the period of my study.

DEDICATION

To my two kids

Tafadzwa Princess Mseva;

Tawananyasha Afios Mseva, for whom-

I hope to set the best example.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Distribution of surface water impacts herbivore-vegetation interactions in arid and semi-arid regions. Limited access to surface water typically results in emergence of vegetation gradients around natural and artificial water sources. In particular, large herbivores can create large-scale gradients of woody vegetation (Du Toit*et al*., 2003). Understanding the dynamics of these gradients is of importance in conservation of ecosystems and herbivores that depend on woody vegetation in areas close to water sources.

Hwange National Park is the largest national park in Zimbabwe, covering 14 651 km^2(Department of National Parks and Wildlife Management (DNPWM), 1998), and hosts more than 100 mammal species.Due to recurrent droughts, natural watering points have not been able to sustain water requirements in the park during the dry season (Tatham, 1995). Perennial water is only found in seep areas which are mostly situated in depressions (Conybeare, 1991). When surface water in these depressions dries up, water is only available below the surface to those animals that are able to dig for it. Seasonal surface water is found throughout Hwange National Park during the wet season. This, however, dries up as the dry season progressesand lasts almost seven months of the year (Potts and Russel, 1995). As a result,70 boreholes have been sunk, 13 dams have been constructed, and some pans have been artificially deepened in order to increase their capacity and augment the natural water supplies (Tatham, 1995; Conybeare, 1991). The artificially supplied watering points are not distributed uniformly, but are concentrated around the north and east (35 boreholes in Main Camp) (Potts and Russel, 1995), leaving an area of 1000km^2 without permanent dry season water (Conybeare,1991).Increased grazing and trampling pressure around the artificial watering points often alters soil and vegetation composition and structure (Fernandez-Gimenez and Allen-Diaz, 2001).

1.2 Problem statement

Piospheresprovide examples of spatial patterning that result from environmental disturbance from animals. Studies have demonstrated the impacts of animals on vegetation around watering points (Gandiwa*et al*., 2012; Tuna *et al.*, 2011; Goodall, 2006; Beukes and Ellis, 2003; Fernandez-Gimenez and Allen-Diaz, 2001; VanRooyen*et al*., 1990). These impacts are attributed to increased trampling and grazing along the disturbance gradient towards watering points.In the case of Hwange National Park, this disturbance is particularly associated with elephants which are the major source of disturbance. The impacts are particularly observable in the form of vegetation structure and composition and soil nutrient status (Gandiwa*et al*., 2012;Beukes and Ellis, 2003).

1.3 Justification

Vegetation around watering points experiencesvariable pressures that depend on frequency and intensity of trampling and grazing. Large mammals that congregate around watering points create clearly defined trampling/grazing -induced gradients (Gandiwa*et al*., 2012). These are often reflected in the nature and properties of soil and vegetation, thus creating distinct piospheres. Such piospheres are indicative of levels of pressure subjected to particular spatial areas. Such pressure leads to substantial reduction in ecological functioning (Fernandez-Gimenez and Allen-Diaz, 2001).Piosphere growth is of particular importance when planning the distribution of watering points. The present study is aimed at providing baseline information relevant in monitoring and managing of plant biodiversity and structure around watering points. The study focused on plant species composition and structure and soil factors as indicators of disturbance around watering points.

1.4 Overall objective

The study sought to assess the nature of variationin plant speciesand soils across disturbance gradients at watering points in the Hwange National Park.

1.5 Specific objectives

The specific objectives of the study were:

1.to assess vegetation structure across a disturbance gradient around watering points;

2. to determine woody and non-woody plant species diversity across a disturbance gradient at watering points in the Hwange National Park;

3. to assess the relationship between vegetation and soil along the disturbance gradient; and

4. to establish the nature of key edaphic characteristics across the disturbance gradient.

1.6 Research questions

1. How does vegetation structure and composition vary across the disturbance gradient?
2. Is there any relationship between soil characteristics and vegetation across the disturbance gradient?

1.7 Hypotheses:

1. Plant species composition, diversity and structure change with increasing distance from watering points.
2. Soil characteristics are deterministic of vegetation characteristics, and change with increasing distance from watering points.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Provision of artificial water in protected areas

One important management intervention in protected areas has been the provision of artificial water. Water provision, however, can have adverse effects on plants over the long-term (Jeltsch*et al*., 1997).The drilling of boreholes has made it possible to sustain wildlife where rainfall variability and lack of surface water is prevalent.Interactions between animals and plants at watering points have led to the development of piospheres (distinct ecological units). Such piospheresare common in national parks(Du Toit*et al*., 2003).Artificialwatering points lead to irreversible vegetation and edaphic changes. Such changes are not confined to the vicinity of the watering points, but often result in landscape mosaics. Animal trampling and grazing create gradients of disturbance from the watering points (Jeltsch*et al*., 1997). These are often correlated with the magnitude of trampling and total volume/mass of grazers. In the case of piospheres, such effectsinclude removal of selected plant species,and soil carbon and nitrogen decrease exponentially from the watering point (Fernandez-Gimenez and Allen-Diaz, 2001).Changes across trampling and grazing gradients include reduction in vegetation cover and altered composition of woody and non-woody species and altered soil conditions.

2.1.1 The effects of watering points on woody vegetation

With regard to browse species, woody plants that are vulnerable to browsing or trampling suffer increased mortality towards the watering point(Gandiwa*et al*., 2012). Within the proximity of watering points where browsing pressure is highest, such woody species tend to be replaced by plants adapted to withstand browsing. Andrew and Lange (1986)observed this trendon livestock stations in arid Australia, whereas Ross (1995) reported similar results from the Succulent Karoo of South Africa. Mukwashi*et al*. (2012) found that

*Baikiaeaplurijuga*recruits were more susceptible to damage at artificial watering points than at natural watering points within ≤ 1 km radius from watering point. This was the case with most other woody species.

Another observable change related to increasing distance from artificial watering points was reduced woody species diversity. At natural watering points, an increase in canopy cover of *Baikiaeaplurijuga* with increased distance from the watering point was observed. The same was observed for mean basal area and height (Mukwashi*et al*., 2012). Overall, Mukwashi (2012) noted higher woody species diversity around natural watering points than around artificial watering points. Gandiwa*et al*. (2012) noted no significant differences in mean height, number of stems per plant, density and diversity with distance from watering points. Only one ephemeral natural watering point showed a decrease in plant density with increase in distance from the watering point.

Elsewhere, contrary to Gandiwa*et al*. (2012),Tuna *et al*., (2011) reported an increase in tree density and canopy cover towards the watering point in Central Chobe, Botswana, in spite of a growing elephant population. In support of Tuna *et al*., (2011),Tolsma*et al*. (1987) observed an obvious change in vegetation cover, species composition and species diversity in a transect from a borehole at Dikeletsane to the surrounding savanna. In the immediate vicinity of the borehole (0-20 m) however, tree and shrubs cover was less than 10%. Another study by Makhabu*et al*. (2002) recorded no severe degradation of habitats around watering points in Central Kalahari Game Reserve of Botswana. Friedel (1988) found that *Dichrostachyscinerea's* relative abundance was inversely proportional to distance from watering points, and *Acacia tortilis* and *Acacia karroo* relative abundances were directly proportional to distance from watering points. The change of species may lead to one association being replaced by another. For example, the *Sclerocaryabirrea*/*Acacianigrescens*savanna association in the central Kruger National Park is slowly replaced by a browsing resistant *Acacia tortilis*/*Dichrostachyscinerea*savanna woodland under high browsing pressures at watering points (Du Toit, 1988).

Reduced competition for moisture and reduced intensity of fires near watering points that result from overgrazing of the non-woody stratum tends to result in an increased woody plant density in areas where there are no elephants (Tolsma*et al*., 1987; Van Vegten, 1983). In areas with large elephant populations, such as the Kruger National Park, however, destruction of trees by these animals occurs at watering points (Thrash *et al*., 1991). This results in a decline in tree density near watering points (Brits *et al*., 2002; Thrash *et al*., 1991; Van Wyk and Fairall, 1969). An increase in stunted growth near water and its decrease away from it occurs in the Kruger National Park (Thrash *et al*., 1991; Van Wyk and Fairall, 1969). In the Kalahari, there is a decline in shrub canopy cover close (< 400 m) to watering points (Perkins and Thomas, 1993). This accompanies an increase in canopy cover in a zone beyond the sacrifice zone (about 400 m to 1500 m) after which shrub canopy cover is unaffected by the watering points (Brits *et al*., 2002; Thrash and Derry, 1999).

2.1.1.1 Impact of elephants

Megaherbivores can have a major impact on woody vegetation. Du Toit (1988) found that elephants are the major agents of woody stratum change in the vicinity of watering points in Kruger National Park. According to the findings of Van Wyk and Fairall (1969), the utilisation of woody plants by elephants in the Kruger National Park is inversely proportional to distance from water and the state of the grass cover. The greatest damage of the habitat by elephants is also in the surrounding areas of rivers and permanent watering points (Laws, 1970; Bax and Sheldrick, 1963). Excessive utilisation of the non-woody stratum by grazers is implicated as the major reason for increased browsing activity and destruction of the woody strata by elephants in the Kruger National Park (Van Wyk and Fairall, 1969).Elephants usually destroy woody plantsselectively according to species (Field, 1971; Van Wyk and Fairall, 1969) and preferred species tend to decline in abundance.

2.1.2 The effects of watering points on non-woody vegetation

The concentration of herbivore utilisation in the vicinity of recently constructed watering points has been found to lead to a decline of various intolerant groups of non-woody plant species (Thrash and Derry, 1999). Friedel (1988) found that the tall and fire climax grasses (e.g. *Cymbopogon* species) are eradicated. The erect palatable grasses, such as species of *Pennisetum*, *Themeda* and *Digitaria*werefound to decline (Van Rooyen*et al*., 1990) and smaller leaved, prostrate grasses, such as *Cynodondactylon* to increase. Weeds (e.g*Tribulusterrestris*) become dominant near the water (Tolsma*et al*., 1987). Species diversity was found to decline near watering points in Botswana (Tolsma*et al*., 1987) but Thrash *et al*. (1991) found no consistent relationship in South Africa between distance from water and non-woody species diversity. This lack of consistency is both unusual in the piosphere literature, and is difficult to explain.

Areas that are naturally dry in the dry season provide only summer grazing for water dependent large herbivores. When watering points are put up in these areas in Tunisia, the range up to about 10 km from water is grazed and trampled more than before(Tarhouni*et al*., 2007). Tarhouni*et al*. (2007) dealt with the changes that occur in these areas and found that this practice results in changes in the non-woody vegetation species composition. Pioneer annuals, such as *Themedaberteronianus* and *Urochloapanicoides*become more dominant over the whole area, and perennial species, such as *Themedatriandra* and *Digitariamilanjiana* become fewer (Tarhouni*et al*.,2007).

In the dry season, a band of land devoid of vegetation develops around watering points (Delany and Happold, 1979). This is referred to as the sacrifice zone (Jeltsch*et al*., 1997) or sacrifice area (Graetz and Ludwig, 1978). Grass production, under-storey cover and basal cover (Delany and Happold, 1979)have been found to be directly proportional to distance from water. Even though large herbivores in Australia prefer natural to artificial watering points, the impact at artificial watering points is not significantly different from that at natural permanent watering points (Howes and McAlpine, 2008).

2.1.3 Edaphic factors

2.1.3.1 Soil moisture

Soil moisture is a key determinant of savanna structure (Van Rooyen*et al*., 1990)and functioning (Jeltsch*et al*., 1997). It sets a limit on maximum plant productivity and a restriction on types of plants that can thrivesporadic periods of drought and favourable water relations. Availability of nutrients also has a constraint on total productivity. The availability of nutrients partly depends on precipitation (Gambiza, 2001). Quantity and seasonal distribution of annual rainfall and water holding capacity of a soil are some of the factors that influence the amount of available moisture.

Soil texture significantly influences the available soil moisture. The adhesive properties of water, in combination with the large surface area of clay-sized particles, allow clay to hold more water than sand. Silt loam contains the greatest quantities of plant available moisture because of the favourable distribution of macro and micro pore spaces (Barnes *et al*., 1998; Brady and Weil, 1996).

According to Dunham (1989), grass and sedge species composition were shown to be strongly related to soil moisture regime in the Zambezi valley downstream of Lake Kariba. In a woody plant ordination exercise, the first axis was related to altitudinal gradient; *Faidherbiaalbida*was a pioneer species on low lying sandbanks, and woody species richness increased with height above the Zambezi River.

In a study of vegetation-environmental relationships in coastal mountains of the fynbos biome, Macdonald *et al*. (1996) showed that the principal gradient was a precipitation gradient. The response of vegetation was dominated by the change from wet to dry conditions (Macdonald et al., 1996).Dissimilarity in the mountain habitats to which the vegetation responded could be predicted from a combination of a few environmental variables. The primary gradient was one of change from high to low mean annual precipitation (Macdonald *et al*., 1996). In line with this, available soil moisture was observed to be the major factor influencing plant species distribution and composition in avegetation survey of 214 miombo woodland sites in the northern region of Zimbabwe (Kanschik and Becker,2001).

2.1.3.2 Soil nutrients

Nutrientavailability is influenced by parent rock, rate of weathering and material transportation by water into or out of an area (Bell, 1982). Soil fertility is negatively correlated with rainfall. In high rainfall areas, nutrients are lost through leaching (Bradyand Weil, 1996). Changes in vegetation structure are attributed to spatial changes in both nutrient status and levels of concentration of growth limiting nutrients like nitrogen and phosphorous. Woody and non-woody plant species display a number of physiological responses to environmental gradients (Aerts, 2000).

2.1.3.1 The effects of watering points on soil

Herbivore trampling gradients, indicated by track development, were shown to radiate from watering points (Andrew and Lange, 1986; Lange, 1969). Soil compaction and capping, removal of the cryptogamiccrust, soil loosening, increases in soil particle mobilization, loss of fine material through wind and water erosion (Beukes and Ellis, 2003), alterations to the normal surface flow (Eldridge and Whitford, 2009; Du Toit*et al*., 2003) all tend to occur.Soil compaction and capping tend to occur at watering points (Andrew and Lange, 1986), but not on almost pure sands (Perkins and Thomas, 1993). Capping is caused by the removal of the protective plant cover and the resulting splash erosion (Rauzi, 1963) as well as the trampling of the moist soil surface by large animals.

There is a direct relationship between rate of soil infiltration and distance from watering points (Eldridge and Whitford, 2009; Andrew and Lange, 1986). This is especially important on heavier textured soils (Walker, 1980), and may be insignificant on very sandy soils, such as those of the Kalahari (Perkins and Thomas, 1993).

The deposition of nutrients in the form of dung in the vicinity of water causes high nutrient concentrations at watering points (Eldridge and Whitford, 2009; Fernandez-Gimenez and Allen-Diaz, 2001; Nash *et al*., 1998; Perkins and Thomas, 1993; Tolsma*et al*., 1987). Tolsma*et al*. (1987) also noted that concentrations of all nutrients were higher in the vicinity of a borehole (0-100m). According to Georgiadis (1987), nutrient effects on soil only become evident after extremely high utilisation intensities.

Several studies supported the view that sites close towatering points are more intensively grazed, with negative consequences for vegetation cover andbiodiversity (Fernandez-Gimenez and Allen-Diaz, 2001).Soiltramplingeffects on palatable species are severe in the vicinity ofwatering points(Tuna *et al*., 2011).Fernandez-Gimenez and Allen-Diaz (2001) defined ‘grazing gradient’ as the spatial pattern in soil orvegetation characteristics that results from grazing activitiesand which are symptomatic of land degradation.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

The study was conducted in HwangeNational Park's Main Camp (Figure 1), where most of the artificial watering points are located (Mukwashi*et al*., 2012) and easily accessible. The park is situated in north-western Zimbabwe, extending from $25^{0}45'$E to $27^{0}25'$E, and $18^{0}53'$S to $19^{0}30'$S. It is bordered to the west by Botswana, to the north by Matetsi and Deka Safari Areas, to the northeast by state forest and farms, and to the southeast by Tsholotsho Communal Land(DNPWM, 1998). The park is divided into three sections which are Sinamatella, Robins and Main Camp (Mukwashi*et al*., 2012), and covers an area of 14 651 km^2(DNPWM, 1998). The Hwange Main Camp covers an area of 1 251 km^2(Mukwashi*et al*., 2012).

3.1.2 Relief

Hwange National Park lies between 840 m (on the Deka River) and 1 153 m (at Bumbuzi) above sea level (DNPWM, 1998). Soils are fine to medium grained sands (Potts and Russel, 1995), with virtually no clay and silt sized particles. They are characterised by very low water holding capacity, and are infertile, agriculturally poor soils. The soils are shallow. Almost two thirds of the park is covered with Kalahari sands (Conybeare, 1991).

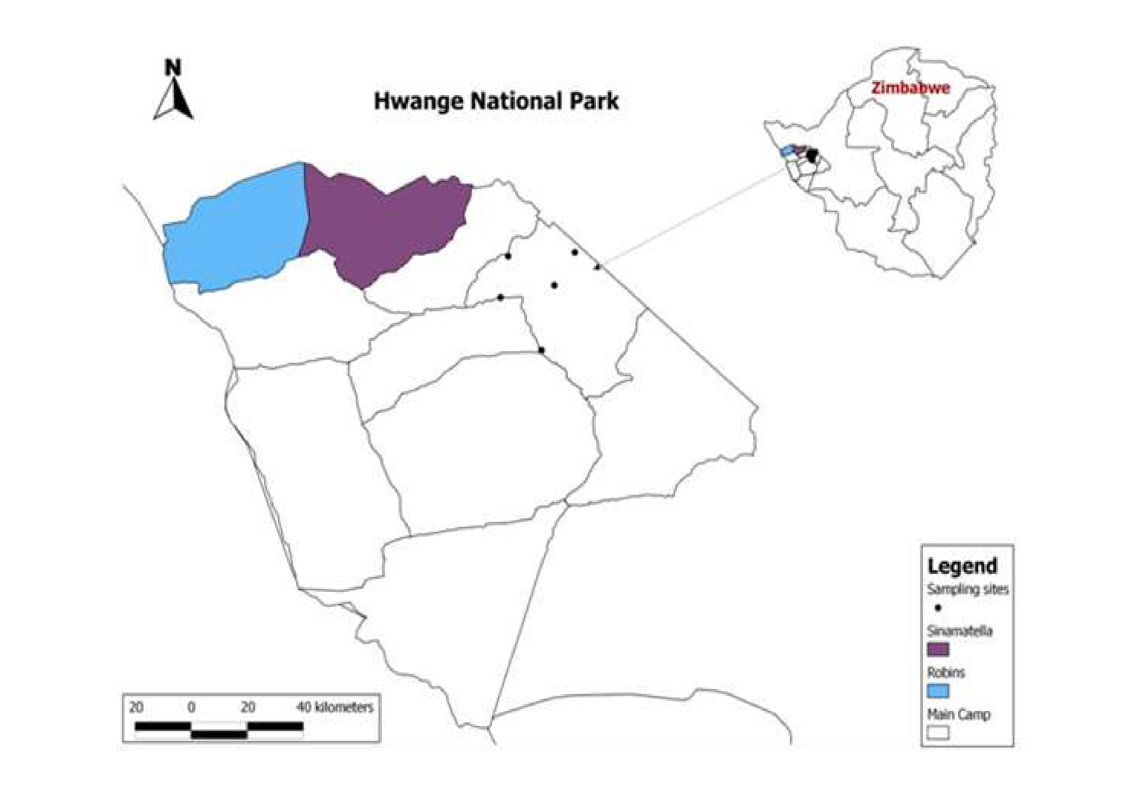

Figure 1: Location of sampled sites, Hwange National Park, Zimbabwe

3.1.3 Climate

Hwange National Park is close to the Kalahari Desert, a region of limited moisture supply. The dry season is hot during the day, but temperatures can drop to below freezing point, particularly on cold winter nights. The cool dry winter months extend from May to August (DNPWM, 1998).Mean monthly minimum and maximum screen temperatures recorded at Main Camp over 40 years range from 24^{o}C in June to a 33^{o}C high in October(DNPWM, 1998), the hottest month of the year. July is the coldest month (Conybeare, 1991), with an average screen temperature of 4.6^{o}C at Main Camp (DNPWM, 1998).Frost occurs in Hwange, especially during May to August. During this period, the temperature drops to a minimum of -5^{o}C or lower. Black frosts, which are usually lower than -7^{o}C, occur approximately every five years (DNPWM, 1998). The lowest ground temperature ever recorded in Hwange was -14^{o}C in 1971.Average annual rainfall is 650 mm/year(Conybeare, 1991). The summer rainy season extends from November to March(DNPWM, 1998) with most rainfall falling during December to February(Conybeare, 1991). Maximum values for a single month may occasionally exceed the average for the whole year (Conybeare, 1991).

3.1.4 Vegetation

Hwange is described as an area of mixed woodland and open savanna (Greaves, 1996; Rogers, 1993). Kalahari sands are characterised by high woody species biomass, and grass is comparatively sparse (Rushworth, 1975). Woodland occupies about 64%, shrub land 32%, and grassland merely 4% (DNPWM, 1998). The dominant vegetation type for Hwange Main Camp is *Baikiaeaplurijuga* mixed woodland and shrubland, commonly associated with *Combretum*spp., *Acacia* spp. and *Terminaliasericea* (Rogers, 1993).

3.2 Sampling design

Fourartificial waterholes (two perennial and two seasonal)were randomly picked for the study. An area located within the Main Camp, and sharing with the study sites similar vegetation and soil characteristics, with a radius of 5 km, andwithout watering points, hence minimal animal disturbance, was used as a control. The area surrounding each water source was stratified (Sutherland, 2000) into three concentric zones: 1000 meters from water (zone 1), 2000 meters from water (zone 2)and >2000 meters from water(zone 3) (Mukwashi*et al*., 2012). Two imaginary 2500 m long transects were drawn at random from the edge of the watering pointusing cardinal points. Small pieces of paper were marked with cardinal points and drawn at random to determine the direction and orientation of atransect around each watering point. Fifty1 m x 2 m quadrats were systematically laid at every 50m interval for the assessment of non-woody species (see Elzinga*et al*., 2001) and collection of soil samples. Soil samples were collectedat the centre of each non-woody quadrat.Some seventeen 10 m x

10 m quadrats were systematically laid at every150 m interval for the assessment of woody species (Elzinga*et al*., 2001).

Assessment was made at seasonal watering points/waterholes(watering points 1 and 4: Category 1),perennial watering points (watering points 2 and 3:Category 2), and the zones were based on elephant occupancy during the dry season (Mukwashi*et al*., 2012).

3.2.1 Woody species sampling

Woody vegetation was assessed from May 2012 to June 2012. Species were identified in the field with the aid of the field identification guides Palgrave (1983) and Timberlake *et al*. (1999). Samples were collected from species that could not be identified in the field and identified later at the Hwange National Park Herbarium and the National Herbarium in Harare.In each 10 m x 10 m quadrat, the woody component of the vegetation was identified (Brooks *et al*., 2006). There were thirty four sampling plots at each of the sites: five sites X two transects X seventeen plots. In each sampling plot, the following variables were recorded:

Woody species height: Height is the vertical distance from the ground to the highest living part of a plant. It was measured using a graduated pole. For multi-stemmed plants, only the height of the tallest stem was considered (Mueller-Dombois and Ellenberg, 1974).

Crowncover: Two measurements of crown cover were recorded for each individual or single species clumps using a tape measure: the longest horizontal canopy diameter and the one perpendicular to this. Plant crown cover was calculated assuming a circular canopy ($A=\pi r^2$) where the radius was half the average of the two diameter measurements (Mueller-Dombois and Ellenberg, 1974).

Stem circumference: Circumference was taken at 20 cm above the ground (Brooks *et al*., 2006). For multi-stemmed woody species (<16) not distinctly joined at the base, individual stem circumferences were measured and averaged to get the stem circumference (Sutherland, 2000). For multi-stemmed woody species (>15) not distinctly joined at the base, measurements were averaged to get the circumference of that particular plant.

Woody vegetation species were also classified according to growth form. Trees were defined as woody plants >3 m in height and >6 cm basal diameter above buttress swelling and shrubs as 0.3-3 m in height and ≤6cm basal diameter. All woody plants rooted within a plot (Brooks *et al*., 2006) were recorded and measured. Woody plants occurring along plot margins werenot included (Elzinga*et al*., 2001).

3.2.2 Non-woody species sampling

Non-woody vegetation was assessed from May 2012 to June 2012. In each 1 m x 2 m quadratthe non-woody component of the vegetation wasidentified (Elzinga*et al*., 2001; Sutherland, 2000). There were 100 sampling plots at each of the sites: 5 sites X 2 transects X 100 plots. Species richness, abundance (number of individuals per species per quadrat) and cover were recorded using the point intercept method as described by Elzinga*et al*. (2001) and Mueller-Dombois and Ellenberg (1974). All non-woody plants rooted within aquadrat (Brooks *et al*., 2006) were recorded and measured(Elzinga*et al*., 2001). A folding magnifier 10x and the field identification guide Van Oudtshoorn(1999) were used to identify grasses encountered in the plots.

3.2.3 Soil sampling

Soil samples were collected from the centre(Anderson and Ingram, 1993) of each of the non-woody plant quadrats to a depth of 20 cm using a soil auger. Sub-sampling was then carried out at every 200 m interval. A 1 kg composite sample was obtained for each of the 200 m intervals and placed in an air proof polythene bag after thoroughly mixing in a clean polystyrene bucket. For soil moisture,the Oven Drying Method as described by Hausenbuiller (1975)was used. Six variables (pH, soil moisture content, soil N, soil P and soil K) were determined. Soil analysis was done with the assistance of the Department of Research and Specialist Services, Ministry of Agriculture.

3.3 Data analysis

Statistical analyses were conducted in SPSS 16.0 (2002) and PCORD programme packages. Descriptive statistics were used to summarise data and graphical representation were made in Microsoft Office Excel 2007 to show variation in measured variables. In addition, woody and non-woody species diversity indices were calculated using Shannon-Wiener diversity index (H') (Townsend*et al*., 2003). Normality tests were performed on all measured variables to determine whether they satisfied ANOVA assumptions (Quinn and Keough, 2002) using Q-Q plot and were found not to be normal. Data were then log transformed. Regression analyses were performed in order to establish the relationship between measured variables and distance from both seasonal and perennial watering points. Principal Component Analysis was performed to assess levels of similarity among the study sites based on woody vegetation structure and composition, non-woody vegetation composition and measured soil variables. Canonical correspondence analysis was carried out to assess the relationship between vegetation variables and soil variables (TerBraak, 1995).

CHAPTER 4

4.0 RESULTS

A total of 52 woody species from 14 families and 43 non-woody species from eight families were identified in the study area. Some 21% of the recorded woody species were common in all sites, and 23% of the recorded non-woody species were also present in all sites. Dominant species in the study area included *Baikiaeaplurijuga, Ochnapulchra, Combretummossambicense, Eragrostis*spp and *Cynodondactylon.*

4.1 Individual study sites

4.1.1 Vegetation

4.1.1.1 Woody vegetation

All study sites showed different patterns in vegetation structure and richness (Figure 2 and Figure 3, respectively). Watering Point 2 showed the lowest values of tree basal area, tree crown cover, tree abundanceand tree species richness in 1000 m zone (Zone 1) (Figure 2 and Figure 3). Figure 3d also shows that shrub species richness and abundance were highest in the 2000 m zone (Zone 2) at Watering Point 1(Figure 3b). On the other hand, lowest shrub height was observed in Zone 1 at Watering Point 2 (Figure 2b).ANOVA resultsshowed no significant change in all measured tree variables with increasing distance from Watering Point 1. However, tree height changed significantly with increasing distance from Watering Points 2 and 3 ($P < 0.05$). Tree species richness varied significantly with increasing distance from Watering Point 4 ($P < 0.05$).ANOVA results showed significant change ($P < 0.05$) in shrub crown cover with increasing distance from Watering Points 1, 3 and 4. Shrub height also changed significantly ($P < 0.05$) with distance from Watering Points 2, 3 and 4.

Generally, diversity (Shannon-Wiener index) was highest at Watering Point 3, and lowest at the control site for woody species (Figure 4). Diversity increased with distance at Watering Point1 and Watering Point 3. Diversity, however, decreased with increasing distance at Watering Point 4 (Figure 4).

Independent samples T test showed a significant difference (P <0.05) in diversity between Watering Points 1 and 3, Control site and Watering Point 1, Control site and Watering Point 2, Control site and Watering Point 3, and Control site and Watering Point 4. On the contrary, diversity was not significantly different (P >0.05) between Watering Points 1 and 2, Watering Points 2 and 3, Watering points 4 and 1, Watering points 4 and 2 and Watering Points 4 and 3.

There was no significant linear relationship between tree height and distance from Watering Point 1 and Watering Point 4 (P > 0.05), but a significant positive linear relationship was observed between tree height and distance from Watering Point 2 and Watering Point 3 (r=0.53, P <0.05; r=0.58, P <0.05, respectively). Shrub height showed a significant linear increase (P < 0.05) with distance from Watering Point 2 (r=0.58) and Watering Point 3(r=0.61). Shrub height, however showed a significant linear decrease (r=-0.66, P <0.05) with distance from Watering Point 4 and no significant linear trend from Watering Point 1. The linear trend was not significant (P >0.05) between tree basal area and distance from watering points except on Watering Point 2 (r=0.5, P <0.05). There was no significant linear relationship (P >0.05) between shrub basal area and distance from all watering points.

Tree abundance showed no significant (P >0.05) linear relationship with distance from Watering Points 1, 3 and 4. Regression analysis on tree abundance showed a significant (P <0.05) linear increase with distance from water. There was a significant positive linear relationship (r=0.49, P <0.05) between tree abundance and distance from Watering Point 2.

Shrub abundance showed a significant positive linear increase ($r=0.53$, $P <0.05$) with distance from Watering Point 1.

Tree richness showed a significant positive linear relationship ($r=0.53$, $P <0.05$) with distance from Watering Point 2. Shrub richness showed a significant ($P <0.05$) positive linear increase with distance from Watering Point1. There was a significant positive linear relationship ($r=0.61$, $P <0.05$) between tree crown cover and distance from Watering Point 2. Shrub crown cover showed a significant positive linear trend ($r=0.59$, $P <0.05$) with distance from Watering Point 4.

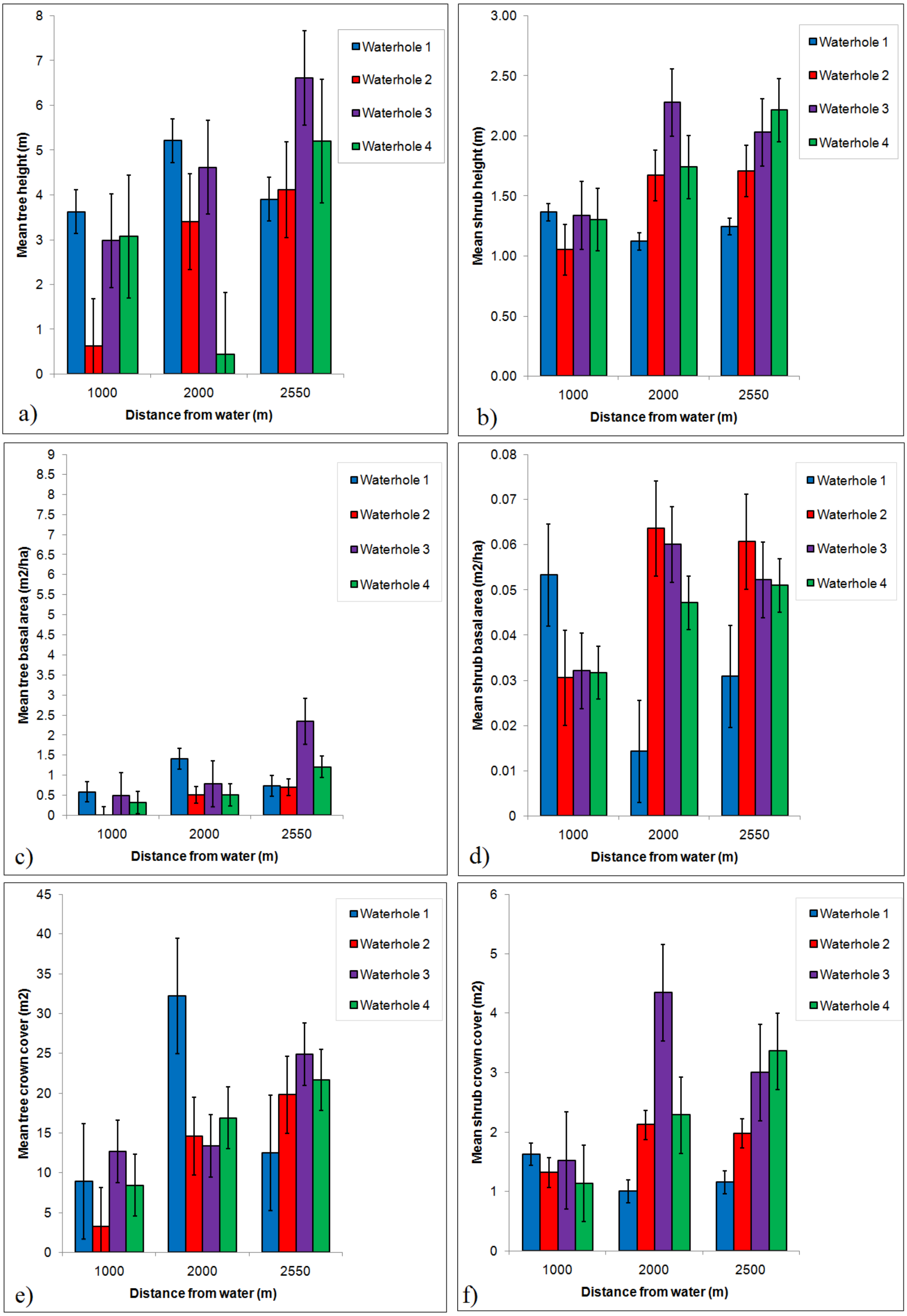

Figure 2: Woody vegetation structure of sampled zones around study sites in Hwange National Park.

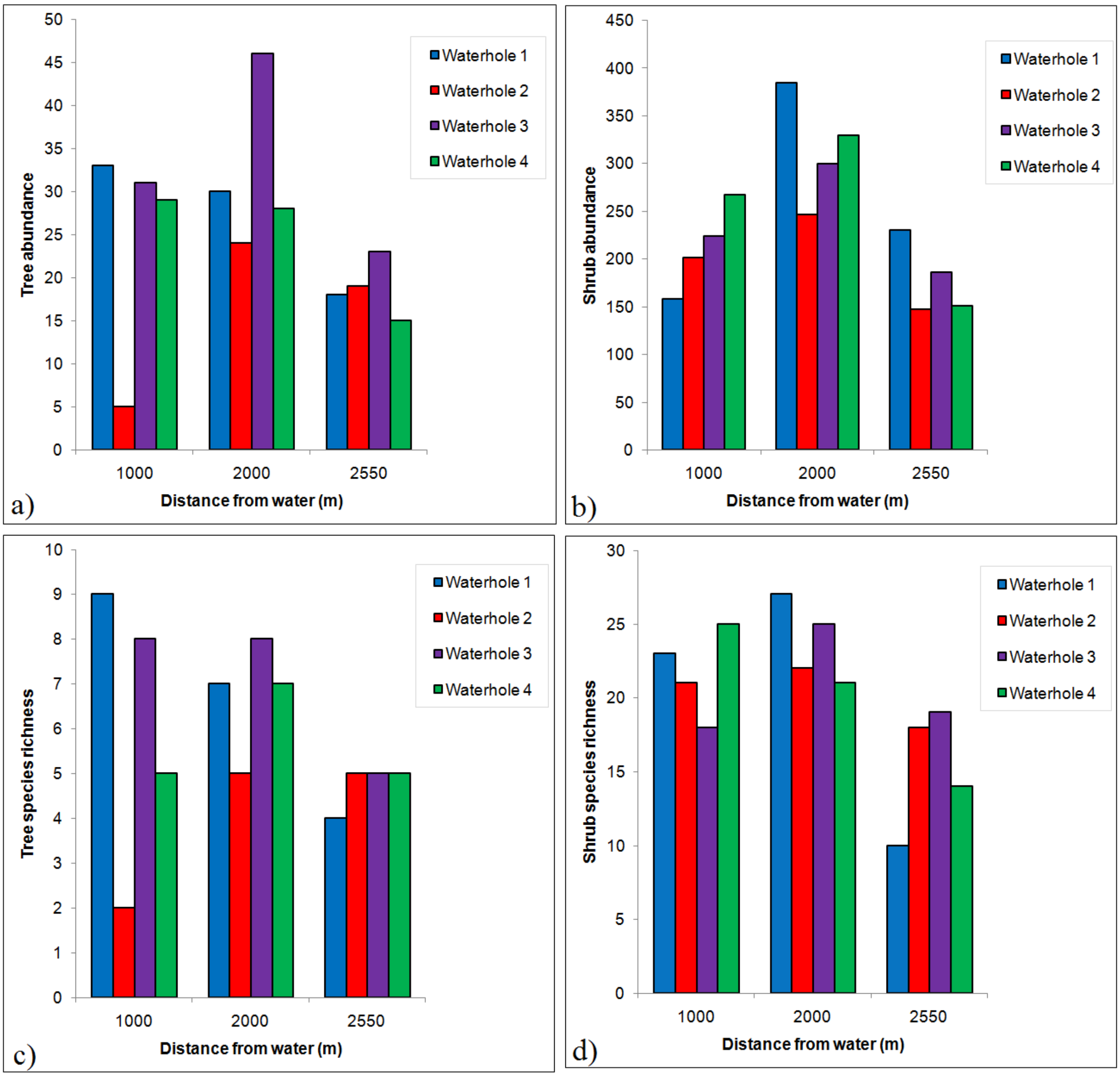

Figure 3: Woody vegetation abundance and richness of sampled zones around study sites in Hwange National Park.

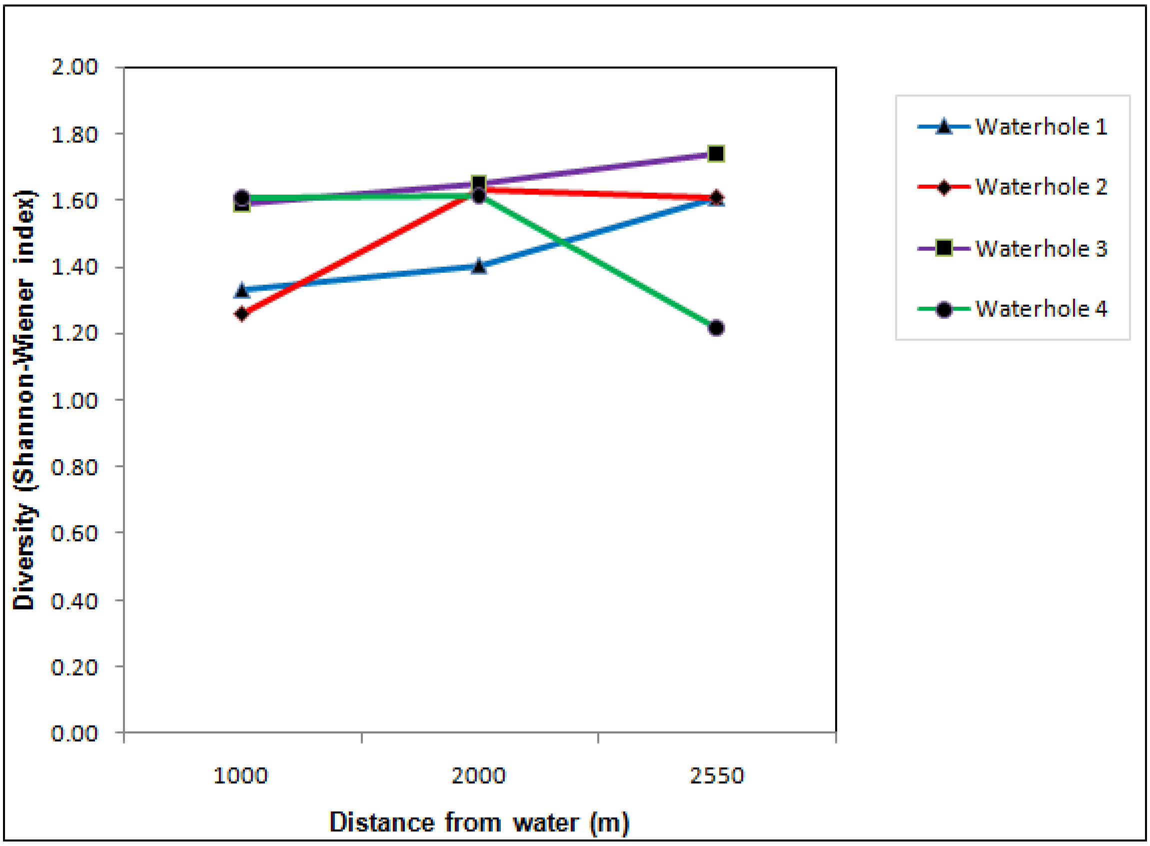

Figure 4:Woody species diversity (Shannon-Wiener index) across the study sites in Hwange National Park.

4.1.1.2 Non-woody vegetation

Variables of non-woody species considered in the current study were percent cover, richness and abundance. Percent cover, abundance and richness were highest at Watering Point 1 Zone 1 (Figure 5). Percent cover was lowest in Zone 3 at Watering Point 3. Abundance was lowest at Watering Point 4 in Zone 3 (Figure 5a and 5b, respectively).

ANOVA results indicated that there was significant ($P < 0.05$) change in all variables with distance from Watering Point 1. At Watering Points 2 and 4 no significant ($P > 0.05$) changes with distance from watering points were statistically shown in all the variables.

Non-woody species showed different patterns from woody species in species diversity (Shannon- Wiener index) in relation to distance from watering points. Diversity decreased with increasing distance from Watering Point 2 and Watering Point 3 (Figure 6). An independent samples T-test however,showed that diversity was not significantly different among all possible study sites combinations(p > 0.05).

At Watering Point 2 and 4, none of the measured variables showed a significant linear trend with distance from water. Abundance and percent cover showed a significant linear decrease with distance from Watering Points 1 and 3(P <0.05).

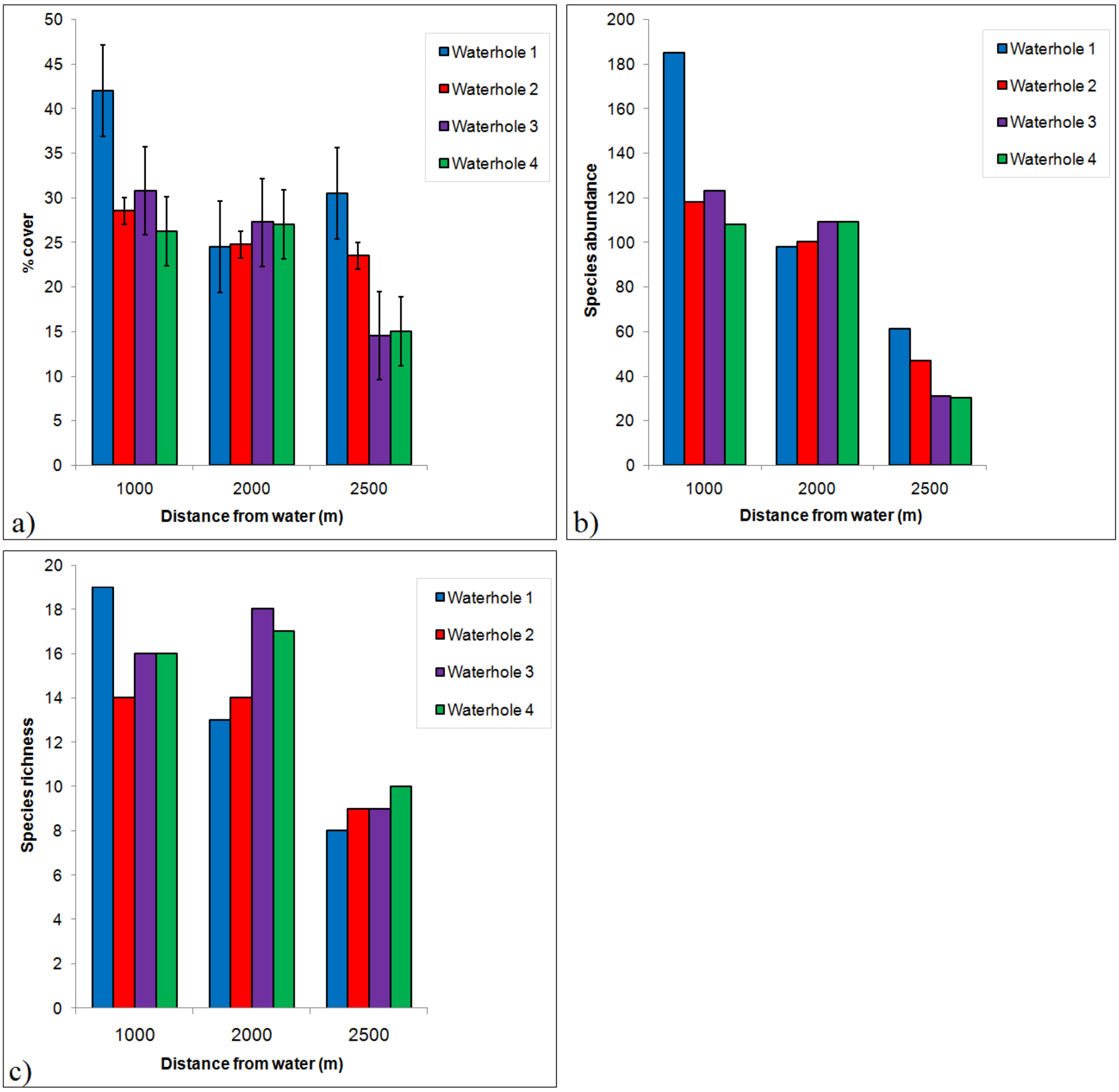

Figure 5: Non-woody vegetation variables of study sites measured with distance from watering points in Hwange National Park.

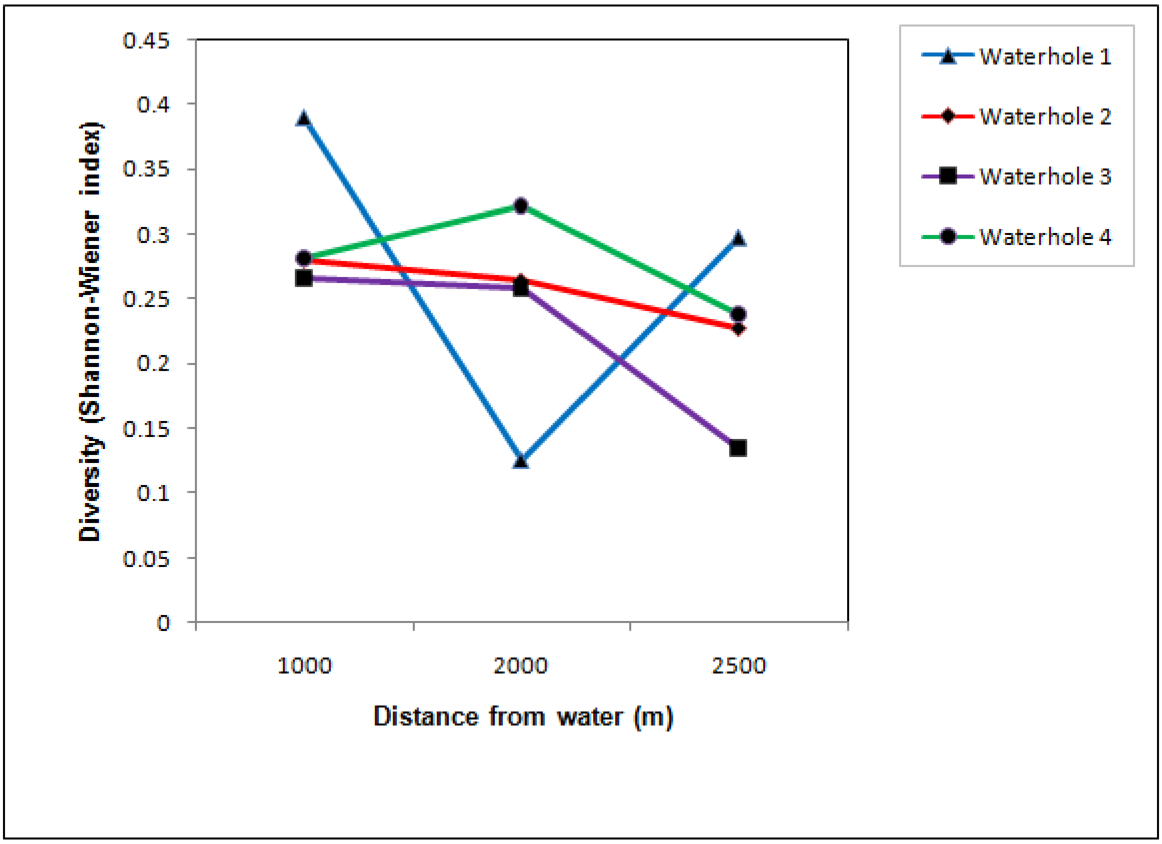

Figure 6: Non-woody species diversity (Shannon-Wiener index) across the study sites in Hwange National Park.

4.1.2 Soil variables

Results showed that soils from all the study sites were medium grained sands. Soil moisture content was highest at Watering Point 1 (Zone 2) (Figure 7a).Highest soil moisture content was recorded in Zone 2 at all study sites, except at Watering Point 4 (Figure 7a). Soil pH was fairlysimilar across all the study sites, ranging from around 4.2 to 5.4 (Figure 7b). Nitrogen and exchangeable potassium levels were highest at Watering Point 2 in Zone 3 (Figure 7c and Figure 7e, respectively). Lowest nitrogen levels were recorded in Zone 3 at Watering Point 1(Figure 7c). Phosphorus levels were lowest in Zone 2 of Watering Points 1, 3 and 4 (Figure 7d).ANOVA results showed significant ($P < 0.05$) decrease in soil nitrogen with increasing distance from all watering points. Soil pH showed a significant (P <0.05) fall with increasing distance from Watering Points 1, 2 and 4.

Nitrogen showed a significant (P <0.05) linear trend with distance from all watering points (Watering Point1 r=-0.71; Watering Point 2 r=0.51; Watering Point 3 r=-0.5 and Watering Point 4 r=-0.62). pH also showed a significant (P <0.05) linear trend with distance from Watering Point 1 (r=-0.58) and Watering Point 4 (r=-0.51).

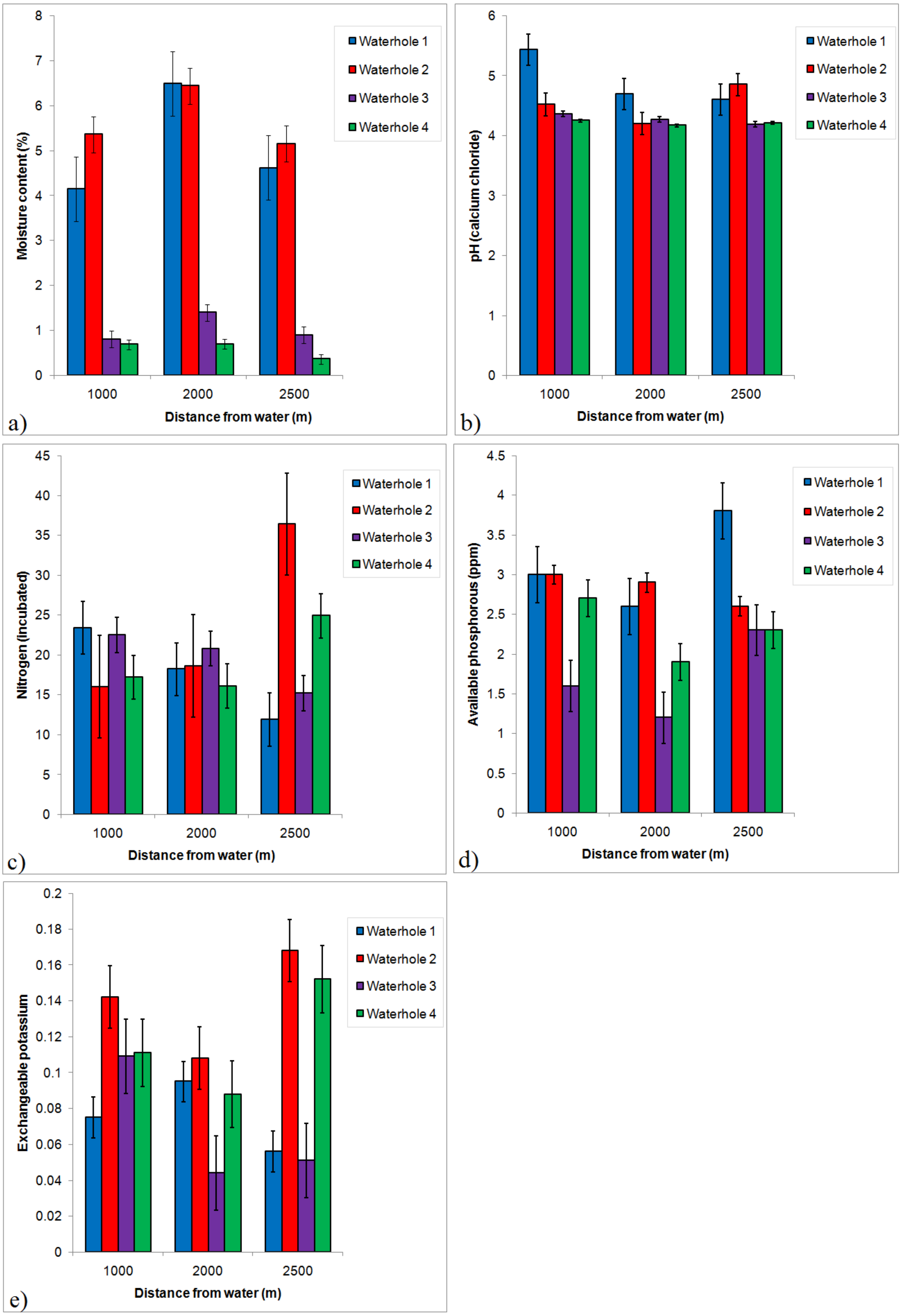

Figure 7: Soil variables of sampled zones (distance from watering points) around study sites in Hwange National Park.

4.2 Seasonal and perennial watering points

4.2.1 Vegetation

4.2.1.1 Woody vegetation

Shrub height was highest in Zone 2 at perennial watering points. Tree basal area was lowest at perennial watering points within Zone 1, (Figure 8e). Zone 1 of the perennial watering points recorded lowest tree crown cover. Highest number of trees was recorded at perennial watering points in Zone 2, whereas shrub highest numbers were recorded in Zone 2 of seasonal watering points (Figure 8). Seasonal watering points recorded highest tree species richness across all the zones. Shrub species richness was also highest in Zone 2 at seasonal watering points (Figure 9).

A Two-way analysis of variance without replication showed a statistically significant interaction (type of watering points *distance from watering points) at $P = .015$ level on tree basal area alone. All other interactions were not statistically significant ($P > 0.05$). Results also show no significant ($P > 0.05$) difference in all woody species variables between seasonal watering points and perennial watering points(Table 1b).

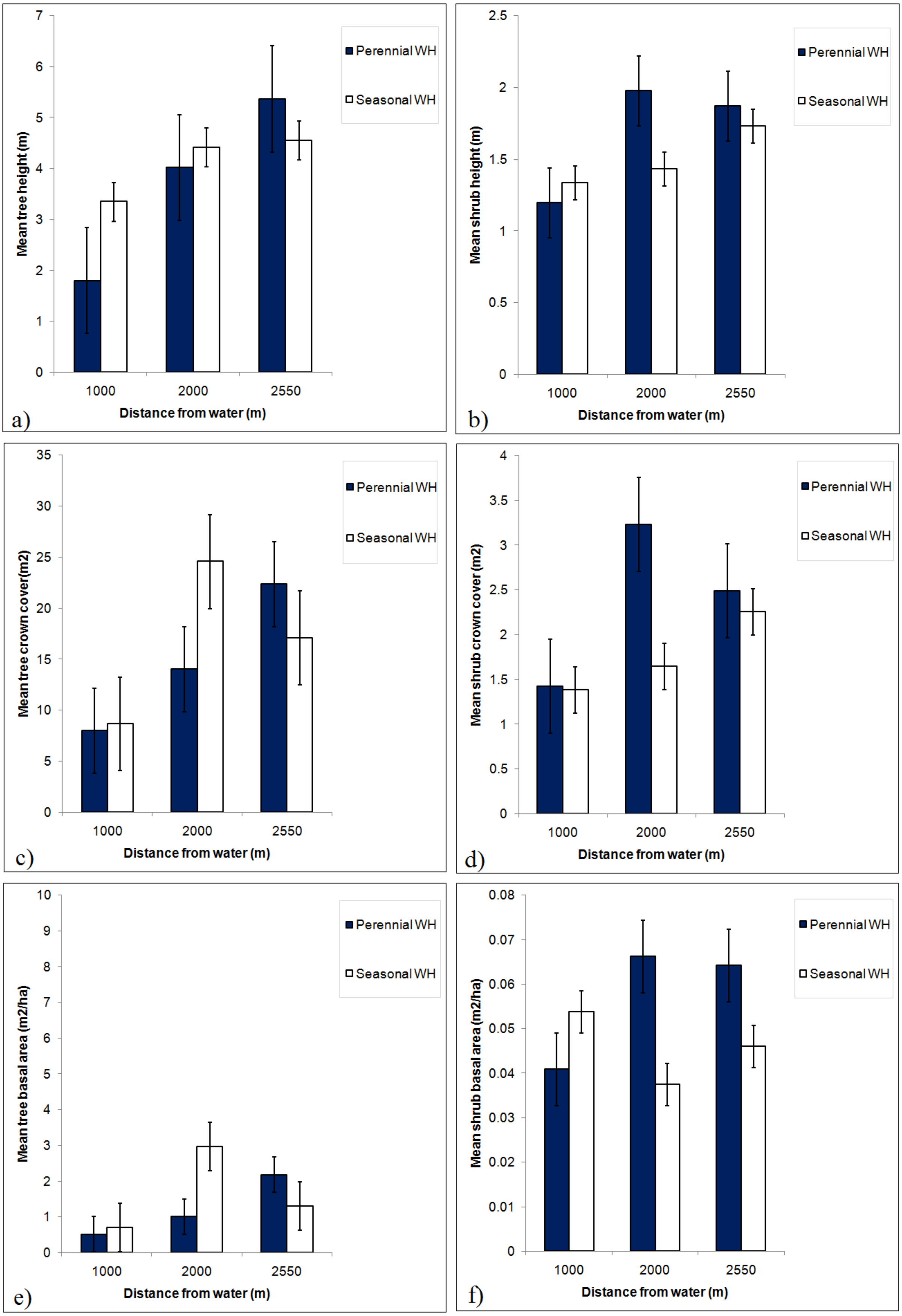

Figure 8: Woody vegetation structure around study sites in Hwange National Park. Notes: WH-Waterhole (watering point).

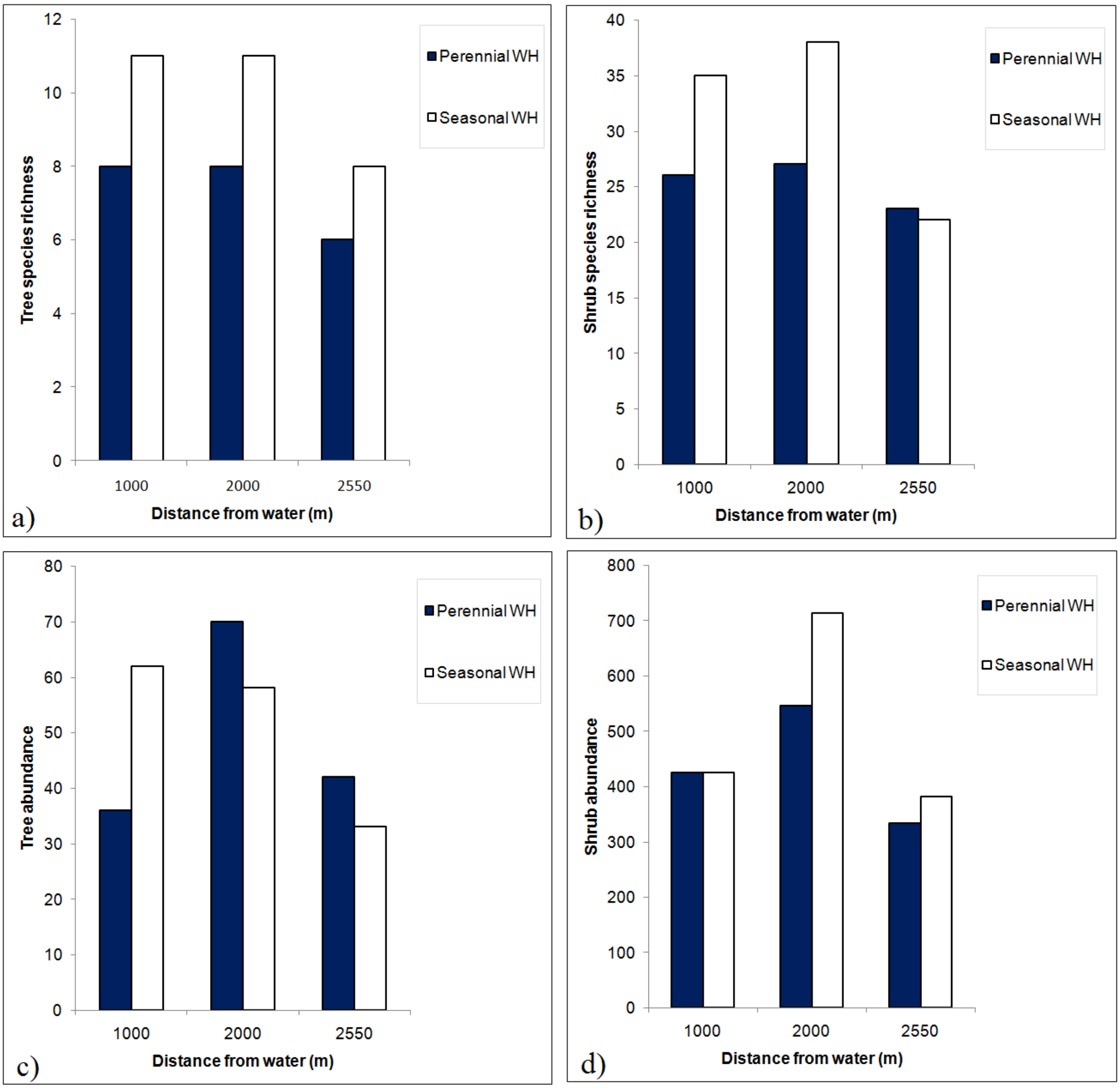

Figure 9:Woody vegetation richness and abundance around study sites in Hwange National Park. Notes: WH-Waterhole(watering point).

Diversity increased with increasing distance from perennial watering points (Figure 10). However, an independent samples T-test showed that diversity was not significantly different ($p > 0.05$) between seasonal and perennial watering points.

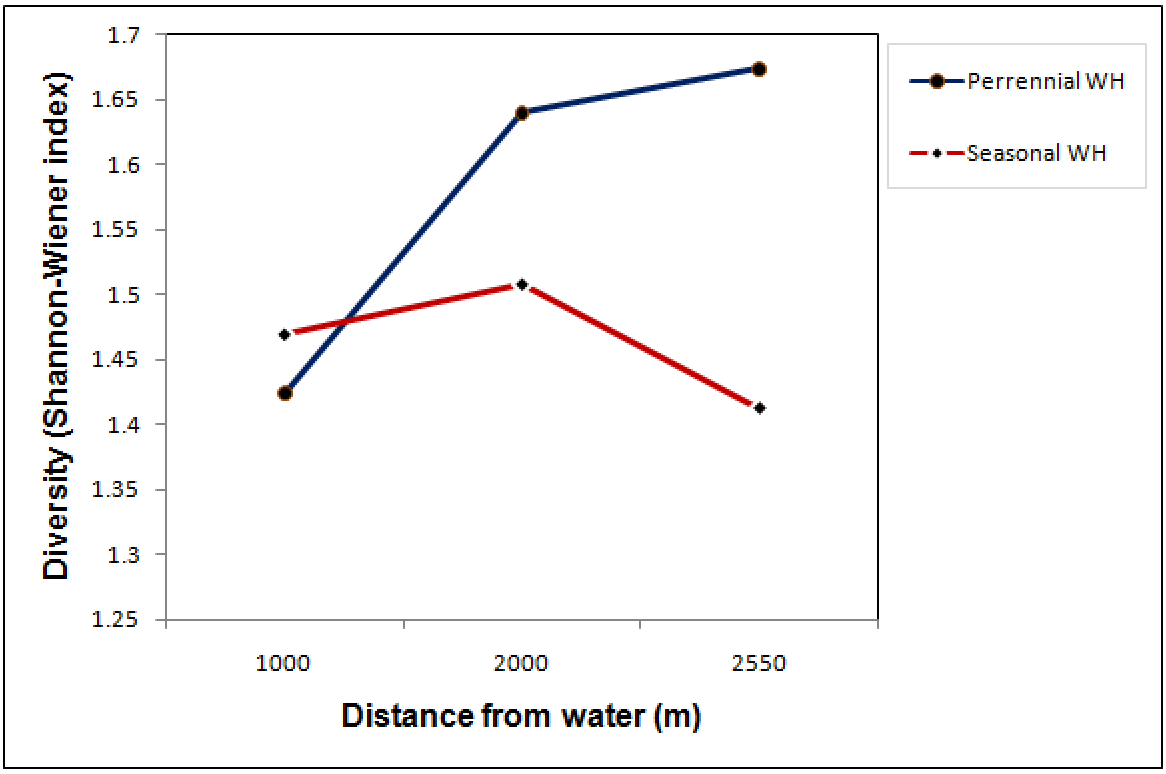

Figure 10:Woody species diversity (Shannon-Wiener index) with distance from perennial watering points and seasonal watering points in Hwange National Park. Notes: WH-waterhole (watering point).

Shrub crown cover showed a significant ($P < 0.05$) linear increase with distance from seasonal watering points ($r=0.53$).Average tree height ($r=0.62$), mean tree basal area ($r=0.52$), tree species richness ($r=0.54$), tree crown cover ($r=0.58$) and mean shrub height ($r=0.52$) showed a significant ($P < 0.05$) linear increase with distance from perennial watering points.

4.2.1.2 Non-woody vegetation

Percent cover decreased with increasing distance from all watering points(Figure 11a). Highest number of species was recorded at seasonal watering points in 1000 m zone (Zone 1) (Figure 11c). All measured variables at all study sites recorded lowest values in Zone 3 (Figure 11). ANOVA results showed no statistically significant ($P > 0.05$) interaction (type of watering points *distance from watering points)at $P=0.359$ level on species percent cover, $P=0.710$ level on species abundance and $P=0.592$ at species richness.Results also show no significant ($P > 0.05$) difference in all non-woody species variables between seasonal watering points and perennial watering points (Table 2b).

Diversity decreased with increasing distance from perennial watering points. Diversity,however at seasonal watering points was lowest in zone 2 (Figure 12).An independent samples T-test, however showed that diversity was not significantly ($p > 0.05$) different between seasonal and perennial watering points.

Non-woody species abundance ($r=-0.56$) and percent cover ($r=-0.54$) showed a significant ($P < 0.05$) linear decrease with distance from seasonal watering points. Similarly non-woody species abundance ($r=-0.51$) and percent cover ($r=-0.51$) showed a significant ($P < 0.05$) linear decrease with distance from perennial watering points.

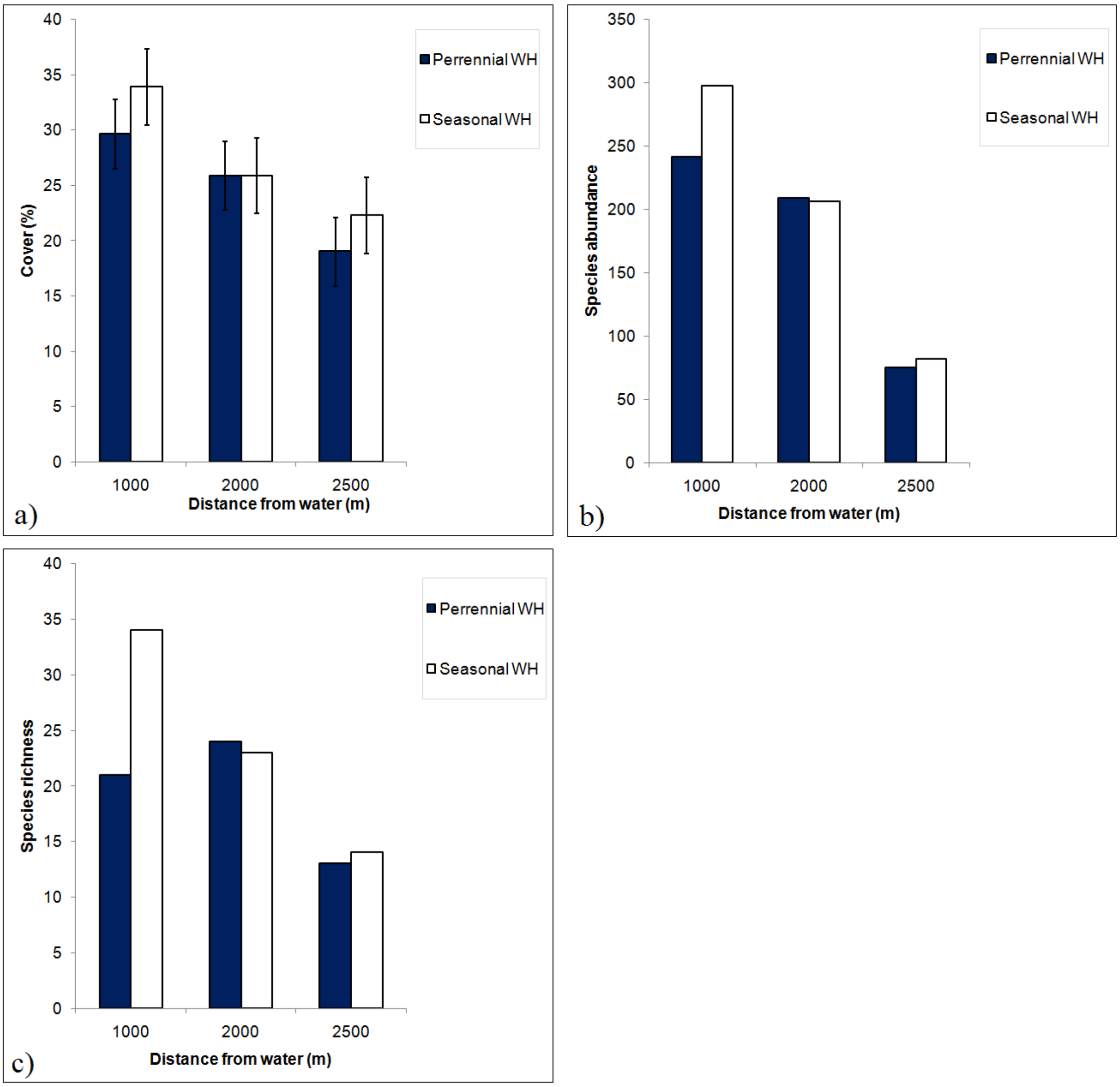

Figure 11: Non-woody vegetation measured variables at perennial watering points and seasonal watering points in Hwange National Park. Notes: WH-Waterhole (watering point).

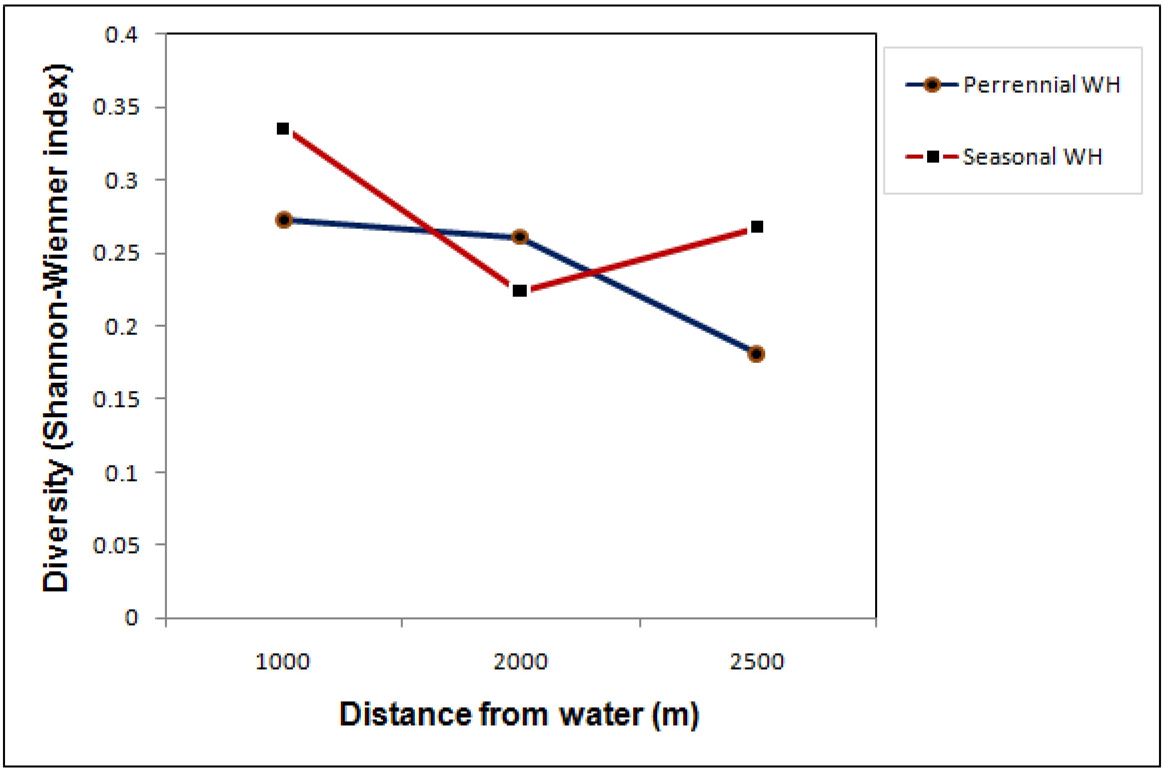

Figure 12: Non-woody species diversity (Shannon-Wiener index) with distance from perennial watering points and seasonal watering points in Hwange National Park. Notes: WH-waterhole (watering point).

4.2.2 Soil variables

Highest soil moisture level was recorded in Zone 2 at perennial watering points and shows no significant difference with moisture level in Zone 2 at seasonal watering points (Figure 13a). pH was not significantly different across all the studysites (as shown by error bars) ranging from about 4.2 to 4.8 (Figure 13b). Nitrogen was also not significantly different across all zones and across all study sites (Figure 13c).ANOVA results indicated no significant interactions between type of watering points and distance from watering points in all soil variables.Results also show no significant ($P > 0.05$) difference all soil variables (except phosphorus) between seasonal watering points and perennial watering points (Table 2b).

Soil pH (r=-0.63) and nitrogen (r=-0.56) showed a significant (P <0.05) linear decrease with distance fromseasonal watering points.Nitrogen (r=-0.5) also showed a significant (P <0.05) linear decrease with distance from perennial watering points.

Table 1a: One way analysis of variance between woody species variables and the study sites (artificial seasonal watering points, artificial perennial watering points and the control site).

	df	F	Sig.
Tree species richness	2	0.08	0.92
Average tree height	2	8.71	0.00*
Tree basal area	2	3.87	0.02*
Average tree crown cover	2	3.20	0.04*
Tree diversity indices	2	16.00	0.00*
Tree abundance	2	1.44	0.24
Shrub species richness	2	18.28	0.00*
Average shrub height	2	1.72	0.18
Average shrub canopy cover	2	2.45	0.09
Average shrub basal area	2	3.87	0.02*
Shrub abundance	2	10.97	0.00*

The asterisks symbol means statistically significant at p < 0.05

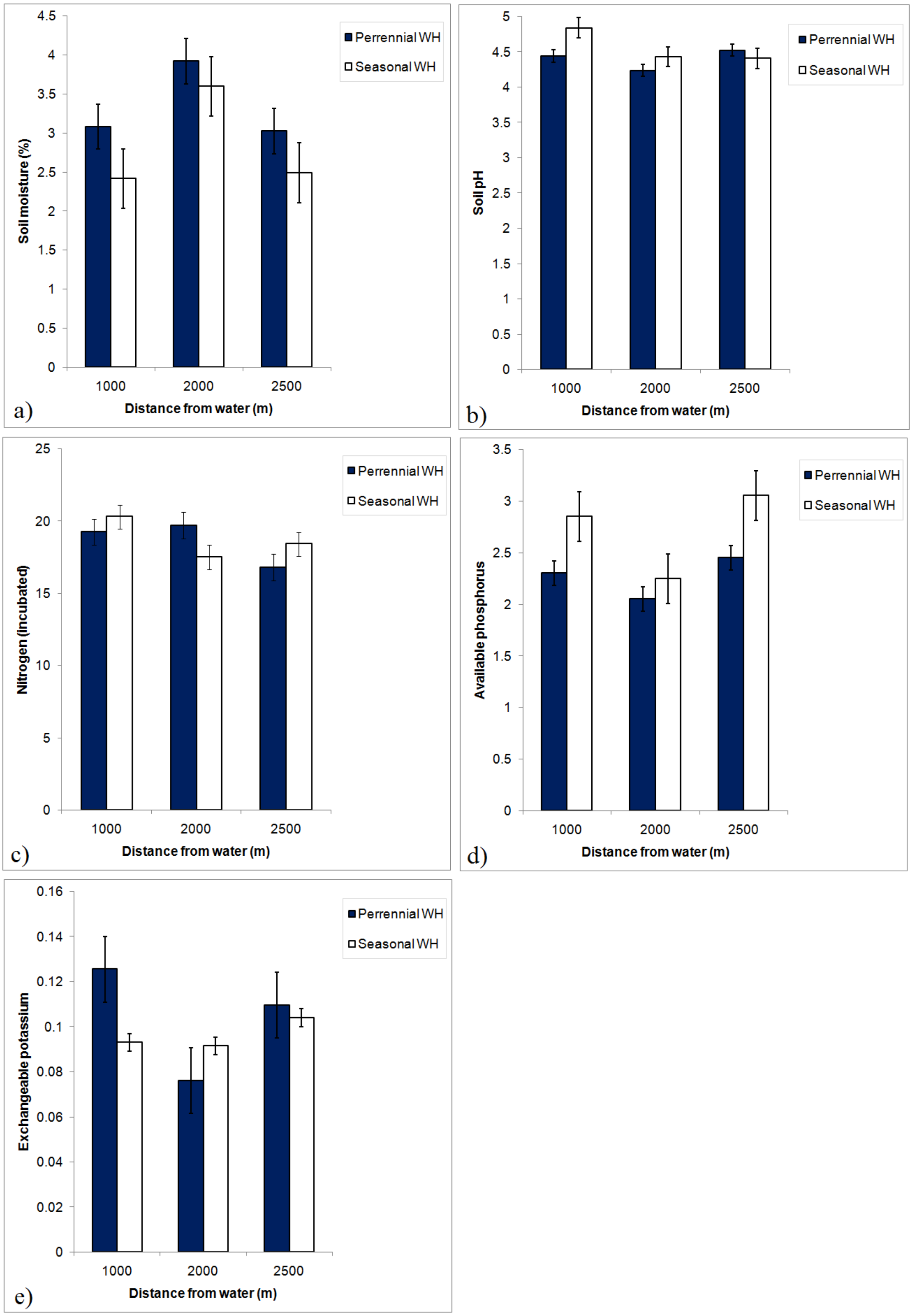

Figure 13: Measured soil variables around study sites in Hwange National Park. Notes: WH-Waterhole (watering point).

Table 1b: One way analysis of variance *post-hoc* among artificial seasonal watering points, artificial perennial watering points and the control site basing on woody species variables

Multiple Comparisons

LSD

Dependent Variable	(I) Category	(J) Category	Sig.
Tree species richness	seasonal	perennial	0.72
	seasonal	control	0.77
	perennial	control	1.00
Average tree height	seasonal	perennial	0.28
	seasonal	control	0.00*
	perennial	control	0.00*
Tree basal area	seasonal	perennial	0.19
	seasonal	control	0.01*
	perennial	control	0.09
Average tree canopy cover	seasonal	perennial	0.61
	seasonal	control	0.04*
	perennial	control	0.01*
Tree diversity indices	seasonal	perennial	0.17
	seasonal	control	0.00*
	perennial	control	0.00*
Tree abundance	seasonal	perennial	0.85
	seasonal	control	0.15
	perennial	control	0.11
Shrub species richness	seasonal	perennial	0.40
	seasonal	control	0.00*
	perennial	control	0.00*
Average shrub height	seasonal	perennial	0.11
	seasonal	control	0.14
	perennial	control	0.85
Average shrub canopy cover	seasonal	perennial	0.09
	seasonal	control	0.05
	perennial	control	0.55
Average basal area	seasonal	perennial	0.19
	seasonal	control	0.01*
	perennial	control	0.09
Shrub abundance	seasonal	perennial	0.08
	seasonal	control	0.00*
	perennial	control	0.00*

*. The mean difference is significant at the 0.05 level.

Table 2a: One way analysis of variance between non-woody species and soil variables, and the study sites (seasonal watering points, perennial watering points and the control site).

ANOVA

	df	F	Sig.
Non-woody species abundance	2	0.82	0.44
Non-woody percent cover	2	0.88	0.41
Non-woody diversity	2	0.45	0.64
Soil moisture	2	21.02	0.00*
N	2	3.79	0.02*
Phosphorus	2	5.67	0.00*
Potassium	2	29.52	0.00*

*. The mean difference is significant at the 0.05 level.

Table 2b:One way analysis of variance *post-hoc* among artificial seasonal watering points, artificial perennial watering points and the control site basing on non-woody species and soil variables

Multiple Comparisons

LSD

Dependent Variable	(I) Category	(J) Category	Sig.
Non-woody species	seasonal	perennial	0.21
	seasonal	control	0.47
	perennial	control	0.75
Non-woody percent cover	seasonal	perennial	0.30
	seasonal	control	0.24
	perennial	control	0.74
Non-woody diversity	seasonal	perennial	0.47
	seasonal	control	0.40
	perennial	control	0.80
Soil moisture	seasonal	perennial	0.13
	seasonal	control	0.00*
	perennial	control	0.00*
N	seasonal	perennial	0.98
	seasonal	control	0.01*
	perennial	control	0.01*
Phosphorus	seasonal	perennial	0.00*
	seasonal	control	0.95
	perennial	control	0.01*
Potassium	seasonal	perennial	0.28
	seasonal	control	0.00*
	perennial	control	0.00*

*. The mean difference is significant at the 0.05 level.

4.2.3 Principal component analysis for seasonal watering points and perennial watering points

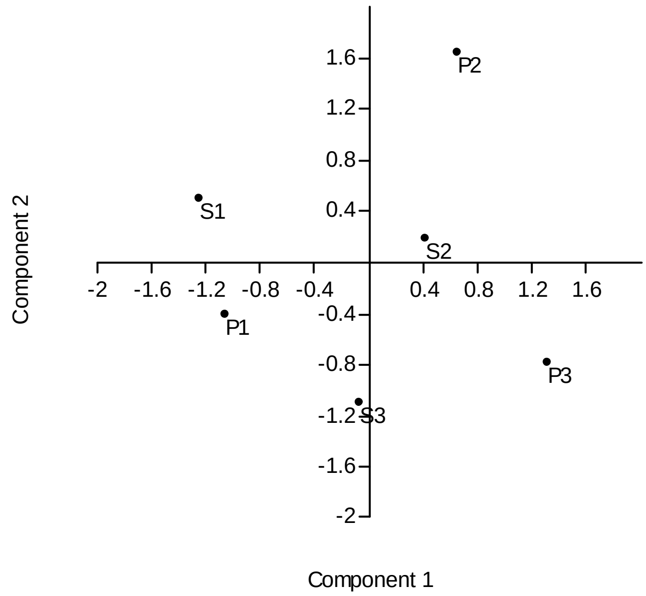

Figure 14: PC scatter for three zones at both Seasonal watering points and Perennial watering points. Notes: S1- Seasonal watering point Zone 1; S2- Seasonal watering point Zone 2; S3- Seasonal watering point Zone 3; P1-l Perennial watering point Zone 1; P2- Perennial watering point Zone 2; P3- Perennial watering point Zone 3.

The PC scatter shows randomly scattered sites. No separate groups are forming indicating no correlation between the sites and among the zones. The PCA yields three first principal components (PC 1, PC 2, PC 3) with Eigen values >1.5, together they explain 83.4% of the total variance (Table 3).

Table 3: Principal components and their corresponding Eigen values, variance they contribute and cumulative percent variance

PC	Eigen value	% variance	cumulative % variance
1	9.20454	46.023	46.023
2	4.364	21.82	67.843
3	3.10597	15.53	83.373

The first PC (46.02%) has high positive loadings of tree height, tree species richness, tree basal area, tree crown cover, woody species diversity, shrub species richness, shrub height, shrub crown cover and soil moisture. The negative loadings from PC1 came from (in decreasing order) shrub abundance, non-woody species richness, non-woody percent cover, soil nitrogen, soil pH, phosphorus and potassium.

The second PC (21.82%) has high positive loadings of tree abundance, woody species diversity, shrub richness, shrub crown cover, shrub basal area, shrub abundance, non-woody species richness, non-woody species percent cover, non-woody species abundance, non-woody species diversity, soil nitrogen and soil moisture. The negative loadings on PC2 came from (in decreasing order) potassium, phosphorus, tree crown cover, tree basal area, tree height and pH.

The third PC (15.53%) has high positive loadings of tree species richness, tree height, woody species diversity, shrub height, shrub crown cover, shrub basal area, non-woody species richness, non-woody species diversity, soil pH, soil nitrogen and soil phosphorus. The negative loadings on PC3 came from (in their decreasing order) shrub abundance, soil moisture, tree basal area, tree crown cover, non-woody species abundance, potassium, shrub richness and non-woody species percent cover.

4.2.4 Canonical correspondence analysis (CCA) for species environmental data

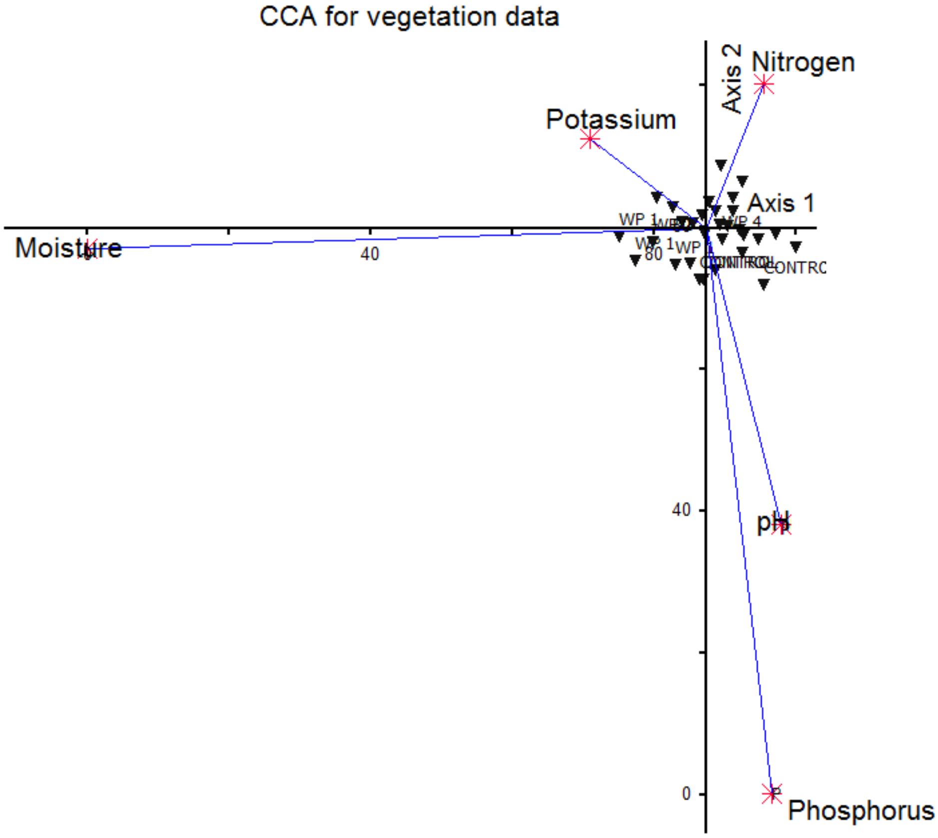

Figure 15: CCA-ordination diagram of the study sites in correlationbiplot scalingwith environmental variables represented by lines with star heads.

Figure 15 shows the influence of soil factors on the separation of study sites (Pielou, 1984). The figure shows that phosphorus, pH, nitrogen, soil moisture and potassium influence vegetation variables which were measured across the study sites. Phosphorus and pH are strongly correlated in terms of the influence they have on measured vegetation variables across the sites. Moisture had a greater influence on watering point 1. pH and moisture, however, were negatively correlated. Similarly, potassium and nitrogen were negatively correlated with phosphorus and pH.

CHAPTER 5

5.0 DISCUSSION

5.1Woody Vegetation

Tree and shrub height

Tree and shrub height increased with increasing distance from watering points. This was distinctively evident within the vicinity of watering points where elephants favoured such tree species as *Terminaliasericea* and *Combretumcollinum* (pers. observ) which occurred close to watering points. These tree species were converted to shrubs, with their growth severely stunted close to watering points. This was attributed to high elephant concentrations, hence increased utilisation pressure around watering points (see Guy, 1989).

Tree and shrub height was highest furthest from watering points where large herbivore pressure was low as animals dispersed away from watering points.The observed increase in plant size (height, basal area and crown cover) with increasing distance from watering points resulted in reduced plant damage. Plant mortality also decreased exponentially as plant size increased. These observations support those by Tuna *et al*. (2011), Todd (2006), Thrash *et al*. (1991) and Van Wyk and Fairrall (1969) which showed an increased tree and shrub height with increasing distance from watering points.

Tree and shrub basal area

Tree and shrub basal area increased with increasing distance from watering points. This is attributed to increased large herbivore year-round browsing within the proximity of watering points (Gandiwa*et al*., 2012).Trampling and increased herbivory do not allow for the recovery of trees close to watering points. Thus, tree and shrub basal area was highest furthest away from watering points where utilisation pressure was low. This allowed for increased height and girth of trees.

Tree and shrub crown cover

Crown cover increased with increasing distance from watering points. High concentrations of animals, which results in increased destructive feeding particularly by elephants, account for the reduced crown cover in Zone 1 (1000 m from watering point). When elephants feed they break tree and shrub branches, thus reducing crown cover (pers. observ). Crown cover was highest furthest away from watering points.   These observations support earlier findings by Tuna *et al*. (2011), Todd (2006), Thrash *et al*. (1991) and Van Wyk and Fairall (1969).

Tree and shrub species richness

Species richness was highest in the moderately utilised zone (Zone 2) in accordance with the Intermediate Disturbance Hypothesis which states that communities contain highest numbers of species when disturbance frequency is at an intermediate level (Townsend *et al*., 2003). The hypothesis predicts that biodiversity is maximised at some intermediate level of disturbance (Krebs, 2001). Zone 1 represents a heavily disturbed landscape due to the high number of animals, particularly large herbivores, concentrated around watering points. Zone 3, which lies furthest from watering points represents a landscape of minimum disturbance where animals are more dispersed. Zone 2 (1000-2000 m from watering point) is between the two extremes of disturbance, and is therefore an area of intermediate disturbance. In line with this, Tegegn*et al*. (2011) andHowes and McAlpine (2008) reported higher species richness in moderately grazed zones. Mukwashi *et al*. (2012) also recorded an increased species richness in moderate elephant occupancy zone and relatively lower species richness in low elephant occupancy zones of artificial watering points and natural watering points.

Tree and shrub abundance

Tree and shrub abundance was highest in Zone 2. In Zone 1, increased herbivore numbers resulted in high levels of browsing and trampling. This had a negative impact on the survival of woody plants. Evidence of dead trees was also observed. As a result, the least number of woody plants was observed in Zone 1 compared to Zone 2 and Zone 3. In Zone 3, due to reduced herbivore numbers and low intensities of browsing, grazing and trampling, trees had the ability to grow to full potential, hence large, mature trees were observed. Large trees occupy a larger spatial area and usually do not allow for the growth of under storey species due to shading effects. In addition, for any given area, fewer large plants occupy the area compared to smaller plants. As a result, fewer plants were recorded in Zone 3 than in Zone 2. This explains why Zone 2 had the highest tree and shrub abundance. Zone 2 had moderate levels of browsing and trampling, thus allowing for the growth of trees but not to their full potential as more plants occupy any given space. Highest shrub abundance was recorded in Zone 2 due to reduced tree shading effects and moderate intensities of browsing and trampling.

Woody species diversity

Woody species diversity was lowest closest to watering points. This low diversity is attributed to high intensities of browsing and trampling by large herbivores around the watering points (Mukaru and Mapaure, 2012). Since such pressure has a negative impact on the survival of seedlings of woody plants, this accounts for the almost absence of woody species in the vicinity (about 20 m radius) of watering points (Brits *et al*., 2002). Trampling results in potential browse material being lost (Mukaru and Mapaure, 2012). Trampling also accounts for physiological changes that lead to competitive pressures among plant species, thus altering diversity. This inhibits primary production (Mukaru and Mapaure, 2012). Thus, only such tolerant species as *Diospyroslycioides* were found within 20 m radius of the watering points.

5.2 Non-Woody Vegetation

Percent cover

An increase in percent cover with decreasing distance from watering points was observed.This is attributed to increased soil nutrient status around watering points (Perkins and Thomas, 1993; Tolsma *et al*., 1987) where accumulation of dung and urine occurs. This tends to enhance herbaceous productivity (Barker *et al*., 1990) close to these watering points. *Cynodon dactylon*, for example, was among the most common grass species close to watering points. It also had high percentage cover. Though under heavy grazing pressure around watering points, the species endured heavy grazing, and thrived in the sandy, fertile soils (Van Oudtshoorn, 1999). Tolsma*et al*. (1987) reported similar results, and observed that herbaceous cover decreased with increasing distance from a borehole. Brooks *et al*. (2006) also reported total annual cover increase with increasing proximity to watering points.

Abundance

An increase in abundance with decreasing distance from watering points was observed, though a band of land devoid of vegetation (sacrifice zone-which was about 20 m) from watering points was observed (Jeltsch*et al*., 1997). Due to intensive grazing and trampling close to watering points, a land devoid of vegetation was observed. This was attributed to continuous suppressing of regeneration of seedlings and shoot growth (Thrash and Derry, 1999), but after the 20 m radius, vegetation was then concentrated up to a radius of about 50 m. This could be a result of high nutrient concentrations close to watering points and lesser utilisation pressure. These observations support those by Howes and McAlpine (2008), which showed an increase in annual grasses in the zone closer to water within the Mitchell grasslandsin Australia.

Decrease in non-woody species abundance with increase in distancefrom watering points in this study may be explained by the development of numerous animal tracks (leading to watering points) in the rangelands, which were observed. Repeated visits to a watering point results in carving of these distinctive tracks to and from that water source (Howes and McAlpine, 2008). These animal tracks were characterised by soil compaction and poor water infiltration making the conditions unfavourable for plant growth. This was worsened by the state of the non-woody species at the time of data collection. Most of the non- woody species were already dry and fragmented due to poor rainfall received in Hwange (during 2012 summer season) hence difficult to count. Point intercept methodas a result, was then used instead of actual counts.

Species richness

Increasing trends with proximityto watering points in species richness were observed.When animals concentrate around waterholes there are greater chances that they bring with them in their dung a number of different types of seeds. Once favourable conditions for germination and growth are prevalent, the seeds germinate and grow giving rise to increased species richness close to watering points. In line with this, Tarhouni*et al*. (2007)reported a decreasing trend with increasing distance from watering points in annual plants. He observed high species richness on transect close to wells characterised by strong animal activity. However, Brooks*et al*. (2006) reported a decrease in total annual plant species richness with proximity to watering points.

Species diversity

No consistent relationship between distance from watering points and species diversity was observed.This lack of consistency is both unusual in the piosphere literature, and is difficult to explain. Thrash *et al*. (1993) reported similar results, and observed no consistent relationship between distance from water and non-woody species diversity. However, Tolsma*et al*.(1987) found diversity to decline with proximity to watering points in Botswana.

5.3 Soil factors

Soil moisture

Soil moisture was lowest close to watering points. There is a direct relationship between rate of soil infiltration and distance from watering points (Eldridge and Whitford, 2009; Pople and Page, 2002; Andrew and Lange, 1986).The infiltration capacity of soils has been shown to be inversely proportional to the grazing pressure and the rate of water infiltration into the soil is directly proportional to distance from watering points (Thrash, 1997).Crust formation together with the loss of cryptogamic material on the surface resulted in a dense, compacted surface layer with low infiltration of water and more run-off (Beukes and Ellis, 2003).In addition, increased evaporation as a result of trampling and reduced vegetation cover also resulted in a decrease in soil moisture content close to watering points(Kauffman and Krueger, 1984).These observations support thoseby Skarpe (1991) and Kauffman and Krueger (1984) which showed a decrease in soil moisture close to waterholes.

Highest moisture content was recorded in the moderate occupancy zone (Zone 2) which was next close to watering point and this might be explained by increasing levels of organic matter or very likely leakage at watering points and also reduced soil compaction due to reduced trampling. Jeltsch*et al*. (1997)also noted that moving away from the borehole moisture declined rapidly, but levelled out after 50-100m.

pH

Soil pH was almost similar across the study sites, ranging from around 4.2 to 5.4, with higher pH values recorded close to watering points.Hwange National Park (sampled sites) is characterised by deep Kalahari sands and sandy soils are usually acidic. Higher soil pH values were recorded close to watering points probably because continuously grazed sites usually have a higher soil pH values when compared to moderately or non-grazed areas (Beukes and Ellis, 2003; Kauffman and Krueger, 1984) Decreased water infiltration caused by compaction close to watering pointsmay limit nutrient loss through leaching. In the process, compacted soils may hold more such ions as calcium and sodium, hence soils close to watering points become less acidic.Results of this study concurs to and Beukes and Ellis (2003)and Kauffman and Krueger (1984)'s findings, who also recorded higher soil pH close to watering points.

Nitrogen, phosphorus and potassium

Soil nutrients were found to be concentrated close to watering points. This is best explained by the deposition of nutrients by animals in the form of dung and urine in the vicinity of watering points resulting in high nutrient concentrations at watering points (Eldridge and Whitford, 2009; Goodall, 2006; Fernandez-Gimenez and Allen-Diaz, 2001; Thrash, 2000; Whitford*et al*., 1999; Nash *et al*., 1998; Turner, 1998; Dougill and Cox, 1995; Perkins and Thomas, 1993; Tolsma*et al*., 1987;Andrew and Lange, 1986). These observations support earlier findings byFernandez-Gimenez and Allen-Diaz (2001) who observed greatest concentrations of phosphorus, potassium and nitrogen in all three zones on the plots closest to water.Moleele and Perkins (1998) also observed elevated nitrogen concentrations near water points. However, in some instances (Waterholes 2 and 3) elevated nutrients were observed in Zone 3. A band of dry swampy area which was encounteredduring soil sampling may best explain these high levels of nutrients further away from watering points.

5.4Seasonal watering points and perennial watering points

No significant difference between seasonal watering points and perennial watering points in terms of vegetation structure was observed. Though water provisioning to the seasonal watering points has been stopped at least 10 years ago, no major differences were noted between seasonal watering points and perennial watering points**.**Provision of artificial water creates a relatively homogenous pattern of disturbance both spatially and temporally. This will be a marked change from what would have been a highly variable pattern previously (Pople and Page, 2002) and it takes a long time (at least 10 years) for the watering point to revert back to its previous variable pattern (DNPWM, 1998). However, this study has shown that the process of seasonal watering points gaining their original status is a long term process and the changes may be evident in some years to come.Goodall's (2006) notion that, the process of artificial watering points gaining their original status is a long term process and the changes may be evident in some years to come support results of this study. In support of these observations, Jeltsch*et al*.(1997)'smodelling results also suggested that the recovery potential of piosphere zones after withdrawal of cattle is negligible in a time span of 100 years.

Failure of seasonal watering points to revert back to their previous (original) state after water provisioning has been stopped is in contrast with the classical ecological theory which states that degraded vegetation, follow progressive succession back to the original vegetation (or its projection in time) once the disturbance has ceased (Skarpe, 1991). Presence of water in seasonal watering points during summer season may explain why these watering points are failing to revert back to their previous state. This means that though grazing and trampling pressure is terminated or ceases in the dry season, in summer season animals still graze and trample around these watering points.

Amongsoil variables onlyphosphorus was significantly different between seasonal watering points and perennial watering points.Phosphorus mineralisation rate can best explain this phenomenon (Dougill and Cox, 1995). The continuous supply of phosphorus to the artificial perennial watering points in the form ofdung and plant litter is massive in comparison to the proportion that is made available to plants as PO_4^{3-}P (average ratio). This explains why the movement of total phosphorus from forage in grazed areas to dung in the sacrifice zone (particularly of perennial watering points) is not reflected in a decrease in PO_4^{3-} in heavily grazed areas (Dougill and Cox, 1995).

The reason why on the other hand phosphorus levels are so much higher in the sacrifice zone of perennial watering points than elsewhere is that, dung contains a much larger proportion of extractable phosphorus than plant litter (Dougill and Cox, 1995) and it highly accumulates in the sacrifice zone.

5.5 Evaluation of methods

Conventional vegetation assessment methods were used in the present study. These methods are often tedious and time consuming. Thus, errors resulting in inflated abundance estimates of shrubs were unavoidable among multi-stemmed plants (Mukwashi, 2006). Overestimation of shrub abundance was also likely in rhizomatous plants (Mukwashi, 2006). The estimation of height using the graduated pole has inherent problems particularly among plants whose heights exceed 5 m. Measurements were also difficult where thickets of *Dichrostachyscinerea* were encountered due to reduced access. In such situations, estimations were used (Mukwashi, 2006). Soil sampling using an auger was time consuming, especially within the vicinity of watering points due to presence of hard soil pans. In order to reduce effects of natural variation, sampling was mostly carried out among sites of similar vegetation and soil type (Conybeare, 1991).

5.6 Conclusion

Results of the present study support earlier findings which show that increased animal grazing and trampling around watering points results in marked spatial variation in vegetation (Gandiwa*et al*., 2012; Mukwashi*et al*., 2012). The study showed that the creation of artificial watering points in the Main Camp of Hwange National Park has resulted in high soil nutrient concentrations near watering points due to deposition of dung and urine. Edaphic factors, particularly phosphorus, soil moisture and soil pH appear to have a pronounced effect on vegetation structure, richness and diversity. Components of vegetation structure, richness and diversity did not differ between seasonal and perennial watering points in the Main Camp of Hwange National Park. Only phosphorus showed significant differences between seasonal and perennial watering points. This reflects continuous accumulation of dung around perennial watering points, and slow mineralisation rates of phosphorus.

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APPENDICES

Appendix A: Regression output for woody species variables, non-woody species variables and soil variables at watering point 1

		df	F value	P-value	rvalue
Woody species	Tree height	1	0.98	0.33	0.17
	Tree basal area	1	0.73	0.40	0.14
	Tree species richness	1	0.24	0.63	0.10
	Tree abundance	1	0.15	0.70	0.00
	Tree crown cover	1	0.87	0.36	0.17
	Shrub height	1	0.15	0.70	0.00
	Shrub basal area	1	4.07	0.05	0.33
	Shrub species richness	1	12.79	0.00*	0.54
	Shrub abundance	1	12.41	0.00*	0.53
	Shrub crown cover	1	1.93	0.17	0.25
	Woody species diversity	1	4.67	0.04*	0.36
Non-woody species	% cover	1	5.37	0.02*	0.22
	Species richness	1	0.80	0.37	0.10
	Abundance	1	10.28	0.00*	0.30
	Diversity	1	1.81	0.18	0.14
Soils	Soil moisture	1	0.92	0.34	0.10
	pH	1	21.20	0.00*	0.42
	Nitrogen	1	19.5	0.00*	0.41
	Phosphorus	1	1.49	0.22	0.14
	Potassium	1	2.59	0.11	0.17

The asterisks symbol means statistically significant at $p < 0.05$

Appendix B: Regression output for woody species variables, non-woody species variables and soil variables at watering point 2

		df	F value	P-value	r value
Woody species	Tree height	1	13.28	0.00*	0.54
	Tree basal area	1	5.41	0.03*	0.37
	Tree species richness	1	12.70	0.00*	0.53
	Tree abundance	1	5.73	0.02*	0.39
	Tree crown cover	1	7.39	0.01*	0.44
	Shrub height	1	7.43	0.01*	0.44
	Shrub basal area	1	3.48	0.07	0.32
	Shrub species richness	1	0.87	0.36	0.17
	Shrub abundance	1	0.54	0.47	0.14
	Shrub crown cover	1	2.66	0.11	0.28
	Woody species diversity	1	3.88	0.06	0.33
Non-woody species	% cover	1	0.77	0.38	0.10
	Species richness	1	0.48	0.49	0.00
	Abundance	1	0.92	0.34	0.10
	Diversity	1	0.03	0.86	0.00
Soils	Soil moisture	1	0.07	0.80	0.00
	pH	1	0.03	0.87	0.00
	Nitrogen	1	17.18	0.00*	0.39
	Phosphorus	1	0.74	0.39	0.10
	Potassium	1	0.75	0.39	0.10

The asterisks symbol means statistically significant at $p < 0.05$

Appendix C: Regression output for woody species variables, non-woody species variables and soil variables at watering point 3

		df	F	P-value	rvalue
Woody species	Tree height	1	8.53	0.01*	0.46
	Tree basal area	1	2.17	0.15	0.24
	Tree species richness	1	0.35	0.56	0.10
	Tree abundance	1	0.04	0.85	0.00
	Tree crown cover	1	1.13	0.29	0.17
	Shrub height	1	7.32	0.01*	0.44
	Shrub basal area	1	2.53	0.12	0.26
	Shrub species richness	1	0.01	0.91	0.00
	Shrub abundance	1	0.34	0.56	0.10
	Shrub crown cover	1	3.77	0.06	0.33
	Woody species diversity	1	0.12	0.73	0.00
Non-woody species	% cover	1	6.64	0.01*	0.24
	Species richness	1	3.12	0.08	0.17
	Abundance	1	6.91	0.01*	0.26
	Diversity	1	1.36	0.25	0.10
Soils	Soil moisture	1	0.07	0.79	0.00
	pH	1	3.28	0.07	0.17
	Nitrogen	1	26.60	0.00*	0.46
	Phosphorus	1	3.58	0.06	0.20
	Potassium	1	47.28	0.00*	0.57

The asterisks symbol means statistically significant at $p < 0.05$

Appendix D: Regression output for woody species variables, non-woody species variables and soil variables at watering point 4

		df	F	P-value	rvalue
Woody species	Tree height	1	2.36	0.13	0.26
	Tree basal area	1	2.11	0.16	0.24
	Tree species richness	1	0.13	0.72	0.00
	Tree abundance	1	1.27	0.27	0.20
	Tree crown cover	1	1.22	0.28	0.20
	Shrub height	1	5.96	0.02*	0.40
	Shrub basal area	1	1.82	0.19	0.22
	Shrub species richness	1	2.01	0.17	0.24
	Shrub abundance	1	0.18	0.68	0.10
	Shrub crown cover	1	7.74	0.01*	0.44
	Woody species diversity	1	3.67	0.06	0.32
Non-woody species	% cover	1	2.70	0.10	0.17
	Species richness	1	0.65	0.42	0.10
	Abundance	1	3.13	0.08	0.17
	Diversity	1	0.05	0.83	0.00
Soils	Soil moisture	1	3.44	0.07	0.17
	pH	1	10.22	0.00*	0.30
	Nitrogen	1	17.55	0.00*	0.39
	Phosphorus	1	11.11	0.00*	0.32
	Potassium	1	2.25	0.14	0.14

The asterisks symbol means statistically significant at $p < 0.05$

Appendix E: Regression output for measured woody species, non-woody species and soil variables at artificial seasonal watering points

		df	F	P-value	rvalue
Woody species	Tree height	1	2.32	0.13	0.17
	Tree basal area	1	0.15	0.70	0.00
	Tree species richness	1	0.13	0.72	0.00
	Tree abundance	1	0.85	0.36	0.10
	Tree crown cover	1	0.68	0.41	0.10
	Shrub height	1	3.75	0.06	0.22
	Shrub basal area	1	0.41	0.52	0.10
	Shrub species richness	1	0.04	0.84	0.00
	Shrub abundance	1	3.36	0.07	0.22
	Shrub crown cover	1	4.50	0.04*	0.24
	Woody species diversity	1	0.10	0.75	0.00
Non-woody species	% cover	1	7.37	0.01*	0.2
	Species richness	1	1.89	0.17	0.1
	Abundance	1	12.65	0.00*	0.24
	Diversity	1	1.42	0.24	0.10
Soils	Soil moisture	1	0.32	0.57	0.00
	pH	1	12.98	0.00*	0.24
	N	1	44.74	0.00*	0.42
	P	1	0.00	1.00	0.00
	K	1	0.39	0.53	0.00

The asterisks symbol means statistically significant at $p < 0.05$

Appendix F: Regression output for measured woody species, non-woody species and soil variables at artificial perennial watering points

		df	F	P-value	rvalue
Woody species	Tree height	1	18.05	0.00*	0.47
	Tree basal area	1	5.82	0.02*	0.28
	Tree species richness	1	7.10	0.01*	0.32
	Tree abundance	1	2.28	0.14	0.17
	Tree crown cover	1	6.43	0.01*	0.30
	Shrub height	1	9.45	0.00*	0.36
	Shrub basal area	1	3.89	0.05	0.24
	Shrub species richness	1	0.98	0.33	0.14
	Shrub abundance	1	1.02	0.32	0.14
	Shrub crown cover	1	3.85	0.05	0.24
	Woody species diversity	1	4.12	0.05	0.24
Non-woody species	% cover	1	6.21	0.01*	0.17
	Species richness	1	1.92	0.17	0.10
	Abundance	1	6.67	0.01*	0.17
	Diversity	1	1.53	0.22	0.10
Soils	Soil moisture	1	0.07	0.79	0.00
	pH	1	0.01	0.93	0.00
	N	1	28.81	0.00*	0.36
	P	1	0.05	0.83	0.00
	K	1	2.92	0.09	0.14

The asterisks symbol means statistically significant at $p < 0.05$