The African Resources Development Journal, Vol 6, No. 1, December 2022: 77-91

Impact of Ungulates on Vegetation Composition Around Waterholes in the Western Part of Etosha National Park, Namibia

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Abstract
Etosha National Park (ENP) is one of the largest conservation areas located in the semi-arid regions of Namibia. Artificial waterholes (boreholes) are the main sources of water for game in the park. Water availability has been largely viewed as a major factor driving ungulate's impact on vegetation composition around waterholes. A nested-intensity sampling design was adopted to collect data from fifty-four (54) quadrats (25m x 25m) on six transects (two at each waterhole) measuring 1 800m from Renostervlei, Dolomietpunt and Olifantsrus waterholes. Results showed that there was no significant difference in species composition with increasing distance away from the waterholes. Herbivory, soil trampling, playing and fighting of ungulates among vegetation before and after drinking has impacted vegetation composition around waterholes. The impacts imposed on vegetation around waterholes by ungulates cannot be completely avoided but be reduced. To reduce the ungulate's impacts on vegetation composition around waterholes, adaptive management measures such as controlled burning, closure of waterholes during rainy seasons, creation of new waterholes that will be evenly distributed within the park and destocking of ungulates is recommended to restore some of the plant species that may have been lost from within those localities.

Keywords: *Ungulates, herbivory impacts, waterholes, vegetation composition, Etosha National Park*

1.0 INTRODUCTION

Globally, large ungulates are known to have a major impact on vegetation dynamics in ecosystems, ultimately influencing ecological processes, species composition and distribution (Chamaillé-Jammes *et al*., 2007). Etosha National Park (ENP) is a semi-woodland savannah (Burke &Strohbach, 1997; Riddell *et al*., 2016) that falls within a semi-arid climatic region found in the central part of Namibia (Wardell-Johnson, 2000). Water provision in semi-arid environments determines the distribution and abundance of ungulates at waterholes (Hagwet *et al*., 2014). De Klerk (2004) indicates that African savannahs are known to have a high level of evolutionary history of grazing and browsing in areas around

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waterholes. It has been noted that the distribution of water is a factor that significantly influences the congregation of wildlife around waterholes (Kamanda *et al*., 2008). Most artificial waterholes in protected areas around the world have been recognized as a common and essential source of water for ungulates, hence the prevalent and evident effects of ungulates on vegetation composition are those related to trampling by large herbivorous mammals, grazing and browsing (Harrington, 2002). Vegetation cover is crucial for a healthy ecosystem, especially in an arid country like Namibia (Riddell *et al*., 2016). As part of protected area management in Namibia, the prevention of vegetation destruction in places like ENP is prioritized to reduce negative impacts of vegetation and loss of ecological processes at the park level.

Elephants (*Loxodonta africana*) are known as ecosystem engineers and play an important role in changing vegetation composition and compositions of African savannahs (Valeix*et al*., 2007). Elephants' feeding behaviours of debarking stems, felling trees and breaking branches off trees subsequently transform woodlands into grassland areas leading to a significant influence on the dynamic of vegetation composition and distribution (Cook*et al.*, 2018). Furthermore, other ungulates such as plains zebra (*Equus burchelli*) which inhabits most of the African savannahs particularly the southern and eastern Africa are classified as bulk feeders and known to have a significant impact on vegetation cover around waterholes (Pedersen *et al.*, 2018; Zvidzai *et al.*, 2013). This has successively resulted in overgrazed areas around waterholes in various savannah ecosystems inhabited by zebras (Valeix *et al*., 2012). Habitually, ungulates in the western part of ENP maintain prolonged stays around waterholes before and after drinking (resting, playing, mating, feeding and fighting), consequently inflicting impacts on vegetation composition thereof (Ben-Shahar, 1993; Brits*et al*., 2002) and in ungulates concentrating more on areas close to waterholes (Owen-Smith, 2008).

In the ENP, waterholes are randomly placed but fairly distributed within the park to supply sufficient water for wildlife throughout the year. Water availability has been largely considered as a major factor driving interaction within herbivore communities, particularly in habitats dominated by seasonal water sources (Zvidzai *et al.*, 2013). Importantly, Auer (1997) stated that water is a key factor in semi-arid environments such as the ENP, influencing regular visits to waterholes by ungulates coupled with destruction and excessive utilization of vegetation around waterholes (Ben-Shahar, 1993; Brits *et al*., 2002). Thus, due to water scarcity, surface watersways the congregation of ungulates around waterholes, particularly in dry seasons. Besides dry seasons, the moisture content in forage material becomes low and when rainwater in puddles has dried up, ungulates congregate around waterholes and the drinking frequency to meet their daily water requirements increases (Chamaillé-Jammes *et al*., 2007; Epaphras *et al*., 2008). Nevertheless, irregular visits are expected in wet seasons due to surface water abundance virtually everywhere in puddles and ample moisture content in forage materials (Epaphras *et al.*, 2008).

In Waterberg Plateau Park (WPP), it has been observed that areas around waterholes are usually in a degraded state during dry seasons, the results of ungulate's impact on vegetation and soil type around these areas (Mukaru *et al*., 2012). Hagwet *et al.* (2014) carried out a study on the impacts of grazing ungulates on vegetation and soils in areas closer to waterholes in Serengeti plains and discovered that during dry seasons, animals spend more time utilizing vegetation in areas close to waterholes. The situation stimulates habitat over-utilization and soil degradation by trampling, leading to vegetation loss by ungulates which will eventually expand the biosphere area around waterholes (Harrington, 2002). Contrary, Pedersen *et al.* (2018) stated that certain shrubs, herbs and grass species are disturbance-dependents thus coppice and flourish well after the first rain when they have undergone serious disturbances. In terms of community recruitment, pioneer grass species will primarily colonize the disturbed habitats around waterholes (Du Plessis, 1994; Huston, 2014). It is further recorded that, large ungulates often change vegetation compositions, particularly in areas close to waterholes (Ben-Shahar, 1993; Brits *et al.*, 2002) when mating, resting, feeding, fighting and/or playing. Over time, the concentration of animals in the vicinity of waterholes will have a significant negative impact on vegetation around waterholes.

This article assessed vegetation structure and composition at waterholes in the western part of ENP and establish factors that affect vegetation composition at different zones with distance away from waterholes.

2.0 METHODOLOGY

2.1 Study Area

The study was conducted in the western part of ENP in Namibia. ENP is the first protected area to be proclaimed in 1907 and one of the largest conservation areas in Namibia with a surface area of 22 700 km² (Cloudsley-Thompson, 1990; Wardell-Johnson, 2000;Brand, 2007; Riddell *et al.*, 2016). According to Oliver & Oliver (1993), ENP is home to 114 mammals and various bird species (of which the majority are migratory) and various tree species. The park inhabits fifteen (15) ungulates species namely: elephant (*Loxodanta africana)*, black rhino (*Diceros bicornis)*, white rhino *(Ceratotherium simum)*, eland (*Taurotragus oryx)*, giraffe (*Giraffe cameloparddalis)*, oryx (*Oryx gazella)*, plain zebra (*Equus burchelli*) and mountain zebra (*Equus zebra hartmannae*) blue wildebeest (*Connochaetes taurinus)*, kudu (*Tragelaphus strepsiceros*), black-faced impala (*Aepyceros melampuspetersi)*, common impala (*Aepyceros melampus*), ostrich (*Struthio camelus*), springbok (*Antidorcas marsupialis*) and warthog (*Phacochoreus africanus*) which carries a significant effect on vegetation composition around waterholes.

Namibia is a semi-arid country located in the south-western region of Southern Africa along the Atlantic Ocean (Wardell-Johnson, 2000). The western side of Namibia is dominated by an escarpment that serves as a transition between the narrow coastal desert and the flat inland plateau (Wardell-Johnson, 2000). ENP is situated in Northern-Central Namibia (Figure 1).

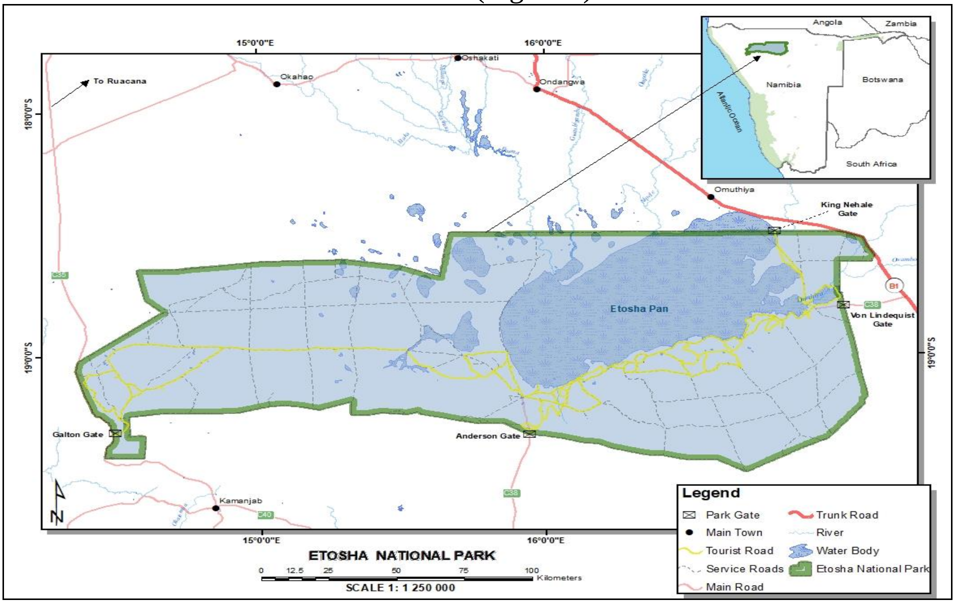

Figure 1: Map of Etosha National Park
Source: https://www.etoshanationalpark.org

ENP comprises a biologically diverse semi-arid woodland savannah ecosystem (Burke & Strohbach, 2000; Riddell *et al.*, 2016). In terms of vegetation composition, the western part of Etosha comprises *Colophospermum mopane* which is the prominent woody plant, while shrubs such as *Leucosphaera-bainesii, Sedderasujjruticosa, Rhigoziumbrevispinosum* and *Commiphoraango-lensis* are often present and grasses include *Anthephorapubescens* and *Eragro-stisdinteri* (Burke & Strohbach, 2000).

The western part of ENP was selected for this study based on the following three key reasons: (i) it has high vegetation and ungulate distribution (Hipondoka *et al.*, 2013) (ii) year-round water provision for wildlife from artificial waterholes unlike the central and eastern part of Etosha National Park with natural springs (Hipondoka *et al.*, 2013) and (iii) the fact that ungulate communities in western Etosha move in packs when going to waterholes and spend time around waterholes before and after drinking. This behaviour is different from other animals in other protected areas such as Waterberg Plateau Park, where ungulates such as Giraffe (*Giraffe cameloparddalis)*, Buffalo (*Syncerus caffer*), Eland (*Taurotragus oryx*), Kudu (*Tragelaphus strepsiceros*), Oryx (*Oryx gazella*) move alone to waterholes, drink and go back to the field shortly after drinking (Mukaru *et al*., 2012).

Three waterholes (Renostervlei waterhole, Dolomietpunt waterhole and the Olifantsrus waterhole) were identified as the study sites (Figure 2). These waterholes were selected because they are operational throughout the year with very minimal problems such as pipeline blockage, cylinder failure and therefore supply sufficient water for wildlife year-round.

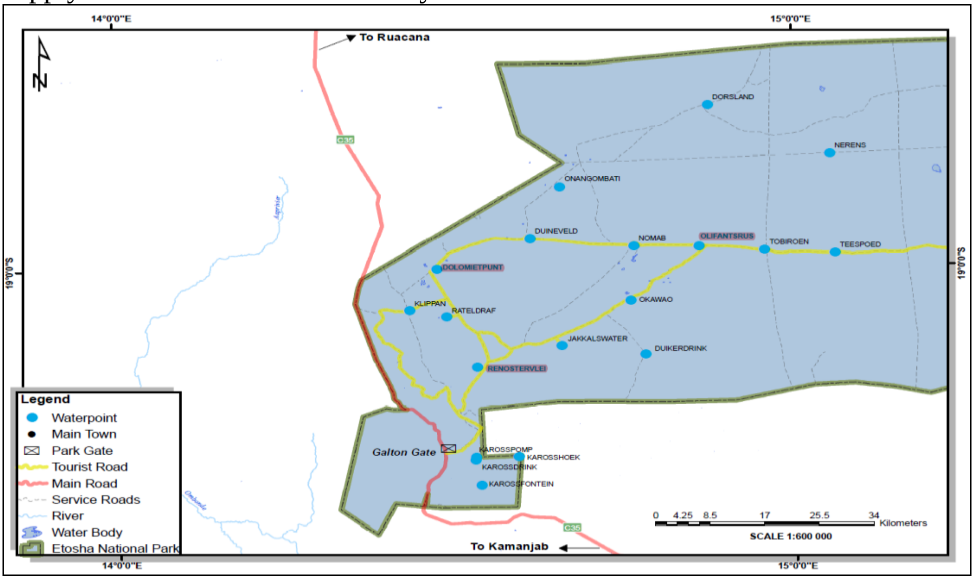

Figure 2: Study sites in the western Etosha National Park
Source: https://www.etoshanationalpark.org

2.2 Methods

A plot-based spatial sampling design was adopted to gather data on the species composition of vegetation around the three selected waterholes. A nested-intensity sampling design was adopted to collect data from 54 quadrats (25m x 25m) on six transects (two at each waterhole) measuring 1800m from Renostervlei, Dolomietpunt and Olifantsrus waterholes. Moreover, a desktop review of the literature was undertaken to interrogate species composition with increasing distance from the waterholes.

The study was conducted during the early vegetation growing season (February to March 2021), while vegetation still has its in-flavescent to ensure easy identification. Two lines of transects were demarcated at each of the three waterholes, running in a cardinal direction. A Global Positioning System (GPS) was used to attest correct placement of transects in the north and south directions. Along each direction, a line of transects measuring 1800m was demarcated from the edge of the piosphere, stretching outwards. Along each transect, nine nested plots of 625 m^2 (25 m x 25 m) were demarcated starting on the edge of the piosphere, at 0 m, 200 m, 400 m, 600 m, 800 m, 1000 m, 1200 m, 1400 m and 1600 m. The 1 m x 1 m plots were nested within the 5 m x 5 m and the 5 m x 5 m were nested inside the 25 m x 25 m of each plot.

2.3 Data Collection

To determine plant species composition and diversity, data were collected from three waterholes in the western part of the ENP. Two line transects starting on the edge of the piosphere, radiating in opposite directions away from waterholes were set and surveyed. Data for plant species composition was gathered by recording names of all plant species that were found in the 54 surveyed quadrants along the two 1800 m line transects at the three waterholes. Grass and herbaceous plants were recorded in the 1 m x 1m plots. Recorded grass species were classified into ecological affinity groups (decreaser and increaser species) considering their response to grazing and disturbance. Shrubs including woody plants with a diameter less than 100 mm at breast height and shorter than 3 m were recorded in the 5 m x 5 m plots while trees woody plants with a diameter ≥ 100 mm at the breast height with the height ≥ 3 m were recorded in the entire 25 m x 25 m plots. Trees could be singular or double stems.

Tree species were identified using Le Roux and Muller's Field Guide to the trees and shrubs of Namibia. The abundance of each species (grass, herb, shrubs, and trees) was counted using the species composition method. Grass and herbaceous plants were counted in 1 m x 1m, shrubs in 5 m x 5 m and trees in 25 m x 25 m plots from all 54 quadrants. The collection of data started from the edge of the piosphere stretching out to the end of the transect.

2.4 Data Analysis

Following Zar (2010), the statistical methods used in this study were a combination of non-parametric Mann-Whitney U-test which was used for the species composition data, and parametric tests namely the Analysis of Variance (ANOVA) with Least Significant Difference (LSD) and the t-test which were used for the plant species diversity data. All probabilities were two-tailed, and the results were recorded as statistically significant when the p-value was less than 0.05. The abundance of plants was calculated as the total number of individuals recorded in the study at different distances and plot sizes. However, variations in site abundance and between the three waterholes was tested using a t-test for samples with normal distribution and Mann-Whitney U-test for samples that do not pass the normality test (Kent and Coker, 1992). In addition, Shannon-Weaver Index of Diversity, (H’) was used to calculate the species diversity
(Kent and Coker, 1992), as follows:

$$H' = -\Sigma(pi \ln^* pi)$$

Where, H’= Diversity Index,
Pi =Proportion of the individuals of the *i*th species
ln = log base n
Species evenness was calculated using Shannon’s evenness index E,

$$E = H'/H_{max},$$

Where, E = Evenness, H_{max} = ln S, S= Number of species in that plot, H’ =Shannon’s Diversity Index.

Variation in plant species diversity between the two seasons was tested using a t-test, and among the three zones was tested using Analysis of Variance (ANOVA) with Least Significant Difference (LSD) as a post-test.The Shannon indices were calculated using past software version4.6 (Hammer*et al*., 2001), and conducted all other data analyses in the XLSTATS version 2015.4.01.22368 (Addinsoft, 2014). Data for plant species composition was gathered by recording names of all plant species that were found in the 54 surveyed quadrants along the two line transects of 1 800 m at the three waterholes. Grass and herbaceous plants were recorded in the 1 m x 1 m plots. Grass species were classified into ecological affinity groups (decreaser and increaser species) considering their response to grazing and disturbance.

3.0 FINDINGS AND DISCUSSION

3.1 Composition of Plant Communities at Waterholes

The abundance of plant species was calculated as the total number of individuals recorded in the study at different distances and plot sizes. Twenty-one (21) grasses, three (3) herbaceous and sixteen (16) woody species were recorded at the three waterholes as shown in Tables 1 and 2. *Enneapogonscaber* and *Schmidtiakalahoriensis* species are the most abundant grass species (Table 1). Mopane is the most abundant tree in the western part of the park, accounting for around 80% of all trees (Table 2). Vachellia and Terminalia trees dominate the sandveld sections of the study area. Thorn bush savanna grows on limestone and alkaline soils and is dominated by Vachellia species such as *Vachellia erioloba, Vachellia mucronata* and*Vachellia melliferra*. The park's grasslands are mostly concentrated around waterholes and open areas, where the soil is sandy.

Table 1: Grass and herbaceous plant species abundance

Species	Dolomietpunt	Olifantsrus	Renostervlei
Aristida congesta	0	0	2
Aristida stipitata	0	0	2
Enneapogoncenchroides	4	10	10
Enneapogondesvauxii	0	0	2
Enneapogonscaber	0	0	1
Eragrostisporosa	0	2	0
Eragrostis rotifer	3	0	2
Eragrostissuperba	0	0	3
Erogrostisnindensis	2	0	0
Erogrostisviscosa	2	0	0
Geigeriaornativa	6	0	1
Heteropogoncontortus	0	0	1
Schmidtiakalahoriensis	1	14	4
Schmidtiapappophroides	2	0	1
Stipagrosisciliata	0	6	3
Stipagrosisobtusa	0	4	0
Stipagrosisuniplumis	7	0	1
Tragus berteronianus	6	5	0
Tragus racemosus	5	0	5
Pechuel-Loescheluebnitziae	3	0	1
Sesamum capense	3	4	4

Tribulus terrestris	5	3	5

Source: Field survey, 2021

Table 2: Woody (shrubs and trees) plant species abundance

Species	Dolomietpunt	Olifantsrus	Renostervlei
Catophractesalexandri	12	9	13
Elephantorrhizaelephantina	9	14	11
Mundulea sericea	2	0	5
Rhigozumbrevispinosum	5	5	7
Sesamothamnusguerichii	0	0	2
Bosciaalbitrunca	0	3	2
Bosciaalbrinca	0	0	1
Colophorspermum mopane	17	17	12
Combretum imberbe	2	0	5
Dichrostachyscinerea	0	0	3
Moringa ovalifolia	1	0	0
Mundulea sericea	2	0	5
Terminalia prunoides	1	0	6
Vachelliaerioloba	0	0	1
Vachellianebrownii	7	0	0
Ziziphusmucronata	0	0	5

Source: Field survey, 2021

Generally, the study recorded twenty-one (21) grass, three (3) herbaceous and sixteen (16) tree/woody species around the three waterholes. The study found that there was no significant difference in plant species composition with distance from the waterholes. A study by Dwire *et al.* (2006), revealed that the microclimate of waterholes and their surrounding areas can be likened to riparian microclimates, adding that there is an influence of water availability and soil type on species composition of plant communities around waterholes. In addition, hydrologic conditions particularly the water-table dynamics associated with seasonal flooding can also influence riparian soils by controlling the areal extent and duration of saturation (Dwire *et al*., 2006). In saturated soils, for example, oxidation-reduction potential, or redox potential indicates the occurrence and intensity of anaerobic conditions and provides an integrative measure of physical and biological conditions in subsurface environments (Eiche *et al*., 2015; Eiche *et al*., 2019).

While soil texture and water availability play a role in shaping vegetation structure, herbivory by ungulates is inevitably one of the major factors that influence the composition of species in plant communities (Eiche *et al*., 2015; Eiche *et al*., 2019). Faison *et al*. (2016), stated that large herbivores are lead drivers of terrestrial plant composition and dynamics, and therefore important determinants of biodiversity and a host of ecosystem services. The consistently high presence and abundance of grass species throughout the transects at all waterholes suggests that these areas were dominated by increaser grass species. According to Magandana *et al*. (2020), indigenous grass species are often the most dominant plants because of their superior adaptation to stress and extreme conditions such as water stress and extensive grazing and thus preserve the stability and productivity of the rangeland in semi-arid environments. Furthermore, such species include increaser II species that colonize areas when the rangeland is overgrazed while increaser I species colonize areas when the rangeland is under-grazed (Magandana *et al*., 2020).

3.2 Composition of species at different distances from the waterhole

The composition of vegetation in relation to waterholes and to distance is shown in Figure 3.

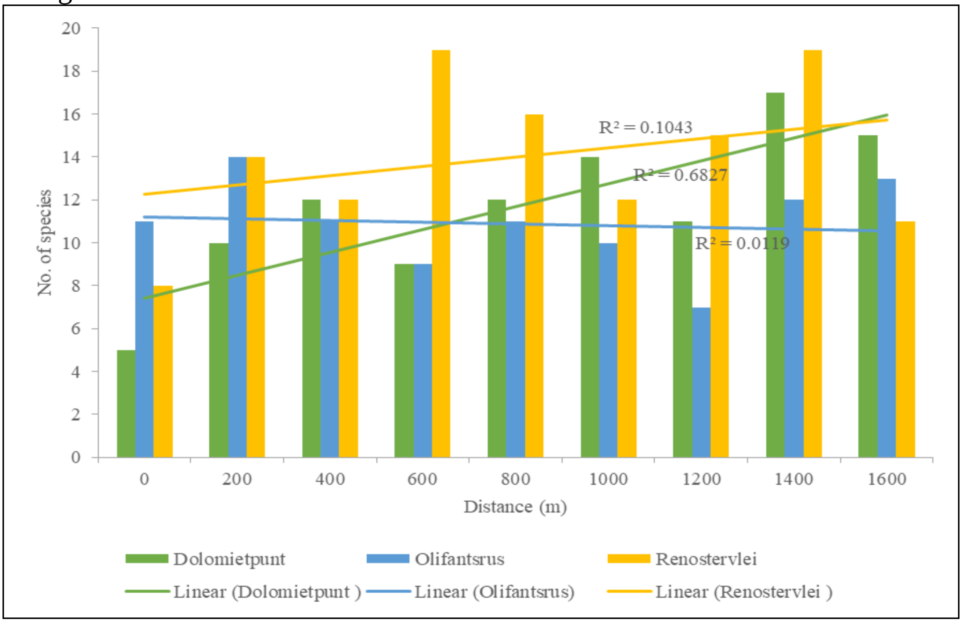

Figure 3: Distribution of plant species with respect to distance from the waterhole
Source: Field survey, 2021

Results from Olifantsrus waterhole show that vegetation species were evenly distributed throughout the transects. While species distribution increased with distance away from Renostervlei and Dolomite waterholes. The composition pattern of species in relation to distance from the waterhole shows varying correlations. For Dolomietpunt, there was a strong correlation between species observed and distance (r= 0.6827, p= 0.0045), i.e., there was an increase in the number of species of plants with reference to increased distance from the waterhole (Figure3). A similar trend was observed at Renostervlei (r= 0.1043, p= 0.211), whereby the number of species increased with distance. However, for Olifantsrus, species slightly declined with distance (r= -0.0119, p= 0.067).

The study further shows that the trend in the number of species was almost the same at all distances, except at 1200m - 1600m from the waterhole, where the number of species fluctuated (Figure 3). Overall, there was no significant variation between waterholes (Dolomietpunt, Olifantsrus, Renostervlei) in species composition in the study area (p =0.103, K = 4.54, df = 2).

This could then justify the relatively high abundance of grass and herb species near waterholes, where water was more abundant and soil texture was much finer compared to the rest of the transect where conditions may have only been more suitable for woody plant species (Mihailou & Massaro, 2021; Mpakairi, 2019; Šmilauer, et al., 2015). This is more apparent at the Dolomietpunt waterhole, where the area gets mountainous with distance away from the waterhole which justifies why there was a relatively higher abundance of grass and herb species near the waterhole and in the middle of the transect. Whereas, a higher abundance of tree species was found in the latter part of the transect which was characterized by a steep slope and rocky soil conditions compared to grasses and herbs.

3.3 Species abundance by plant type

Species abundances by plant type generally declined with increasing distance from water across the three waterholes as shown in Figure: 4. For grasses, the distance category of 0m to 100m had been significantly higher in abundance than the 200m to 600m distance category. However, it later picked up from 600 m toward the end of the transect.

The effective number of herbaceous species has been relatively high at the beginning of transects (first plot at 0 m) at all three waterholes. However, a general decline was revealed at all waterholes, with a persistent decrease from the distance category of 200m to 600m and a complete decline from 600m until the end of the transect at Olifantsrus waterhole. Herbaceous species abundance decreased from the distance category of 0 m to 200 m and an increase was observed at the distance category of 200 m to 400 m and 800 m at Dolomietpunt and Renostervlei waterholes respectively. It was further revealed that there was relatively very low herbaceous species at all three waterholes at the distance category of 800 m to 1 000 m along the transects. However, an increase was again observed from the distance of 1 000 m to 1 200 m before it decreased toward the end of the transect. At Dolomietpunt waterhole, herbaceous plant species remained on increase from the distance of 1 200 m till the end of the transect.

In contrast, there was a general increase in the effective number of shrub species with increasing distances from the waterholes. This increase was observed for the distance categories of 0 m to 600 m and that of 1200 m to 1600 m along the transects. Trees species abundance increased steadily from the distance category of 0 m up to 1400 m from waterholes. However, trees’ abundance started decreasing at a distance beyond 1400 m along the transects at all three waterholes.

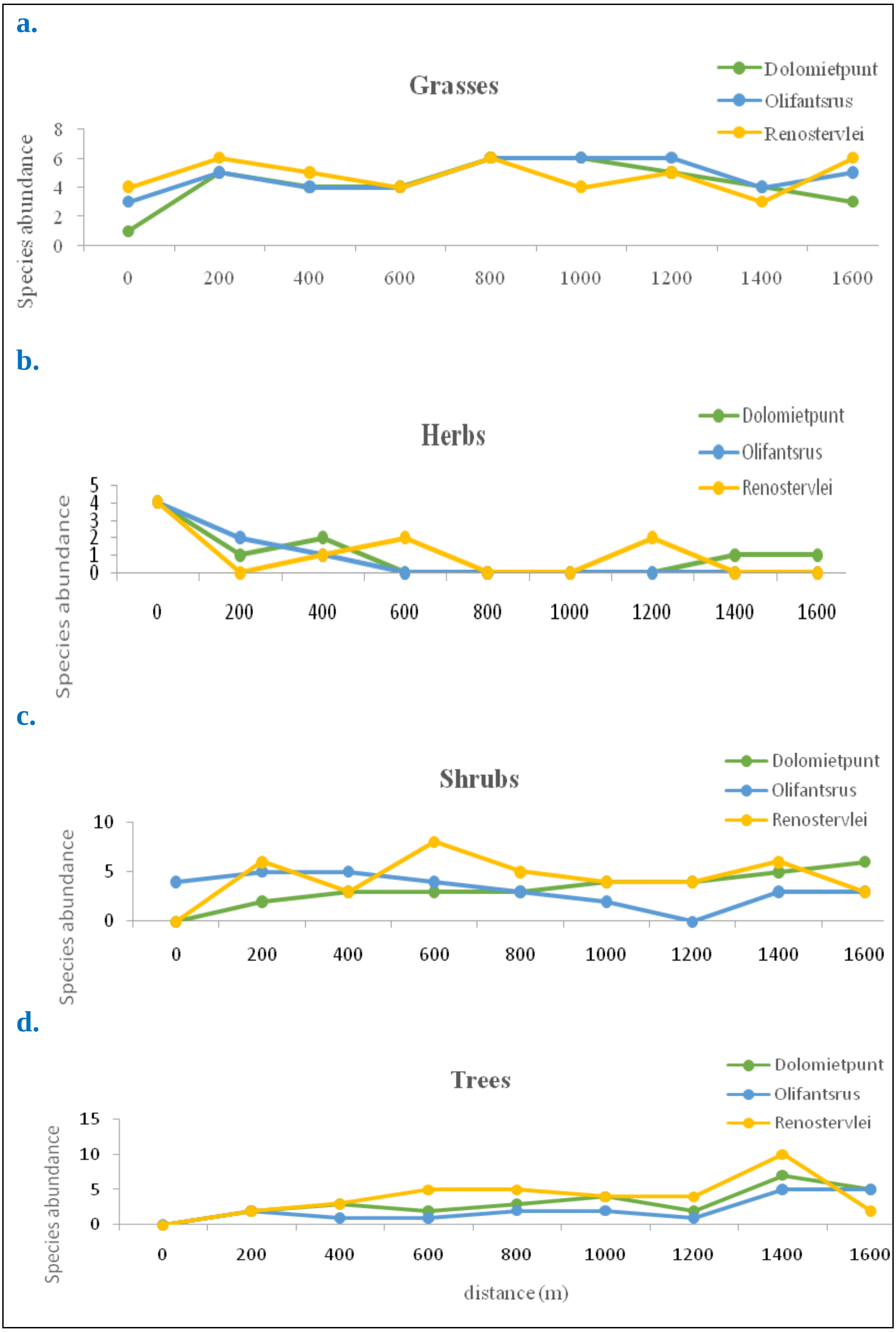

Figure 4: Species abundance of (a). grasses, (b). herbs, (c). shrubs, (d). trees, measured at different distances from the waterhole.

Source: Field survey, 2021

4.0 CONCLUSIONS AND RECOMMENDATIONS

The study concluded that there were no significant differences in species composition of similar vegetation type at the three waterholes. However, changes have been observed in vegetation type varying with distance away from waterholes. The abundance of trees, shrubs and grass species generally remained stable throughout transects at all waterholes. In contrast, herbaceous species significantly decreased with increasing distance away from waterholes. This implies that herbaceous species are increaser species thus dominated heavily disturbed areas (areas closer to waterholes) and decreases with increasing distance away from waterholes. While trees, shrubs and grass are generally decreaser species thus, increasing with increasing distance when the level of disturbance is decreasing with increasing distance away from waterholes.

The impacts of ungulates on vegetation composition around waterholes in the park cannot be completely avoided due to the interdependence of variables (water, vegetation and ungulates). Thus, the implementation of adaptive management measures is highly recommended. Such measures should include but are not limited to controlled burning, and closure of waterholes during rainy seasons when rainwater is plentily available in water puddles to enable the recovery and restoration of some of the vegetation species that may have been lost from areas around waterholes. In addition to already existing waterholes, new waterholes should be created in already disturbed and/or open areas with low vegetation cover to avoid immersing vegetation during the construction process. Such waterholes should be evenly distributed within the park to calm accessibility, and avoid prolonged waits and congregation of ungulates and other game species at waterholes during drinking times, which will subsequently reduce ungulates' impact on vegetation around waterholes. Furthermore, such measures should be incorporated in the Etosha National Park's Management Plan (ENPMP) and other relevant framework documents for implementation while promoting ecosystem-based adaptation and resilience. To effectively implement adaptive management practices, the management team of the ENP should know and understand how ungulates are distributed in relation to vegetation and waterholes within the park.

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