EFFECT OF UNGULATES ON THE VEGETATION STRUCTURE AND COMPOSITION AROUND WATERHOLES IN THE WESTERN PART OF ETOSHA NATIONAL PARK, NAMIBIA

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Open University of Tanzania a thesis entitled, "***Effect of Ungulates on the Vegetation Structure and Composition Around Waterholes in the Western Part of Etosha National Park, Namibia",*** in fulfilment of the requirements for the award of the Degree of Master of Science in Biology of the Open University of Tanzania.

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DECLARATION

I, **Joseph Tashiya Tashiya**, declare that, the work presented in this thesis is original. It has never been presented to any other University or Institution. Where other people's works have been used, references have been provided. It is in this regard that I declare this work as originally mine. It is hereby presented in fulfilment of the requirement for the Degree of Master of Science in Biology of the Open University of Tanzania.

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Signature

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Date

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ABSTRACT

This thesis investigated the effects of ungulates on vegetation structure and composition in the western part of Etosha National Park (ENP) to determine whether or not ungulates have significant effects on vegetation structure and composition at different distances on transects radiating away from waterholes. The thesis addressed three specific objectives, to determine the variation in plant species composition (*abundance*) with increasing distance from the waterhole in ENP, to assess species diversity (*Shannon index and evenness*) of plant communities along transects close and away from waterholes in the park and, to identify conservation implications of vegetation condition in close proximity and further away from waterholes along transects. ENP falls within a semi-arid area and is one of the largest conservation areas, with a surface area of 22 270 km² in Namibia. Due to water scarcity, artificial waterholes are the main sources of water for wildlife. Water availability has been largely viewed as a major factor driving ungulate's effect on vegetation around waterholes. ENP inhabit about 14 ungulate species of significance for this study. 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 structure (species diversity and evenness) and composition (abundance) with increasing distance away from the waterholes. In order to address the ungulate's effects on vegetation around waterholes, adaptive management measures such controlled burning, closure of waterholes, creation of new waterholes within the park and destocking of ungulates is recommended to restore plant species.

Keywords: *Ungulates, herbivory effects, waterholes, vegetation assessment, Etosha National Park, species composition*

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
DWNP	Directorate of Wildlife and National Parks
ECC	Environmental Clearance Certificate
EIA	Environmental Impact Assessment
EMA	Environmental Management Act 7 of 2007
EMP	Environmental Management Plan
ENP	Etosha National Park
ENPMP	Etosha National Park Management Plan for 2013-2018
FA	Forest Act 12 of 2001
GPS	Global Positioning System
IPT	Intermediate Productivity Theory
MEFT	Ministry of Environment, Forestry and Tourism
MEFT	Ministry of Environment, Forestry and Tourism
NCO	Nature Conservation Ordinance 4 of 1975
NPTN	National Policy on Tourism for Namibia
NPTN	National Policy on Tourism for Namibia of 2008
NUST	Namibia University of Science and Technology
OUT	Open University of Tanzania
RNHWCP	Revised National Human-Wildlife Conflict Policy for 2018-2027
WPP	Waterberg Plateau Park
WRMA	Water Resources Management Act 11 of 2013

CHAPTER ONE

INTRODUCTION

1.1 Overview

This chapter introduces the study on vegetation structure and composition at waterholes in the western part of Etosha National Park (ENP) in Namibia. Specifically, this chapter covers the introduction, background to the problem, statement of the problem and research objectives. It further presents the research question and the significance of the study.

1.2 Background to the Problem

Globally, large ungulates are known to have a major effects on vegetation dynamics in ecosystems, ultimately influencing ecological processes, species composition and distribution (Chamaillé-Jammes *et al.*, 2007). Etosha National Park is a semi-woodland savannah (Burke & Strohbach, 2000; Riddell *et al.*, 2016) that falls with 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 ungulate at waterholes (Hagwet *et al.*, 2014). In addition, De Klerk (2004) indicated that African savannahs are known to have a high level of evolutionary history of grazing and browsing in areas around 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).

Elephants (*Loxodonta africana*) are known as ecosystem engineers and play an important role in changing vegetation structures and compositions of African savannahs (Valeix *et al*., 2007). Their feeding behaviours of debarking stems, felling trees and breaking branches off trees subsequently transform woodlands into grassland areas leading to significant influence on the dynamic of vegetation structure, 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 effect 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 (Valeix *et al.*, 2007). Habitually, ungulates in the western part of Etosha National Park maintain a prolonged stay around waterholes before and after drinking (resting, playing, mating, feeding and fighting), consequently inflicting impacts on structures and compositions vegetation thereof (Ben-Shahar, 1993; Brits, Van Rooyen & Van Rooyen, 2002). This has resulted in ungulates concentrating more on areas close to waterholes (Owen-Smith, 2008).

Universally, artificial waterholes' distribution in protected areas is chiefly determined by groundwater availability and wildlife distribution (Riddell *et al*., 2016; Chamaillé-Jammes *et al*., 2007). However, waterholes in Etosha National Park are randomly placed but fairly distributed within the park to supply sufficient water for game throughout the year. Waterholes has been largely considered as a major factor driving interaction and congregation of ungulates around waterholes particularly in dry seasons (Zvidzai *et al*., 2013). Auer (1997) stated that, waterholes are key factors in semi-arid environments such as the Etosha National Park, influencing regular visits by ungulates coupled with destruction and excessive utilization of vegetation around waterholes (Ben-Shahar, 1993; Brits, Van Rooyen & Van Rooyen, 2002). Thus, due to water scarcity, waterholes sway the congregation of wildlife around waterholes, particularly in dry seasons. Besides dry seasons, the moisture content in forage material becomes low and when rainwater in puddles have dried up, ungulates' congregation around waterholes and drinking frequency to meet their daily water requirements become frequent (Chamaillé-Jammes *et al*., 2007; Epaphras *et al*., 2008). Nevertheless, irregular visits of waterholes are expected in wet seasons when rainwater is virtually present everywhere in puddles and the moisture content in forage materials is high (Epaphras *et al*., 2008).

1.3 Statement of the Problem

Most artificial waterholes in protected areas around the world are recognized as common ungulates' meeting points of wildlife but associated with negative environmental implications. Evidently, ungulates in the western part of Etosha National Park congregate around waterholes before and after drinking. Ungulate's activities such as trampling by large herbivores, extreme grazing and browsing on vegetation are evident and prevalent in areas around waterholes (Harrington, 2002). Subsequently, the piosphere area around waterholes is large. Vegetation composition and structure 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 Etosha National Park is prioritized to reduce negative effects on vegetation and loss of ecological processes at the park level.

In Waterberg Plateau Park (WPP), it has been observed that areas around waterholes are usually in a degraded state during dry seasons, the resultant of ungulate's impact on vegetation and soil 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 around and utilizing vegetation in areas close to waterholes. However, this stimulates habitat over-utilization, soil degradation by trampling, leading to vegetation loss by ungulates which will eventually expand the piosphere around waterholes (Harrington, 2002). On the contrary, Pedersen *et al.* (2018) stated that certain shrub, herb 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, grass mainly pioneer species will primarily colonize the disturbed habitats around waterholes (Du Plessis, 1994; Huston, 2014).

It is further recorded that large ungulates often change floristic structures and compositions of vegetation, particularly in areas close to water sources (Ben-Shahar, 1993; Brits, Van Rooyen & Van Rooyen, 2002) when resting, feeding, fighting and/or playing. Over time, the concentration of animals in the vicinity of water sources will have a significant negative effect on vegetation around waterholes. Thus, this research assessed vegetation structure and composition along transects close and away from waterholes in the western part of Etosha National Park and determine the factors that affect vegetation structure and composition at different zones with distance away from waterholes.

1.4 Objectives of the Study

1.4.1 General Objective of the Study

The overall objective of this study was to assess the effect of ungulates on vegetation structure and composition along transects close and away from waterholes in the western part of Etosha National Park in Namibia.

1.4.2 Specific Objectives of the Study

i. To determine the variation in plant species composition (*abundance*) with increasing distance from the waterhole in Etosha National Park.
ii. To assess species diversity (*Shannon index and evenness*) of plant communities along transects close and away from waterholes in the park.
iii. To identify conservation implications of vegetation condition in close proximity and further away from waterholes along transects.

1.5 Research Questions

i. What are the comparative differences in vegetation structure and species diversity (Shannon index and evenness), close and away on transects from the waterholes?
ii. What are the comparative differences in vegetation composition (abundance) along transects close and away from the waterholes?
iii. What are the conservation implications of vegetation are along transects at a closer distance and away from waterholes in the western part of Etosha National Park?

1.6 Significance of the Study

Effective protected area management requires the involvement of landscape managers, ecologists and scientists to plan, manage and monitor resource variations over time, identify possible threats within protected areas and implement scientifically proven management practices. The Etosha National Park stretches from the east to the west in a somewhat rectangular shape and is divided into three operational management sections, namely: eastern Etosha, central Etosha and western Etosha, the latter being the study area. Vegetation in any natural environment forms part of fundamental units of life-supporting systems and is the essential unit of natural resource management and resilience. It has been observed that areas around waterholes in western Etosha have very little vegetation and piosphere areas are lengthy. The congregation of ungulates around and near waterholes among other factors affect vegetation structure and composition. The findings of this study will contribute towards understanding the factors that affect vegetation close and away from artificial waterholes and along the transect. Thus, informed measures and efforts to manage and monitor vegetation structure and composition in areas in close proximity of waterholes will be crafted. Furthermore, this study will influence, contribute, and advise the review of the park's management plan to address set recommendations that will sustain ecological processes and maintain vegetation composition and diversity around waterholes.

1.7 Organization of the Thesis

This thesis is organized into six chapters. Chapter one presented the introduction of the study, background and statement of the problem, objectives, and research questions of the study. The significance of the study and the organization of the thesis are further presented. Chapter two presents the literature that discusses issues about ungulates, plant communities and waterholes. The chapter postulates on theories and empirical literature reviews with bearing to the study. It also discusses the policy review, research gaps and conceptual framework that serve as the study's foundation. The research technique and methods are described in chapter three, while the analysis and discussion of the results are found in chapter four. Discussion of the findings and conservation implications are clarified in chapter five while summary, conclusion, recommendations and areas for further researches are presented in chapter six.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter elucidates the definition of concepts, placing into light linguistic elements such as ungulates, plant communities and waterholes. The chapter also postulates on theories and empirical literature with bearing to the study which is to be undertaken. It further includes the research gap and conceptual framework, which serves as the cornerstone of this study.

2.2 Definitions of Concepts

2.2.1 Plant Communities

Zimmerman & Vitousek (2012) postulates that, plant community is a collection of plants which shares common habitat and interact with one another, animal populations, and the physical environment. Due to similar environmental requirements, several plant groups frequently coexist on the landscape. This allows for the organization of biological data, as well as the creation of mapping units for land management and conservation planning. Cadotte *et al.* (2009) and Sutie *et al.* (2005) also place observation that a plant community can be classified by the species it contains (floristically) or by its physical structure (physio-gnomically). Communities are often defined by dominant plant species which provide useful habitat information for many animal species. The concept of each plant kind is defined and standardised by plant community classification, which is a vital function. Plant community descriptions include information on the makeup of common and rare species, their physical appearance, vegetation structure, and the physical environment in which they usually occur.

2.2.2 Ungulates

According to Mendoza *et al*. (2002) ungulates are hoofed mammals of which the term comes from the Latin word *ungula*, meaning hoof. Amongst others, large ungulates such as black rhinoceros (*Dicerosbicornis*), giraffe (*Giraffa camelopardalis*), eland (*Taurotragus oryx*) and the smallest ungulate the damara dik-dik (*Madoquakirkii*) are found within the boundary of Etosha National Park including the western part of the park (Estes, 2012; Stuart, 2015). Owing to its wildlife abundance, Namibia's wildlife is fascinating, and this is a key reason for many travellers to visit this vast country of which Etosha National Park has become one of the most preferred traveller's destinations (Hipondoka & Versfeld, 2006). In addition, the park is a home of various game species and for this research; the focus has been given to specific ungulates. These ungulates are: 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 hartmanne*) 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*) as listed in Appendix II that are believed to have a significant effect on vegetation around waterholes.

2.2.3 Waterholes

Waterholes are defined as depressions in which water is collected especially a structure that provides water for wildlife consumption. It is further viewed as a conservatory system in which water is stored during dry seasons. Waterholes can be natural or man-made (artificial), they can be natural in the sense that stagnant water can erode topsoil forming a gulley that will store water during the rainy season. Meanwhile, artificial waterholes are concrete structures created by humans to conserve water for animals during dry seasons or when rainwater is depleted in puddles in the field (Hagwet *et al.*2014). Etosha National Park has a combined total of sixty-three (63) water provisional points of which forty (40) are artificial water holes and thirty-three (33) are natural springs (Winter, 1985). All eighteen (18) water holes in the western part of the park are artificial, out of seventeen (17) water holes in the central part of the park, two are natural springs while the eastern part of the park has twenty-eight (28) water holes, twenty-one (21) are natural springs. These water holes supply sufficient water for the game throughout the year and they are not evenly distributed (Auer, 1997).

2.3 Theoretical Literature Review

2.3.1 Intermediate Productivity Theory

Huston (2014) stated that the Intermediate Productivity Theory (IPT) has been a widely recognized theory for patterns of species diversity. The theory proposes that the relationship between plant diversity and productivity has remained a highly contentious issue in community ecology. According to Hickley *et al.* (2004) assumption of the theory is that plant productivity and diversity attract large ungulate communities which in return have significant effects on/vegetation cover near water sources such as rivers and lakes. It further assumes that; land ecotones are characterized by high biodiversity compared to their adjacent systems due to constant disturbances that facilitate the existence of heterogeneous habitats. Hence, they play a critical role in the conservation of global diversity and support vital ecosystem services such as carbon sequestration, nutrient, water cycling and resource partitioning.

However, the intermediate productivity theory has gone through scholarly criticism. Lachavanne and Juge (1997) critique the theory in the sense that it only associates the impact on vegetation cover with ungulate communities and dismisses the bearing of other factors such as human action in depletion of vegetation; deforestation and desertification having an impact on vegetation around water sources. They further observe that humans prefer vegetation near water sources to feed their domestic animals and roof thatching, which will also impact vegetation cover around water holes. Regardless of the criticism associated with the IPT, the researcher employed the theory as part of the study since the research undertaken mainly focused on the effects of ungulates on plant communities around water holes where there is less human interference. It is therefore relevant for the research to evaluate the crucial relationship of the ungulate community and plant community, an attraction of two antagonistic ecological systems, as assumed by the intermediate productivity theory.

2.3.2 Piosphere Theory

Harris *et al*., (2008) defined piosphere as a zone around a waterhole without any form of live vegetation due to grazing and trampling pressure from ungulates. According to Farmer (2010), the Piosphere theory has been used in southern African savannas since the early 1900s to understand the pattern of herbivores’ impact around waterholes. This model is based on herbivores' balance of water and fodder requirements, and it states that degradation decreases as the distance from waterholes increases (Farmer, 2010). Species composition and herbaceous vegetation reveal gradients of herbivore utilization from waterholes. Furthermore, the survival of woody vegetation, trees and shrubs are higher at greater distances from waterholes though patterns differ between species (Thrash, 2000). The Piosphere theory presented by Smith (2016) complements the IPT as it suggests that with veld condition, woody species diversity, and woody species height is predicted to decrease in areas closer to waterholes. Chamaillé-Jammes *et al.*, (2009) found that habitat integrity is lower closer to water sources, due to disturbance caused by large herbivores increasing toward to waterholes. It is against this background that, the researcher ought to adopt this theory for this study as it focusses on the very parameters that the study is based on. It also provides a hypothetical projection of possible scenarios that the researcher expects from the data gathered for the study as per the sets of objectives.

2.4 Empirical Literature Review

Empirical literature review refers to the identification, location and examination of documents containing information related to the problem under investigation (Lubere, 2016). Destruction and loss of vegetation around water holes, particularly in Southern Africa has raised concerns among conservationists (Harris *et al.*, 2008).

Amongst others, vegetation communities form part of fundamental units of life-support systems and they are also regarded as essential units of natural resources management (Mendelsohn, 2002; Strohbach, 2001). Therefore, quantifying the effects of ungulates on vegetation is of great significance to the management of the park/protected area.

2.4.1 Structure of Vegetation Communities Around Waterholes

A vegetation community is a grouping of plant species within a geographical unit that is distinguishable from other types of vegetation patches (Petersen, Young, Hoffman, Musil, & van Staden, 2004). A study in North American desert shrub land, showed that the grazing season had a more pronounced effect on floristic composition than grazing intensity (Burke, 1997). In Kruger National Park in South Africa and Australian Arid Zone, the structure of species richness and species diversity particularly woody species is significantly lower around waterholes (Brits, Van Rooyen & Van Rooyen, 2002; James *et al*., 1999). This is a result of high intensities of herbivory and trampling, which led to only a few tolerant species to no species at all surviving at the water holes (Mukaru, 2009). The study carried out in the Naukluft Mountains investigates the floral composition and vegetation structure of enclosed and comparable sites subjected to grazing by large herbivores to determine (i) whether grazing has had an impact on the flora during the last two decades and (ii) if so, whether vegetation recovery is influenced by the nature of the rainy season. This study concluded that there are no significant differences in vegetation (Le Roux *et al*., 1988). Therefore, the recovery of African savannah vegetation is influenced by seasonal effects such as rainfall, grazing, browsing and soil trampling intensity.

The vegetation of the Namib Naukluft Park (NNP) is classified as a semi-desert and savannah transition zone' which is dominated by dwarf shrubs on the plateau (Burke, 1997; Du Plessis, 1999). Water holes in the western part of Etosha National Park are all manmade and were randomly placed due to groundwater availability and the location of other water holes (Auer, 1997). According to Burke and Strohbach (2000) vegetation structure of the western part of Etosha National Park is savannah woodland with few isolated grassland patches. Furthermore, it is documented that increaser species are more dominant than decreaser species proximity of waterholes (Bredenkamp & Trollope, 1998; Du Plessis, 1999). In their research, Mukaru *et al.* (2012) also observed a similar situation observed in Waterberg Plateau Park whereby vegetation species richness and diversity has declined around waterholes as a result of overutilization and soil trampling by large ungulate species.

Etosha National Park has been divided into thirty (30) major vegetation communities using floristic data and topographic features equated with mapping units relevant for management purposes (Burke & Strohbach, 2000). The dominant woody plant in the western part of Etosha is *Colophospermum mopane*, while *Leucosphaera bainesii*, *Seeders suffruticosa*, *Rhigozium brevispinosum* and *Commiphora angolensis* are common. Grasses include *Anthephora pubescens* and *Eragrostis dinteri* (Burke & Strohbach, 2000). The landscape is predominated by the *Colophospermum mopane* followed by *Vachellia nerbrownii* tree species around water holes with few types of grass and weedy species growing in-between. Trees are slender in diameters and not taller than 15 m which could be influenced by disturbances and soil type (Auer, 1997) and low average annual rainfall patterns (Hipondoka & Jousse, 2013). However, (Hagwet, 2005) argued that vegetation structure and composition in areas close to waterholes are highly disturbed and usually have low plant species diversity.

2.4.2 Effects of Ungulates on Vegetation Around Waterholes

Water provision in wildlife management areas is one of essential management practices. Interestingly, it comes with attached implications on the vegetation community. Ungulate communities, vegetation covers, and waterholes form a major part of the environment and have a significant role in the control of the ecosystem. Eventually, they are significant components in the management system of protected areas (Hagwet, 2005). According to James *et al*. (1999) vegetation is not directly affected by the presence of water but are often affected by the presence of a large number of grazing and browsing animals and their activities around water holes.

In Australia and North America, it has been observed that grazing and browsing impacts are greatest on areas close to watering points which decreases with the distance from water due to two facts: (1) the available foraging area increases with distance from the water hole resulting in a reduction of stock density and (2) water-dependent ungulates drinks regularly thus are limited in how far they can travel away from water holes between drinking intervals (James *et al.,* 1999). In light of the above, similar situations have been observed in Kruger National Park, South Africa;

(Redfer, *et al*., 2003) and WPP, Namibia (Mukaru *et al.,* 2012). Thus, the situation in Etosha National Park cannot be treated differently.

The concentration of ungulate species around waterholes is more prominent in dry seasons, resulting in frequent vegetation used by the ungulate community (Lange, 1969). Ungulates tend to play, fight and feed on vegetation around water holes before and/or after drinking (Brits *et al.,* 2002). These activities are impacting vegetation structure and dynamics, ultimately influencing species composition and distribution leading to the piosphere effect(Chamaillé-Jammes *et al*., 2007). Furthermore, the concentration of ungulates around waterholes leads to soil trampling and dusting resulting in vegetation degradation (Makhabu *et al*., 2002).

2.4.3 Effects of Ungulates on Vegetation with Distances From The Waterholes

Ungulates affect vegetation communities through grazing, browsing, trampling, urinating, and defecating (Mysterud, 2006; Nsor & Gambiza, 2013). Ungulates have a wide variety of profound effects on the ecosystem, including reduction of vegetation cover, and canopy heights litter production resulting in more direct sunlight reaching the soil surface and an increase in soil temperature, decomposition, and evaporation (Mukaru, 2009). In systems where water, nutrients and ungulates are limiting plant growth, as is the case in most semi-arid regions, plant growth is expected to decline with water run-off and loss of soil nutrients (Mukaru, 2009). The feeding behaviour of ungulate communities in areas nearby waterholes is a common habit particularly during dry seasons when forage contains low moisture content than in wet seasons. The feeding distance of ungulates (water-dependents) from water holes is persuaded by the water demand of their bodies (Chamaillé-Jammes *et al.*, 2007). Subsequently, ungulates concentrate on areas close to waterholes than those that are far away to enable them to reach water sources timely when need be (Owen-Smith, 2008). The most obvious effects are those that are associated with grazing, browsing, and trampling by large ungulates. Furthermore, ungulates may decrease plant species richness near water holes, depending on grazing or browsing intensity and soil nutrient availability (Mysterud, 2006). Harrington (2002) noted that the impact of ungulates on vegetation decreases as the distance from the waterhole is increasing.

2.4.4 Intervention Measures to Reduce Vegetation Losses and Destruction at Waterholes

Wildlife and livestock in arid and semi-arid savannas depend on perennial watering points during dry seasons and notably, there is little or no vegetation around waterholes. African elephants can create a large-scale vegetation gradient of woody species around water holes (Ndaimani, 2019). Conservationists and management bodies of protected areas are determined to understand the herbivore-vegetation dynamics around waterholes to enable them to implement correct and sustainable management practices to reduce further vegetation losses around water holes. The recovery potential of savanna vegetation in Namibia after grazing pressure, mainly depends on rainfall timing and intensity which may also be influenced by seasonal effects such as erosion, soil trampling, veld fire and drought (Burke, 1997).

Except for already existing water holes, new water holes should be established and be evenly placed on open areas with low vegetation cover or already disturbed areas with low vegetation cover to reduce further vegetation losses (Ben-Shahar, 1996). Additionally, more water holes should be created to avoid a prolonged congregation of elephants and other ungulate communities around water holes during drink periods (Ndaimani, 2019). Having more water holes that are evenly distributed will ease animal access to water holes and spend less time playing, fighting, and feeding on vegetation around water holes before and after drinking. Furthermore, artificial water holes should be closed during rainy seasons when ample water is present in water bundles in the field to allow vegetation around waterholes to recover and maintain resilience.

2.5 Policies and Legal Framework Review

Many policies, regulations and laws have been put in place to strengthen environmental control and biodiversity protection, guard and fortify the protection of wildlife and national parks in Namibia. These instruments were enacted for the purpose and based on the foundations of environmental protection. The following legal instruments were analysed and found relevant to this research.

2.5.1 Nature Conservation Ordinance 4 of 1975 (NCO)

The Ordinance focuses on the protection of wildlife and wildlife products in a protected area, including the maximization of wildlife population mainly mammals to enhance income generation through tourism activities particularly photographic tourism. Furthermore, all protected areas in Namibia are gazetted under this

Ordinance. The objective of the ordinance is to promote protection and care of wildlife, sustainable utilization of natural resources and biodiversity conservation inside and outside protected area networks within the country.

2.5.2 Environmental Management Act 7 of 2007

The Environmental Management Act (EMA) promotes sustainable environmental management and natural resource use by establishing environmental decision-making principles. EMA also aids in the development of Environmental Management Plans (EMPs) that are used as a tool to prevent and minimise potential environmental effects during the Environmental Impact Assessment (EIA). This is aimed to provide for assessment and control process of activities which may have significant effects on the environment, governs environmental activities and prohibit the execution of listed activities such as mining, irrigation projects, the establishment of tourism facilities, drilling of boreholes without the Environmental Clearance Certificate.

2.5.3 Forest Act 12 of 2001

Forest Act (FA) regulates the management and use of forests and forest produce, provides for the control and management of forest fires and protection of bees and honey. It prohibits the importation of exotic invasive plant species in the country, especially in protected areas such as Etosha National Park, the exportation of unprocessed forest products such as timber, regulates the issuing of harvesting, transport, market, and export permits of forest products and promotes sustainable utilization of forest products.

2.5.4 Water Resource Management Act 24 of 2004

The Water Resource Management Act (WRMA) manages, protects, and conserves Namibia's water resources and it is responsible for addressing the increasing challenges caused by the demand and supply of the resource. Furthermore, it enables the responsible authority to regulate the use and monitor the provision of water services (Davis, 2000).

2.5.5 The National Policy on Tourism for Namibia of 2008

The National Policy on Tourism for Namibia (NPTN) aims to mobilize tourism resources for sustained economic growth, job creation, poverty reduction, reduced disparities in income, gender, and regions and promotes economic empowerment.

2.5.6 Etosha National Park Management Plan for 2013-2018

This Etosha National Park Management Plan (ENPMP) is a five-year document that sets out objectives and guidelines for the development, management and protection of flora, fauna, natural and cultural features of the Etosha National Park. Moreover, it is used as an information source that gives direction to park managers and decision-makers considering business proposals that require authorization to undertake activities within the Etosha National Park as it outlines permitted and prohibited activities in specific areas of the park.

2.6 Research Gap

Redfern *et al.* (2003) investigated the surface-water constraints on herbivores' forage in Kruger National Park with the primary focus on herbivore distribution and foraging distance from water sources with a special interest in water-dependent animals during dry seasons. However, Redfern *et al.* (2003) did not investigate vegetation intensity and the type of vegetation found in far and close vicinities of waterholes. Hagwet *et al.* (2014) assessed the impact of ungulates on vegetation and soil around waterholes but did not mention the seasons (wet/dry season) in which the animals are most prominent at these water sources. The latter and the former did an excellent evaluation of interactions between animals, water, vegetation, and soil. Mukaru and Mapaure (2012) investigated how interspecific competition within herbivore communities affects vegetation and soil in Waterberg Plateau Park with the primary focus on soil trampling around waterholes. However, these three studies did not assess the change in species composition, abundance and diversity of plant communities s radiating away from ungulates' waterholes. Therefore, this study sought to assess species composition, abundance and diversity of plant communities and transects radiating away from at ungulates' waterholes in the western part of Etosha National Park in Namibia.

2.7 Conceptual Framework

A conceptual framework is defined as a set of wide-ranging ideas and principles taken from a related field under investigation that can be used to guide the researcher to develop awareness and understanding of the situation under scrutiny (Johnson, 2004). A conceptual framework is a useful tool that can potentially assist the researcher to communicate and making the study meaningful. Wildlife in protected areas depends on natural and/or artificial water provisional points and often visit such water sources to accomplish water demands for their bodies (Hagwet *et al.*, 2014). Mukaru *et al.* (2012) and Garshong *et al.* (2013) stated that due to limited surface water, boreholes are usually drilled in arid and semi-arid protected areas to provide water for wildlife consumption, mainly ungulates, especially during dry seasons. This is true of Etosha National Park where habitual year-round grazing and browsing around waterholes inflict immense pressure on vegetation and soils around water points. In protected areas in arid environments, vegetation around water holes are in the denudated stage and areas are becoming prone to erosions (De Beer *et al.*, 2006).

Different ungulate species behave differently before and after drinking thus feeding, fighting, flaying and playing impacting heavily on vegetation around waterholes, leading to overgrazing around waterholes (Burke, 1997; Crosmary *et al.*, 2012; Cook *et al.*, 2018). This may result in adverse ecological effects such as soil erosions resulting from the trampling of topsoil and overgrazing around waterholes (Augustine & McNaughton, 1998). Overall, this could lead to the change of plant species composition such as species loss, loss of palatable and nutritious plants/grasses (Moretto & Distel, 1997; Du Plessis, 1999). This has the potential to change species composition and production leading to species losses and regime shift (Leggett, 2006; Didion *et al*., 2009). This forms distinctive zones or piosphere on areas near water holes arising from intensive grazing and soil trampling (Pickup, 1994).

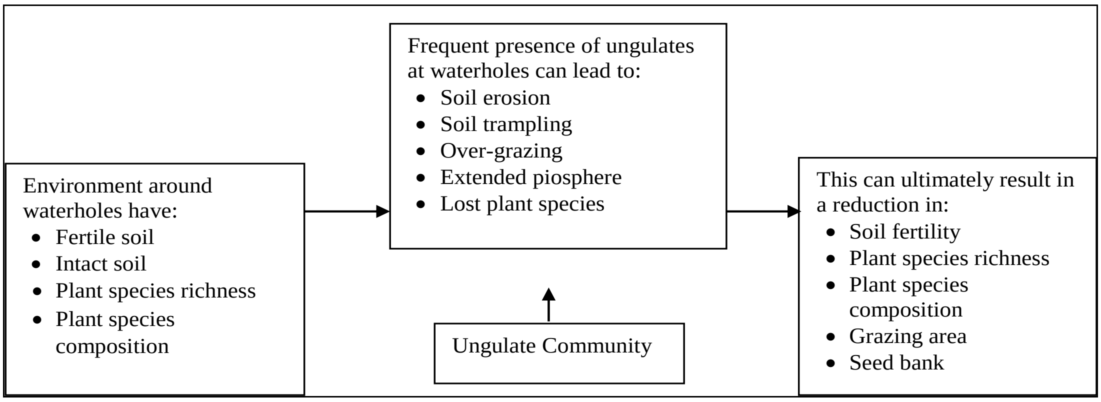

Figure 2.1: Effects of ungulate on vegetation around waterholes in the western part of ENP

Source: Adopted from Lubere, 2016

Interestingly, wildlife managers in protected areas are aware that areas around waterholes undergo continuous stress from wildlife pressure (Zvidzai *et al.*, 2013). However, these areas are compromised over the provision of water for game, thus (Perkins & Thomas, 1993). Consequently, these degraded areas around waterholes are referred to as a 'sacrifice zone' (Perkins & Thomas, 1993). These areas are sacrificed for non-consumptive wildlife utilization such as photographic tourism(Blanc *et al*., 2006).

There are both independent and dependent variables in this study. Independent variables in this study include water in waterholes, plant species richness and composition, fertile soils around waterholes and ungulate species. According to Lubere (2016), dependent variables depend on independent variables. Therefore, effects of ungulate community on vegetation and soils such as overutilization of vegetation, loss of vegetation species and soil erosion around waterholes in the western part of Etosha National Park are the dependent variables.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Overview

This chapter presents the description of the study area, site selection, research design and vegetation sampling. It further presents data collection and analysis and ethical issues.

3.2 Study Area

3.2.1 Location

This study was conducted in the western part of Etosha National Park. Etosha National Park is the first protected area proclaimed in 1907 and one of the largest conservation areas in Namibia. Namibia is a semi-arid country located in the southwestern region of southern Africa along the Atlantic Ocean (Cloudsley-Thompson, 1990; Wardell-Johnson, 2000; Brand, 2007; Riddell *et al.*, 2016). According to Oliver & Oliver (1993), Etosha National Park is home to 114 mammals and various bird species (of which the majority are migratory) and various tree species. The park inhabits fourteen (14) ungulates species which have a significant effect on vegetation around waterholes.

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). The Etosha National Park is situated in Northern-Central Namibia about 120 km south of the Angolan border (Fig.3.1). In 1907, the park was established as a game reserve, and in 1958, it was officially designated as a National Park, covering 99,530 km² and including a section of the Skeleton Coast (Cloudsley-Thompson, 1999). However, in 1970 the park was reduced in area and this time it presents 22,270 km² in size (Hoole & Berkes, 2010; Brand, 2007). Officials of the Ministry of Environment, Forestry, and Tourism (MEFT) are currently responsible for the management of the park under the Directorate of Wildlife and National Parks (DWNP).

The Etosha National Park is the largest protected area in the northern central part of country and second largest in Namibia (Mendelsohn, 2002; Hoole & Berkes, 2010; Riddell *et al.*, 2016). Furthermore, the park forms part of four political regions; Omusati, Oshana, Kunene and Oshikoto regions, surrounded by commercial farmlands in the south and communal farmlands in the north (Mendelsohn, 2006). The land border of the Kunene region is in the south and covers the entire southern part of the Omusati region. Inside the park, on a tourist road, it runs from the Galton Gate to the firebreak found east of Bitter-water waterhole covering the distance of about 105km on the Galton Gate-Olifantsrus camp-Okaukuejo road. The western section of Etosha National Park runs along the C35 road that runs from Kamanjab to Ruacana. For management reasons, Etosha National Park is divided into three sections: eastern Etosha, central Etosha and western Etosha, the latter being the study area. Entirely, western Etosha falls in Okahao constituency within the Omusati region (Kangombe, 2012).

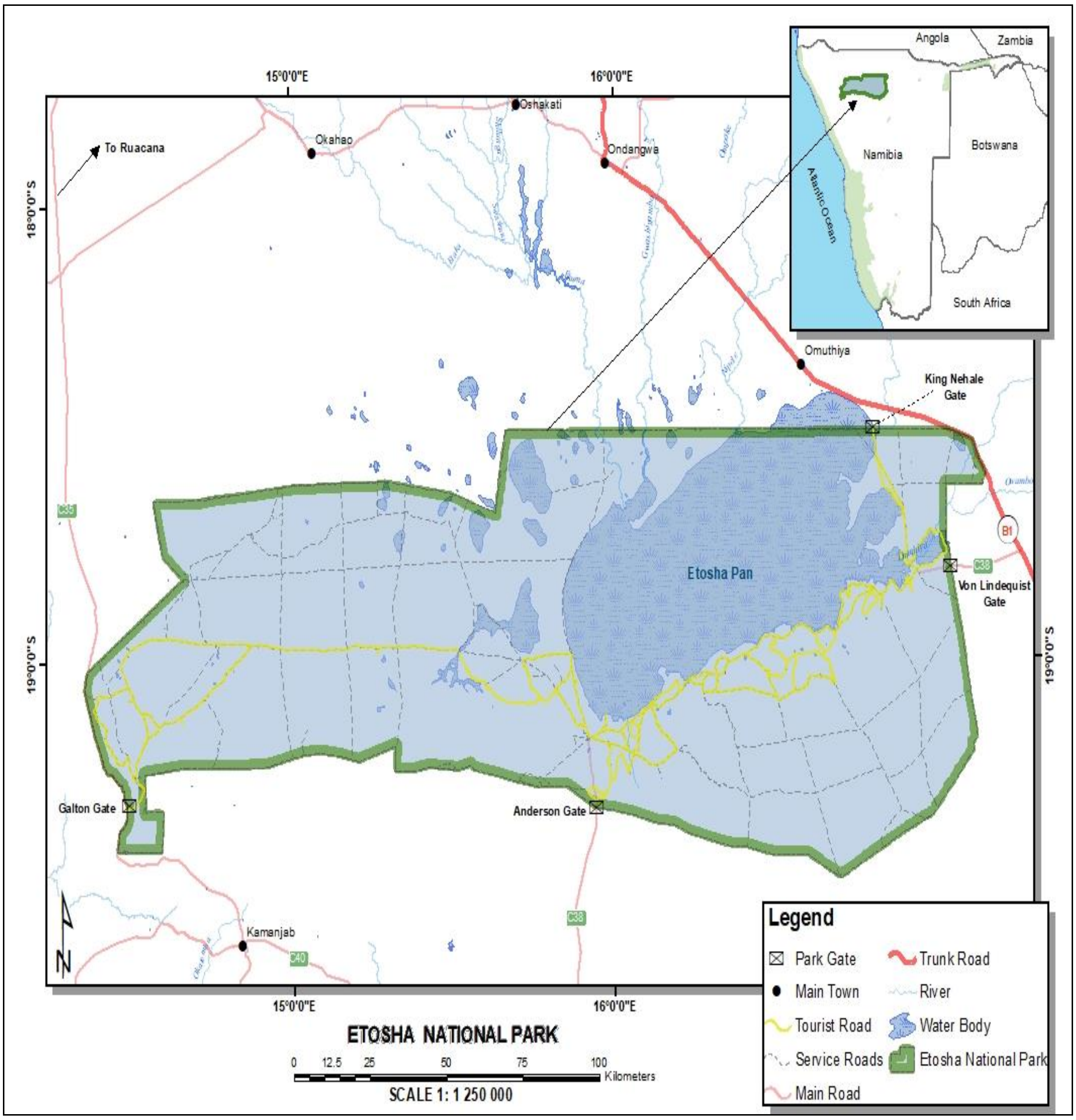

Figure 3.1: Map of Etosha National Park

Source: www.etoshanationalpark.org

3.2.2 Vegetation

The Etosha National Park comprises a biologically diverse semi-arid woodland savannah ecosystem (Burke & Strohbach, 2000; Riddell *et al.*, 2016). In terms of vegetation structure, the western part of Etosha comprises of *Colophospermum mopane* which is the prominent woody plant, while *Leucosphaera bainesii, Seeders suffruticosa, Rhigozium brevispinosum* and *Commiphora angolensis* are often present and grasses include *Anthephora pubescens* and *Eragrostis dinteri* (Burke & Strohbach, 2000).

3.2.3 Climate

The east and central parts of Etosha National Park receive annual average rainfall ranging between 550 mm and 600 mm while, the western Etosha receives an annual average rainfall of about 300 mm (Hipondoka & Jousse, 2013; Nakanyala *et al.*, 2015). The rainfall season in Etosha National Park runs from January to April (Brand, 2007) and occasionally occurs between October and December (Auer, 1997).

3.3 Site Selection

The western part of Etosha National Park was selected for the following three key reasons are: (i) it has a vast vegetation and ungulate distribution (Hipondoka & Jousse, 2013) (ii) year-round water provision from artificial waterholes (Hipondoka & Jousse, 2013) (iii) land use plan which is wildlife management and photographic tourism (Namibia Wildlife Resorts, 2007) and (iv) 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 quite different from 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 were identified within the western part of Etosha National Park (Figure 3.2). They were chosen based on being operational throughout the year with very minimal problems such as pipeline blockage, cylinder failure and supply sufficient water for the game. The specific sites are: Renostervlei waterhole, Dolomietpunt waterhole and the Olifantsrus waterhole.

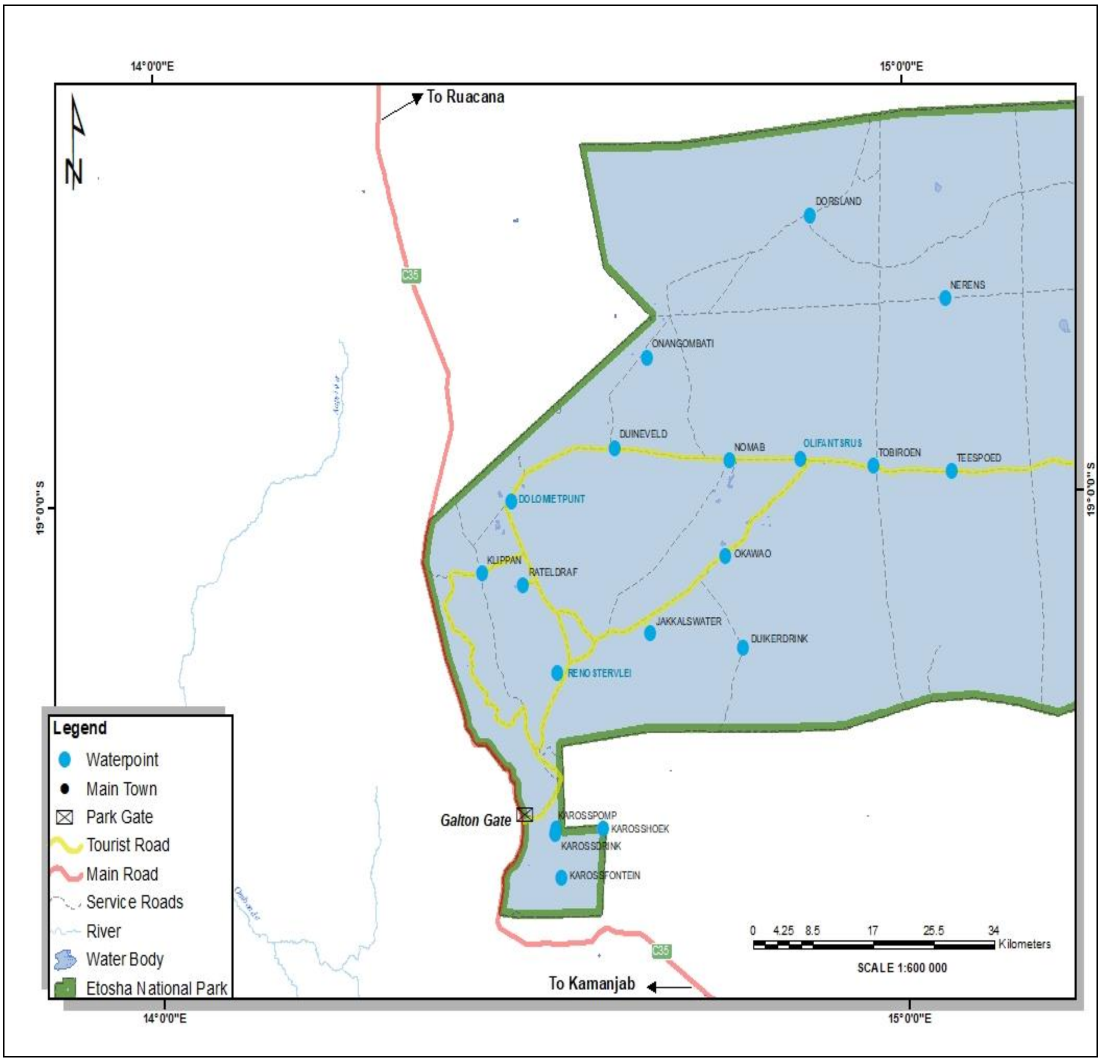

Figure 3.2: Study sites: Western Etosha National Park

Source: www.etoshanationalpark.org

3.4 Research Design and Sampling

A plot-based spatial sampling design was adopted to gather data on species composition (objective i) and species diversity (objective ii) of vegetation communities at the three selected waterholes. Spatial sampling design refers to the mechanism for distributing plots across research sites. Moreover, a desktop review of relevant literature was undertaken to interrogate the conservation implications of vegetation conditions (objective iii) which were identified in the context of vegetation parameters such as the change in species composition, diversity and evenness with increasing distance from the waterholes.

The study was conducted during the early vegetation growing season (February to March 2021), while vegetation remains in-flavescent to ensure easy identification. Two-line 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 on the north and south directions. Along each direction, a line of transects measuring 1 800 m was demarcated from the edge of the piosphere, radiating outwards.

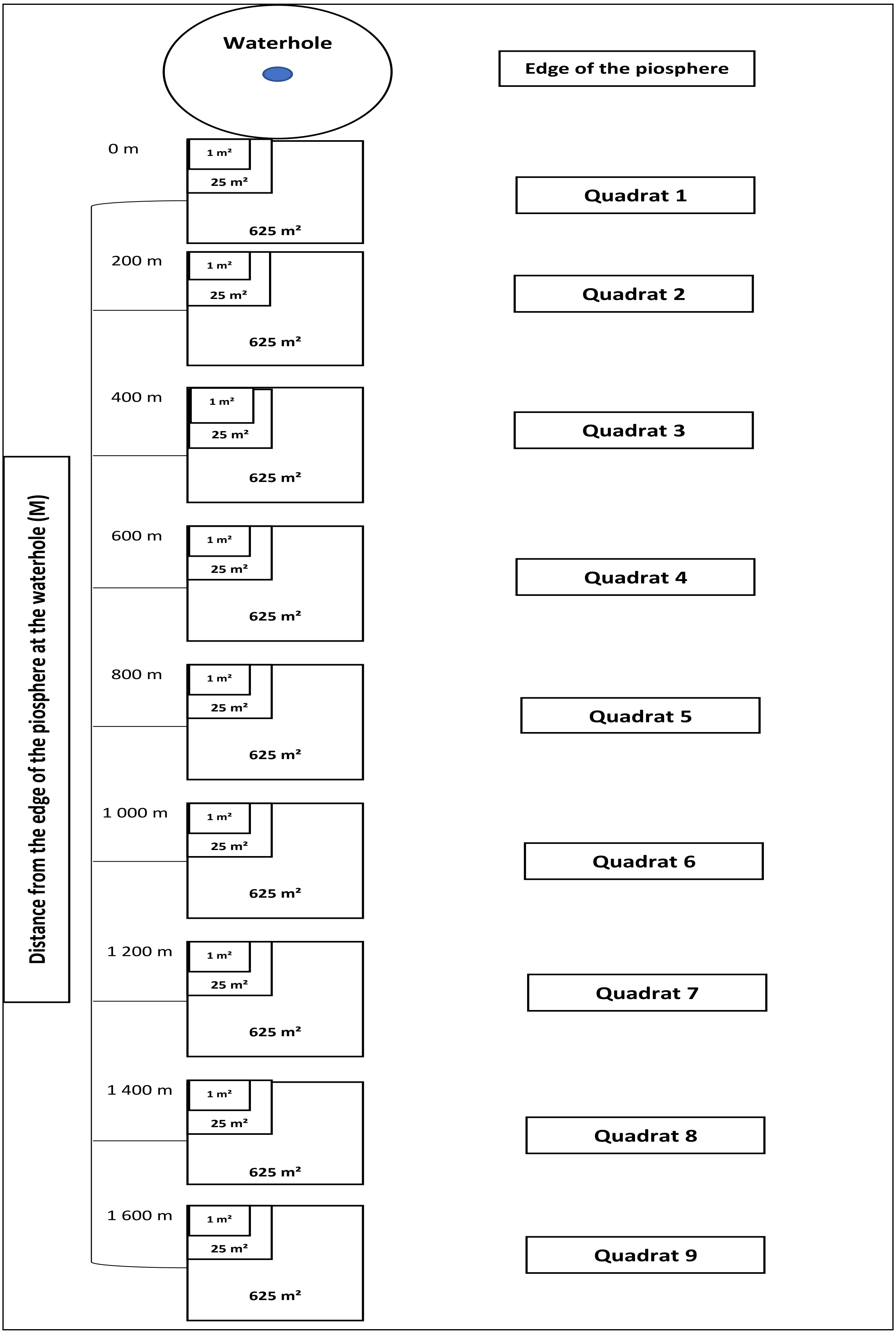

Figure 3.3: Diagrammatic illustration of transect where sampling was undertaken

Along each line transect, nine nested square plots of 625 m^2 (25 m x 25 m) were demarcated starting on the edge of the piosphere radiating away from the waterhole, at the distance of 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 plots.

3.5 Data Collection

Data to determine plant species composition and diversity were collected from three ungulates' waterholes in the western part of Etosha National Park. Two-line transects starting on the edge of the piosphere, radiating in opposite directions away from waterholes were set and surveyed as translated in the following subheadings.

3.5.1 Plant Species Composition

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 1 800 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. Tree species were identified using Le Roux and Muller's Field Guide to the Trees and Shrubs of Namibia.

3.5.2 Plant Species Diversity

The abundance of each species (grass, herb, shrubs, and trees) was counted using the species composition method. Grass and herbaceous plants were counted in all 54 plots of 1 m x 1m along six transects at the three ungulate's waterholes. Shrubs were counted in all 54 plots 5 m x 5 m at the three ungulates' waterholes. All trees found in all 54 quadrants of 25 m x 25 m were counted. The collection of data started from the edge of the piosphere radiating out to the end of the transect.

3.6 Data Analysis

Following Zar (2010), the statistical methods used in this study were either parametric or non-parametric, depending on the nature of the data. All probabilities were two-tailed, and the results were recorded as statistically significant when the p-value was less than 0.05.

3.6.1 Plant Species Composition

The abundance of the plant was calculated as a total number of individuals recorded in the study at different distances and plot sizes (Figure 3.1). However, variation in site abundance and between the three water holes was tested using t-test for samples with normal distribution and Mann-Whitney U-test for samples that do not pass the normality test (Kent & Coker, 1992).

3.6.2 Species Diversity

Shannon-Weaver Index of Diversity, (H') was used to calculate the species diversity (Kent & 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 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 version 4.6 (Hammer *et al*., 2001), and conducted all other data analyses were in the XLSTATS version 2015.4.01.22368 (Addinsoft, 2014).

3.7 Ethical Issues

During the research in Etosha National Park, ethical issues were considered. Since the study involves water, ungulates and vegetation in a protected area, the ruling of relevant laws, regulations and policies that govern national resources and activities within the study area were adhered to. The data collection process was wholly conducted in the presence of law enforcement officials as directed in the park’s management plan. The researcher reviewed and acknowledged relevant publications related to this study to avoid any possible academic crime that may resort to any form of plagiarism or copyright. Information provided in this research is unbiased.

CHAPTER FOUR

FINDINGS

4.1 Overview

Chapter four is organized based on specific objectives. It starts with species composition of plant communities at waterholes followed by species diversity of plant communities at waterholes in the western part of Etosha National Park and lastly, conservation implications of the vegetation condition around waterholes are presented.

4.2 Composition of Plant Communities at Waterholes

4.2.1 Grass, Herbaceous and Woody Species Composition

Twenty-four (24) grass and three (3) herbaceous species were recorded at the three waterholes as shown in Table 4.1 whereby, *Enneapogon scaber* and *Schmidtia kalahariensis* are the most abundant grass species.

Table 4.1: Grass and herbaceous plant species abundance

Species	Dolomietpunt	Olifantsrus	Renostervlei
Aristida congesta	0	0	2
Aristida stipitata	0	0	2
Enneapogon cenchroides	4	10	10
Enneapogon desvauxii	0	0	2
Enneapogon scaber	0	0	1
Eragrostis porosa	0	2	0
Eragrostis rotifer	3	0	2
Eragrostis superba	0	0	3
Erogrostis indensis	2	0	0
Erogrostis viscosa	2	0	0
Geigeria ornativa	6	0	1
Heteropogon contortus	0	0	1
Schmidtia kalahariensis	1	14	4
Schmidtia pappophroides	2	0	1
Stipagrosis ciliata	0	6	3
Stipagrosis obtusa	0	4	0
Stipagrosis uniplumo	7	0	1
Stipagrostis ciliata	0	2	2
Stipagrostis obtusa	0	0	3
Tragus berteronianus	6	5	0
Tragus racemosus	5	0	5
Pechuel-loeschea leubnitziae	3	0	1
Sesamum capense	3	4	4
Tribulus terrestris	5	3	5

Source: Field survey, 2021

A total of 15 woody plants species were observed at the three waterholes, with *Colophospermum mopane* being the most abundant woody species. Meanwhile, *Catophractes alexandri*, *Elephantorrhiza elephantina* and *Rhigozum brevispinosum* were the most abundant shrub species around the waterholes (**Error! Reference source not found.**).

Table 4.2: Woody plant species abundance

Species	Dolomietpunt	Olifantsrus	Renostervlei
Catophractes alexandri	12	9	13
Elephantorrhiza elephantina	9	14	11
Mundulea sericea	2	0	5
Rhigozum brevispinosum	5	5	7
Sesamothamnus guerichii	0	0	2
Boscia albitrunca	0	3	2
Colophorspermum mopane	17	17	12
Combretum imberbe	2	0	5
Dichrostachys cinerea	0	0	3
Moringa ovalifolia	1	0	0
Mundulea sericea	2	0	5
Terminalia prunoides	1	0	6
Vachellia erioloba	0	0	1
Vachellia nebrownii	7	0	0
Ziziphus mucronata	0	0	5

Source: Field survey, 2021

4.2.2 Plant Species Composition (Plant Type) At Waterholes

The results revealed that *Catophractes alexandri, Elephantorrhiza elephantina* and *Rhigozum brevispinosum* were the most abundant shrub species observed around the waterholes (Table 4.1). Meanwhile, herbs significantly decreased were grass species dominated. Only in Olifantsrus, tree species had a low proportion in species composition. In contrast to grass species, woody species abundance was low along transects at all three waterholes (Figure 4.1). It was discovered that grasses and shrubs may be restricting the composition of herbs species at all three waterholes. Results further showed that, distance has no significant effect on species composition around the three waterholes in the western part of Etosha National Park (Figure 4.2).

This pattern shows that decreaser forage species dominated and these are species that increase with a decrease in grazing pressure.

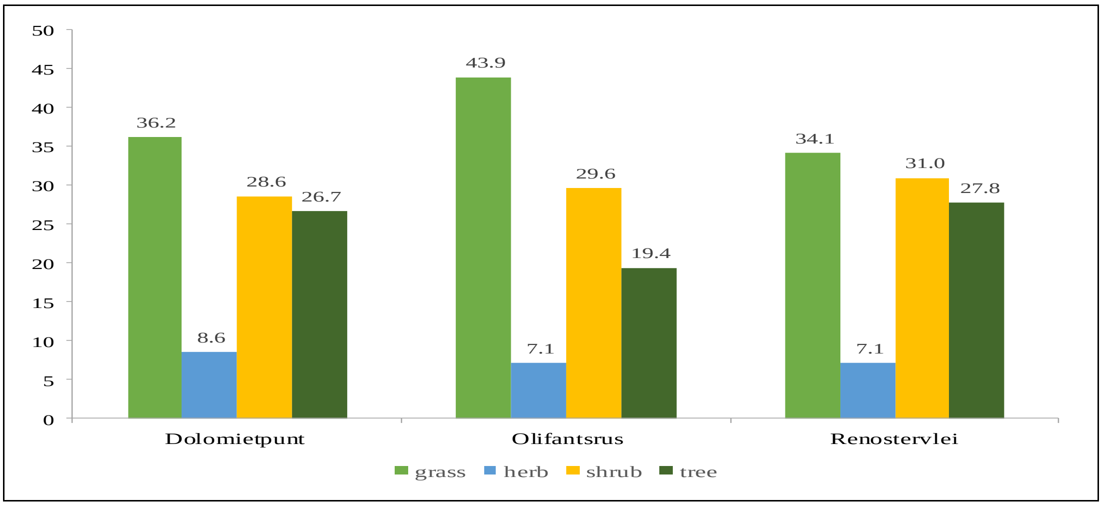

Figure 4.1: Composition percentage of plant types per waterhole in all plots

4.2.3 Composition of Plant Species at Different Distances from the Waterhole

The distribution of vegetation in relation to increasing distance away from waterholes is shown in Figure 4.2. Results from the three waterholes revealed that the number of plant species increases with distance from the waterholes. The distribution pattern of species with distance from the water holes 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 plants species with reference to increased distance from the waterhole (Fig. 4.2). A similar trend was observed at Renostervlei (r= 0.1043, p= 0.211), the number of species increased with distance. However, for Olifantsrus, species declined with distance (r= -0.0119, p= 0.067).

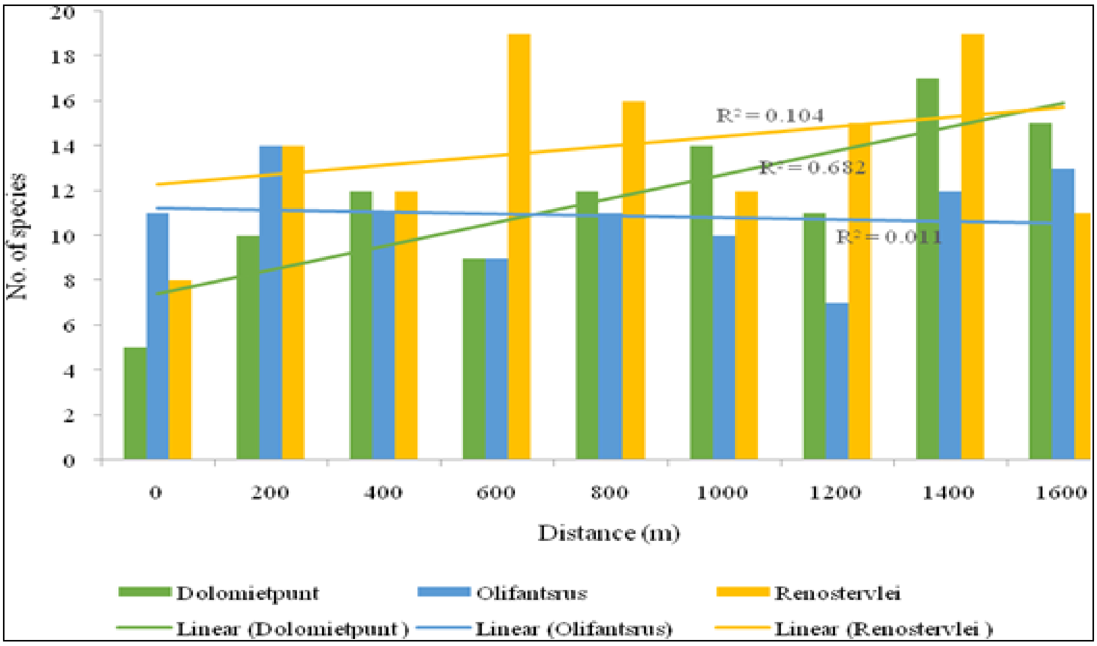

Figure 4.2: Distribution of plant species with respect to increasing distance from the waterhole

The study shows that there was a high number of species recorded at distances between 0 m to 800 m from the waterholes. The number of species was almost the same at all distances except at 1200 m to 1600 m from the waterhole, where the number of species fluctuated (Fig. 4.2). Overall, there was no significant variation between waterholes (Dolomietpunt, Olifantsrus, Renostervlei) in species composition in the study area in relation to the distance (p =0.103, K =4.54, df =2).

4.2.4 Species Abundance by Plant Type

Species abundances generally declined with increasing distance across the three waterholes (Figure 4.3). For grasses, distance categories 0 through to 100 m, had significantly high abundance than the 200 m to 600 m category. Generally, there could be weak effects of disturbance on grass species' abundance, hence, the trends for declines with increasing distance from waterholes. The effective number of herb species declined with distance from 0 m to 1600 m. In contrast, there was a general increase in the effective number of shrub species with increasing distances from waterholes. This was observed for the distance categories 0 m to 600 m, i.e., species abundance increased with distance and a similarly trend occurred in the 1200 m to 1600 m categories. For trees species abundance increased with distance from waterholes and abundance increased steadily from the 0 m through to 1600 m (Figure 4.3).

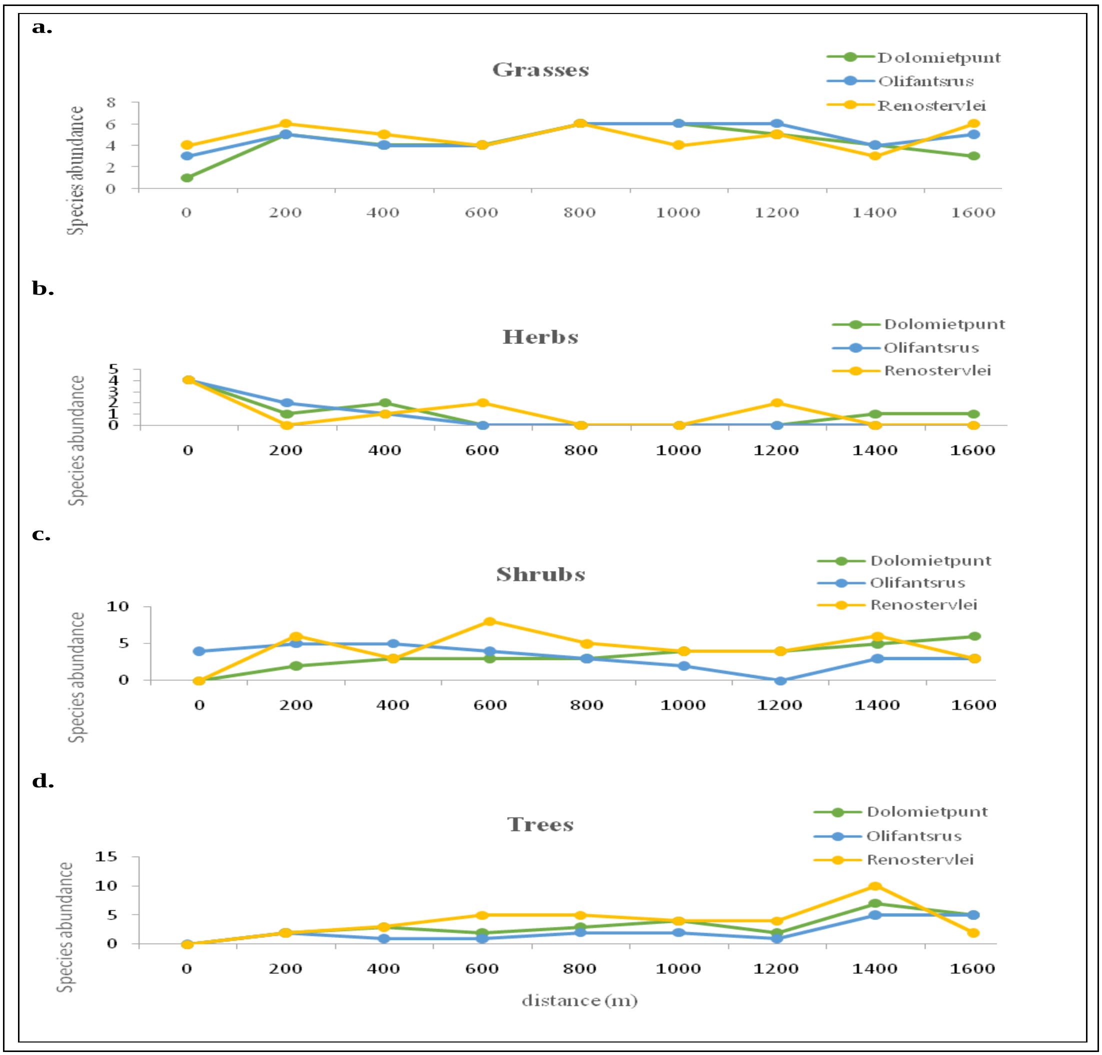

Figure 4.3: Species abundance of a. grasses, b. herbs, c. shrubs, d. trees, measured at different distances from the waterhole

4.3 Plant Species Diversity (H') and Evenness (E)

Plant species diversity and evenness were presented in Table 4.3. Mean diversity shows that Olifantsrus was the least diverse and Renostervlei was the most diverse (Table 4.3).

Table 4.3: Mean plant species diversity Index (H') and Evenness (E)

	Dolomietpunt	**Olifantsrus**	**Renostervlei**
Species richness	22	14	32
Individuals	105	98	126
Shannon_H	2.716	2.354	3.037
Evenness_e^H/S	0.6871	0.7518	0.6516

Species diversity was, however, high in Renostervlei (32) when compared to Olifantsrus (14) and Dolomietpunt (22). Olifantsrus (0.6871) had higher species evenness than Dolomietpunt (0.6871) and Renostervlei (0.6516). However, there is no significant differences in species evenness across the three sites (Dolomietpunt, Olifantsrus and Renostervlei) (F= 0.383, p= 0.683). Dunn's post hoc test indicated a separation of means between Olifantsrus and Renostervlei (p= 0.0268) with Bonferoroni corrected p values. The mean species diversity was significantly high in Olifantsrus (0.7518) when compared to Renostervlei (0.6516).

One-way ANOVA showed that plant species diversity (H') was not significantly different between waterholes (*F*= 4.467, p=0.701). However, the evenness between the Dolomietpunt and Olifantsrus waterholes was significantly different (p= 0.046, t= 2.01, df= 10). The mean evenness was higher in Olifantsrus than in Dolomietpunt (0.76 ± 0.04, 0.68 ± 0.06) respectively. But between Dolomietpunt and Renostervlei the evenness was not significantly different (p= 0.891).

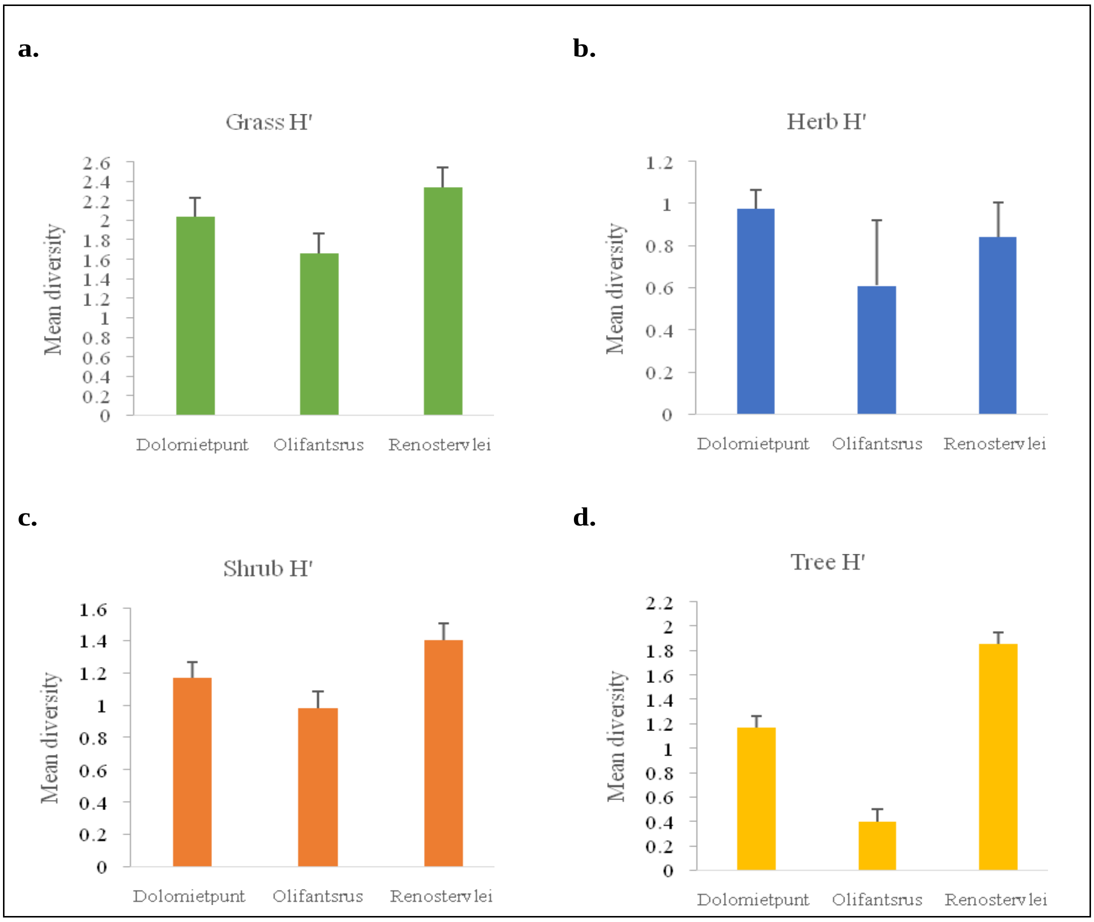

Figure 4.4: Species diversity for a. grasses, b. herbs, c. shrubs, d. trees, measured at three waterholes

Note: The figure presents mean ± SE.

Generally, Renostervlei had higher diversity of grass, shrubs and tree species than Dolomietpunt and Olifantsrus. However, Dolomietpunt had higher diversity of herbs than Renostervlei and Olifantsrus waterholes (Figure 4.4). For grasses (Figure 4.4a) the Shannon diversity index means were significantly similar in all the three waterholes ($F= 0.046$, $p= 0.955$). Species diversity was statistically similar across the three waterholes. Species diversity in herbs did not significantly differ in all three sites ($F= 0.433$, $p= 0.667$). The same pattern was observed for shrubs and trees.

Whereby, the diversity was statistically not different in shrubs (F= 0.249, p= 0.784) and in trees (F= 0.418, p= 0.662).

4.4 Conservation Implications of the Vegetation around Waterholes

Vegetation around waterholes in nature reserves have been shown to be disturbed by ungulates (Mihailou & Massaro, 2021). According to the findings of this study, plant species and disturbance were related to the distance between waterholes. It is the type of plant that determines the extent to which a waterhole has an effect on the surrounding vegetation, with woody species having the greatest effect. With regard to ungulate use of waterholes and given the high frequency with which they are used (particularly for wallowing), it is recommended that the water supply be kept open and properly managed, while the pressure at waterholes be reduced. According to Owen-Smith (1996), stocking rates have an impact on the effect of herbivores on the vegetation surrounding waterholes in the surrounding area. Accordingly, it is recommended that ongoing monitoring of the vegetation surrounding waterholes be carried out, as well as proactive monitoring and management of ungulate stocking rates, as increased population sizes result in increased impact on the environment. A special emphasis should be placed on grazing species because overall habitat integrity and ungulate utilisation are inversely proportional in nature.

The management of water sources has been shown to be an effective management tool for controlling the impact of ungulates on the landscape (Smit *et al*., 2007), and this is supported by other research (Crosmary *et al.*, 2012; Hayward & Hayward, 2012; Kasiringua *et al*., 2019; Mihailou & Massaro, 2021). The findings of this study did not reveal a negative relationship between ungulates and habitat integrity, suggesting that manipulating water sources may not be necessary to control the impact of ungulates on habitat integrity.

CHAPTER FIVE

DISCUSSION OF THE FINDINGS

5.1 Overview

The waterholes in Etosha National Park are mostly devoid of vegetation, except for halophytic *Sporobolus salsus*, a protein-rich grass consumed by grazers like blue wildebeest and springbok. In exception of sections near the Etosha Pan, most of the park's vegetation type is savanna woodland.

5.2 Plant Species Composition

In the study twenty-one (21) grass, three (3) herbaceous and sixteen (16) woody species were recorded at the three waterholes starting from the edge of the piospheres. *Enneapogon cenchroides, Enneapogon scaber, Tribulus terrestris, Tragus berteronianus, Sesamum capense* and *Schmidtia kalahoriensis* species are the most abundant grass and herbaceous species found in the study area. These dominant plants are increaser species that colonised the heavily disturbed areas (areas closer to waterholes) and decreases with increasing distance away from waterholes. While *Stipagrosis ciliate, Stipagrosis obtuse, Eragrostis rotifer* and *Schmidtia pappophroides* are dominant decreaser grass and herbaceous species. Decreaser species increases in number with increasing distance away from waterholes where disturbance intensity (trampling and overgrazing) by ungulates decreases with increasing distance from waterholes. High grass and herbaceous concentration are found on areas close to waterholes and open range lands within the study area.

Mopane is the most frequent tree species in the western part of the park, accounting for around 80% of all trees. Vachellia and Terminalia trees dominates the sandveld of the study area. Vachellia species such as *Vachellia erioloba, Vachellia mucronata* and *Vachellia melliferra* dominated thorn bush plant species.

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 influence of water availability and soil type and texture on species composition of plant communities around waterholes. In addition, hydrologic conditions particularly the water-table dynamics associated with seasonal flooding 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).

Furthermore, fine-textured soils are common and longitudinal gradients are less steep than elsewhere along the stream-riparian corridor (Eiche *et al.,* 2015). This could then justify the relatively high abundance of grass and herb species near the waterhole where water was more abundant and soil texture was much finer compared to the rest of the transect where conditions may have 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, and a higher abundance of tree species compared to grasses and herbs in the latter part of the transect which was characterized by a steep slope and rocky soil conditions.

While soil texture and water availability play a role in shaping vegetation structure (Eiche *et al.,* 2015), herbivory by ungulates is inescapably one of the major factors that influence the composition of species in plant communities. According to Faison *et al*. (2016), large herbivores are leading drivers of terrestrial plant composition and dynamics and therefore important determinants of biodiversity and a host of ecosystem services. The consistent high presence and abundance of grass species throughout the transects at all waterholes suggests that these areas were dominated by increasing 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 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).

5.3 Species Diversity and Evenness

The findings of this study revealed that species evenness was relatively lower on the edge of the piosphere at Renostervlei and Dolomietpunt waterholes and was higher in the rest of the quadrants away from the waterholes except for quadrant 4 at the

Dolomietpunt waterhole. On the other hand, high species evenness was consistently observed throughout the transect at the Olifantsrus waterhole. The low species evenness on the edge of the Renostervlei and Dolomietpunt waterholes is justified by the high relative abundance of some grass and herb species such as *Tribulus terrestris* and *Sesamum capense* recorded in these areas, compared to areas in the middle and further part of the transects which were characterized by a relatively more balanced mixture and abundance of species. Asides from that, the continuous mixture of grass, herbs and tree species such as *Tragus berteronianus*, *Tribulus terrestris* and *Colophospermum mopane* appears throughout the transect at the Olifantsrus waterhole also justifies the high species evenness recorded thereat. Several studies such as Augustine and McNaughton (1998); Skarpe and Hester (2008), argued that abundant ungulates populations can affect primary productivity and nutrient flow in different ecosystems, as ungulates can alter the flow of energy and nutrients by changing plant species composition of the community; altering the chemical composition of plant tissues during digestion; altering inputs from eaten plants to the soil due to changes in the root system or leaf-litter quality, and altering plant and soil microenvironments.

Furthermore, the results from the Olifantsrus waterhole species composition analysis could further be justified by the presence and dominance of increaser species, whose abundance is only affected positively by ecological disturbance, in this case, herbivory and trampling by ungulates. This means that the diversity of the plant communities in a grass-dominated waterhole area remained unchanged throughout the transect, despite consistently being grazed and trampled upon by ungulates.

5.4 Conservation Implications

The study found that there was no significant difference in species composition with distance from the waterhole at all three waterholes. Various factors were attributed to the species composition observed at the waterholes, one of them being that, the area is evenly disturbed through herbivory. The effect of herbivory on plant diversity boils down to the modulation of colonisation and species extinction processes, caused primarily by disturbance (Csergo *et al.*, 2013). Grazing ungulates cause a series of additional disturbances which are often overlooked in models of grazing effect on diversity (Csergo *et al.*, 2013). For instance, trampling by ungulates can destroy soil porosity and increase soil density through compaction and homogenisation which may affect root development of vegetation. They may also cause a reduction in infiltration capacity (puddling effect), which can cause a concentration of nutrients (e.g., phosphorus from animal excreta) in the topsoil, and might interfere with seed germination.

Another factor that could account for the species composition results is that the waterhole areas surveyed are characterized by generalist species that often benefit from highly variable ecological conditions found at the edge of the piosphere, resulting in species dominance (Phelps & Bosch, 2002; Saayman *et al*., 2016). In light of this, the fact that all three waterhole areas were equally affected by herbivory and other physical factors such as drought, does not take away from the reality that vegetation communities at all three waterholes have been impoverished in the process, particularly in areas closer to the waterholes. This, therefore, requires adaptive management measures such as controlled burning to be put in place to restore some of the species that may have been lost from within those localities. Such measures could be incorporated in the Etosha Management Plan or other relevant framework documents for the park to make provision for ecosystem-based adaptation and restoration measures. Another possible intervention that could be pursued is to destock the area of the ungulate through translocation to allow for the vegetation in the area to recover before more wildlife numbers are reintroduced.

The data shows that species diversity and evenness was relatively lower on the edge of the piosphere and increased with distance away from the waterholes. The high species diversity in areas further away from the waterholes may be explained by a combination of species with different ecological requirements corroborating the intermediate disturbance hypothesis. The low diversity in areas closer to the piosphere is perhaps and, probably related to the selective herbivory that occurred during the extractive period (Da Silva *et al.*, 2016). According to Csergo *et al.* (2013), the functional character of dominant species is critical to species diversity and community stability. For instance, in communities governed by competition-colonisation, the best competitors will dominate, whereas good colonisers will play subordinate roles. Higher biomass of dominant species may also prevent colonisation processes and lower diversity. In other communities, dominant species increase diversity by facilitating effects (Csergo *et al.*, 2013). Understanding the diversity of management-maintained ecosystems, therefore, means first and foremost identify the functional role of dominant species and the effect of altered dominance hierarchies on species interactions. To inform and guide conservation efforts in the surveyed areas and the Etosha National Park as a whole, further studies, particularly concerning ecosystem-based measures to improve species diversity a highly recommended.

CHAPTER SIX

OVERVIEW, SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Overview

The study assessed the vegetation structure and composition at areas around waterholes in the western part of Etosha National Park, Namibia. The study focused on key vegetation attributes namely species structure (diversity and evenness) and composition (abundance) which were assessed at Renostervlei, Dolomietpunt and Olifantsrus waterholes in the western part of Etosha National Park. Areas around waterholes in the western part of Etosha are characterized by rather little mopane shrub vegetation and lengthy piosphere areas. Overall, results from the study yielded that there was no significant difference in species composition, diversity and evenness with distance away from the waterholes. The minor differences in the study were attributed to various factors including similar disturbance through herbivory by ungulates, landscape type and water availability.

6.2 Summary

The general objective of this study was to assess the effect of ungulates on vegetation structure and composition along transects close and away from waterholes in the western part of Etosha National Park. The specific objectives were (i) to determine the variation in plant species composition (*abundance*) with increasing distance from the waterhole in Etosha National Park, (ii) to assess species diversity (*Shannon index and evenness*) of plant communities along transects close and away from waterholes in the park, and (iii) to identify conservation implications of vegetation condition in close proximity and on further areas away from waterholes along surveyed transects. Etosha National Park is characterised by drawl mopane savanna biome located in the semi-arid areas of Namibia. The study shows that both species composition (trees, shrubs, herbs and grasses) and diversity changes with increasing distance away from waterholes. Species evenness was relatively lower on edges of the piosphere (areas close to waterholes) and higher toward the ends of the transects/areas far from waterholes. On some transects, high species evenness was consistently observed throughout transects. Therefore, these changes are not necessarily significant.

Furthermore, the study revealed that vegetation, waterholes and ungulates are crucial variables in park management and can therefore not be managed individually in a free-roaming wildlife area. Lastly, it was found superlative to close all artificial waterholes in Etosha National Park during rainy seasons when water for ungulates is readily available in rain puddles to allow vegetation recovery and retain resilience in areas close to waterholes.

6.3 Conclusion

There was no significant difference in species composition, and species diversity and evenness with distance from the waterholes. In order to address the factors affecting vegetation communities in the survey areas of the park and beyond, adaptive management measures such as controlled burning are to be put in place in order to restore some of the species that may have been lost from within those localities. Such measures could be incorporated in the Etosha Management Plan or other relevant framework documents for the park to make provision for ecosystem-based adaptation and restoration measures. It has been further identified in the current study that further research on the rate and intensity of disappearance of plant species around the waterholes is recommended. Lastly, ungulates such as elephants are characterized by unique foraging behaviours which may include non-herbivory related destruction to plants, and this ought to be considered when conducting future studies on the effects of ungulates on vegetation structure and composition.

6.4 Recommendations

Wildlife forms a major resource for management in the protected area management system. Given that, the main objective of protected area management is to manage wildlife populations while maintaining ecological processes, it is recommended that the management of Etosha National Park should know how ungulate populations are distributed in relation to vegetation and waterholes within the park. Protected Area managers also need systems of inventory and monitoring that assess large areas to understand the appropriate sample size and method, and understand how both might change as data are collected and new questions are arising. In exception of already existing water provisional points, waterholes should be evenly distributed. New waterholes should be created on already disturbed land or open areas with low vegetation cover to avoid immersing vegetation losses. The creation of more operational waterholes will eliminate the prolonged stay and congregation of ungulates around waterholes during drink periods. The implementation of the above measures will tranquil the pressure of ungulates to access waterholes and eventually spend less time playing, fighting and feeding on vegetation around waterholes before and after drinking. Furthermore, waterholes should be closed during rainy seasons when ample water is present in water puddles in the field to allow vegetation recovery around waterholes and maintain resilience.

6.5 Possible Areas for Further Research

Considering that the effect of ungulates on vegetation around waterholes in Namibia in relation to increasing distance has not been studied in details, there is still loads of work to be done. The process linking science and practice is rarely linear and often complex. Nonetheless, the effect of ungulates on the structure and composition of plant communities at waterholes in the western part of Etosha National Park became more apparent in the current study. Therefore, further research is required to concretely establish the synergistic effect of herbivory on vegetation structure, with other factors such as water availability in rain puddles and soil texture. Moreover, it is worthwhile to conduct similar studies on a wider landscape to comprehensively establish the full extent of ungulates' effects on plant communities around waterholes.

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APPENDICES

Appendix 1: Scientific and common names of plant species present in the study area

Common names	Scientific names
Carrot-seed grass	*Tragus berteronianus*
Stalked bur grass	*Tragus racemosus*
Puncture vine	*Tribulus terrestris*
Wild Sesame	*Sesamum capense*
Nine-awned grass	*Enneapogon cenchroides*
Kalahari sour grass	*Schmidtia katahariensis*
Windgras	*Eragrostis porosa*
Elephant's root	*Elephantorrhiza elephantina*
Trumpet-thorn	*Catophractes alexandri*
Cork bush	*Mundulea sericea*
Mopane	*Colophospermum mopane*
Kalahari sand quick	*Schmidtia pappophoroides*
Simple-leaved rhigozum	*Rhigozum brevispinosum*
Leadwood	*Combretum imberbe*
Small bushman grass	*Stipagrostis obtusa*
Buffalo thorn (Wait-a-bit tree)	*Ziziphus mucronata*
Tall bushman grass	*Stipagrostis ciliata*
Tassel three-awn	*Aristida congesta*
Sickle bush	*Dichrostachys cinerea*
Herero sesame-bush	*Sesamothamnus guerichii*
Purple-pod Terminalia	*Terminalia prunoides*
Long-awned three-awn	*Aristida stipitata*
Pappus grass	*Enneapogon desvaux*
Pearly love grass	*Eragrostis rotifer*
Saw-tooth love grass	*Eragrostis superba*
Spear grass	*Heteropogon contortus*
Silky bushman grass	*Stipagrostis uniplumis*
Bitter bush	*Pechuel-loeschea leubnitziae*
Shepherd tree	*Boscia albitrunca*
Rock nine-awned grass	*Enneapogon scaber*
Camelthorn tree	*Vachellia erioloba*
Stalked bur grass	*Tragus racemosus*
Geigeria	*Geigeria ornativa*
Water thorn	*Vachellia nebrownii*
Trumpet thorn	*Catophractes alexandri*
Sticky love grass	*Erogrostis viscosa*
Wether love grass	*Erogrostis nindensis*
Ghost tree	*Moringa ovalifolia*

Appendix 2: The list of ungulate species with common and scientific names found in the study area

Common name	**Scientific names**
	Grazers
Zebra	*Hartman's mountain zebra*
Plain zebra	*Burchell's zebra*
Mountain zebra	*Equus zebra hartmannae*
Wildebeest	*Connochaetes taurinus*
Warthog	*Phacochoreus africanus*
Ostrich	*Struthio camelus*
Oryx	*Oryx gazella*
White rhino	*Ceratotherium simum*
	Browsers
Giraffe	*Giraffe cameloparddalis*
Eland	*Taurotragus oryx*
Black rhino	*Diceros bicornis*
Impala	*Aepyceros melampus*
Kudu	*Tragelaphus strepsiceros*
Elephant	*Loxodanta africana*
Springbok	*Antidorcas marsupialis*

Appendix 3: Vegetation sampling datasheet

Vegetation sampling Datasheet

Nr. ………………… Date ……… Locality ………………………………………
Coordinates …………………………Altitude ………………………………………
Aspect………………………………Slope …………………………………………
Size of the stand ……………………Plot size ……………………………………...
Plant community ……………………………………………………………………
Soil type ……………………………………………………………………….…
Land use ………………………………………………………………………….….....

Species	% cover	Height	DBH	Canopy diameter	Density

Observations:

Appendix 4: List of materials and equipment

No.	Materials
1	Disc pasture meter
2	Clinometer
3	Calliper and diameter tape
4	Meter tapes (30 m and 50 m length)
5	GPS receiver
6	Field guides (Plant and mammal identification field books)- one each
7	Satellite imagery (Landsat, Aster)
8	Cooler boxes
9	Hand shears, hand saw and machete (one each)
10	Stone (blocks) to be obtained from the park
11	Paint (15 litre x 3)
12	Painting brushes
13	Binocular
14	Spade

Appendix 5: Species Diversity Calculations

Tree diversity

	Dolomietpunt	*Olifantsrus*	*Renostervlei*
Taxa_S	6	2	9
Individuals	30	20	40
Dominance_D	0.3655	0.7316	0.1474
Simpson_1-D	0.6345	0.2684	0.8526
Shannon_H	1.166	0.3977	1.854
Evenness_e^H/S	0.5348	0.7442	0.7095

Shrub diversity

	Dolomietpunt	*Olifantsrus*	*Renostervlei*
Taxa_S	4	3	5
Individuals	28	28	38
Dominance_D	0.2989	0.3624	0.2347
Simpson_1-D	0.7011	0.6376	0.7653
Shannon_H	1.171	0.9833	1.407
Evenness_e^H/S	0.8059	0.8911	0.8164

Herb diversity

	Dolomietpunt	*Olifantsrus*	*Renostervlei*
Taxa_S	3	2	3
Individuals	11	7	10
Dominance_D	0.2909	0.4286	0.3556
Simpson_1-D	0.7091	0.5714	0.6444
Shannon_H	0.9762	0.6115	0.8433
Evenness_e^H/S	0.8848	0.9216	0.7747

Grass diversity

	Dolomietpunt	*Olifantsrus*	*Renostervlei*
Taxa_S	10	7	16
Individuals	38	43	43
Dominance_D	0.1038	0.1872	0.08306
Simpson_1-D	0.8962	0.8128	0.9169
Shannon_H	2.041	1.666	2.344
Evenness_e^H/S	0.7698	0.7559	0.6515

Appendix 6: Distance and species abundance

Sample	N	Nbr. of categories	Mode	Mode frequency	Category	Frequency	Rel. frequency (%)
Distance (m)-0	24	3	Olifantsrus	11	Dolomietpunt	5	20.8333
					Olifantsrus	11	45.8333
					Renostervlei	8	33.3333
Distance (m)-1000	36	3	Dolomietpunt	14	Dolomietpunt	14	38.8889
					Olifantsrus	10	27.7778
					Renostervlei	12	33.3333
Distance (m)-1200	33	3	Renostervlei	15	Dolomietpunt	11	33.3333
					Olifantsrus	7	21.2121
					Renostervlei	15	45.4545
Distance (m)-1400	48	3	Renostervlei	19	Dolomietpunt	17	35.4167
					Olifantsrus	12	25.0000
					Renostervlei	19	39.5833
Distance (m)-1600	39	3	Dolomietpunt	15	Dolomietpunt	15	38.4615
					Olifantsrus	13	33.3333
					Renostervlei	11	28.2051
Distance (m)-200	38	3	Olifantsrus	14	Dolomietpunt	10	26.3158
					Olifantsrus	14	36.8421
					Renostervlei	14	36.8421
Distance (m)-400	35	3	Dolomietpunt	12	Dolomietpunt	12	34.2857
					Olifantsrus	11	31.4286
					Renostervlei	12	34.2857
Distance (m)-600	37	3	Renostervlei	19	Dolomietpunt	9	24.3243
					Olifantsrus	9	24.3243
					Renostervlei	19	51.3514
Distance (m)-800	39	3	Renostervlei	16	Dolomietpunt	12	30.7692
					Olifantsrus	11	28.2051
					Renostervlei	16	41.0256