COMPARISON OF THE WHITTAKER METHOD AND DISTANCE SAMPLING SOFTWARE FOR WOODY VEGETATION AT LOSKOP DAM NATURE RESERVE

by

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DISSERTATION

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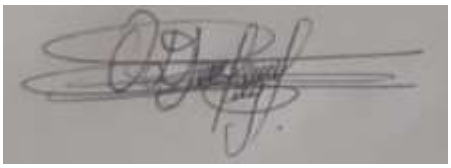
I hereby declare that the dissertation submitted for the degree of Master of Science in Environmental Science, at the University of South Africa (UNISA) is my own original work and has not previously been submitted to any other University. I further declare that all sources that I have cited or quoted are indicated and acknowledge by means of complete list of references.



15 December 2021

Signature Date

(JW Ossanda)

DEDICATION

I dedicate this dissertation to:

God, Emmanuel, "through him all things were made; without him nothing was made that has been made"
John 1:3

My grand-mother AMANAKANA Henriette, who raised and nurtured me and further, for her encouragement and amazing support throughout my life.

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ABSTRACT

Efficient management decision-making within protected and rangeland conservation areas depends on the monitoring activities that are in place as well as the type of methods used in vegetation sampling. No single method is sufficient to achieve all sampling objectives within different vegetation areas. Sampling methods vary in terms of accuracy, precision, time and cost efficiency. In this study, distance sampling software (DSS) was compared to the Whittaker method for determining species richness, diversity and density of woody vegetation. The Whittaker method was used as a baseline to determine the overall accuracy and precision of the DSS. Sampling plots that were randomly distributed were selected in two structural habitats, namely open and closed woody vegetation. The precision of the DSS was assessed and compared to the Whitaker method using the coefficient of variation (CV). Further, the power to detect change was also assessed for both sampling methods. This study compared DSS measures of time and cost efficiency, accuracy and precision to those of Whittaker method. There was a statistically significant difference ($P < 0.05$) between DSS and Whittaker method when estimating the time and cost of the survey, suggesting that the Whittaker method is time efficient while DSS is cost efficient. Furthermore, there was no significant difference in terms of precision between the two methods at detecting species richness, species diversity and species density in the entire study area. Moreover, both Whittaker method and DSS showed greater power with an 80% probability of being able to detect significant change in species richness, diversity and density.

KEYWORDS:

Accuracy, Circular transect, Distance sampling, Distance Sampling Software, Precision, species density, species diversity, species richness, Whittaker method

OPSOMMING

Die doeltreffende bestuursbesluitneming binne beskermde en weiveld-bewaringsgebiede hang af van die moniteringsaktiwiteite wat in gereedheid is, sowel as die soort metodes wat in steekproefnemings van plante gebruik word. Geen enkelmetode is voldoende om al die steekproefnemingsdoelwitte in verskillende plantegroeigebiede te bereik nie. Steekproefnemingsmetodes verskil ten opsigte van akkuraatheid, presisie, tyd en kostedoeltreffendheid. In hierdie studie is twee metodes van plantegroei-steekproefneming vergelyk om die beste metode te vind vir die bepaling van spesierykheid, diversiteit en digtheid van houtagtige plantegroei. Die metodes wat getoets word, is die afstand-steekproefnemingsagteware (DSS) (puntopnametegniek van afstand-steekproefneming) en die Whittaker-metode. Verskillende plantegroei-steekproefneming-terreine (sirkelpunte en kwadrante) – óf ewekansig óf sistematies-ewekansig versprei – is gekies. Die akkuraatheid van die twee plantegroei-steekproefnemingsmetodes is vergelyk in die navorsingsgebied. Die presisie van die plantegroei-steekproefnemingsmetodes is geassesseer en vergelyk as die variasiekoëffisiënt (CV). Die mag om verandering te bespeur is ook geassesseer vir albei steekproefnemingsmetodes. Verder was die Whittaker-metode na verhouding meer akkuraat as DSS met die assessering van spesierykheid. Daarteenoor was DSS meer akkuraat met die digtheidsassessering van houtagtige spesies. Die twee metodes was ewe akkuraat met die opsporing van spesiediversiteit. Boonop was daar geen beduidende verskil wat betref die presisie tussen die twee metodes in die opsporing van spesierykheid, -diversiteit en -digtheid in die algehele navorsingsgebied nie. Sowel die Whittaker-metode as DSS het ook groter mag getoon, met ’n 80%-waarskynlikheid dat ’n beduidende verandering in spesierykheid, -diversiteit en -digtheid opgespoor kan word.

SLEUTELWOORDE:

Afstand-steekproefnemingsagteware (DSS), Whittaker-metode, Sirkelpunt, Akkuraatheid, Presisie, Spesierykheid, Spesiediversiteit, Spesiedigtheid

TSHOBOKANYO

Go tsaya ditshwetso go go nonofileng ga botsamaisi mo mafelong a a sirelеditsweng le a tshomarelo ya naga go ikaegile mo ditiragatsong tsa peoleitlho tse di gona le mefuta ya mekgwa e e dirisiwang go tsaya disampole tsa dimela. Ga go na mofuta o le mongwe o o ka lekanang go fitlhelela maitlhomo otlhe a go tsaya disampole mo mafelong a a farologaneng a a nang le dimela. Mekgwa ya go tsaya sampole e farologana go ya ka go nepa, nako le go nna tlhotlhwatlase. Mo thutopatlisisong eno, go bapisitswe serweboleta sa go tsaya sampole ya sekgala (DSS) le mokgwa wa ga Whittaker wa go swetsa ka go nona, go anama le go kitlana ga mofuta wa dimela tsa ditlhare. Mokgwa wa ga Whittaker o dirisitswe jaaka motheo wa go swetsa ka nepo ya DSS ka kakaretso. Go tlhophilwe mafelo a a farologaneng a disampole tsa dimela tse di kitlaneng le tse di sa kitlanang a a tlhophilweng kwa ntle ga thulaganyo . Go nepa ga DSS go ne ga sekasekwa go bapisitswe le mokgwa wa Whittaker go dirisiwa rešio ya phapogo (coefficient variation (CV)). Go sekasekilwe gape maatla a go lemoga phetogo mo mekgweng ya go tlhopha sampole ka bobedi. Thutopatlisiso eno e bapisitse ditekanyetso tsa DSS tsa nako le botlhotlhwatlase le nepo le tsa mokgwa wa ga Whittaker. Go ne go na le pharologanyo e e maleba ya dipalopalo ($P < 0.05$) magareng ga DSS le mokgwa wa ga Whittaker fa go fopholediwa nako le ditshenyegelo tsa tshekatsheko, e leng se se tshitshinyang gore mokgwa wa ga Whittaker o boloka nako fa DSS e le tlhotlhwatlase. Mo godimo ga moo, go ne go se na pharologano e e kalo malebana le nepagalo magareng ga mekgwa e mebedi go lemoga go nona ga mefuta, dipharologano tsa mefuta le kitlano ya mefuta mo karolong yotlhe ya thutopatlisiso. Go tlaleletsa, mekgwa ya ga Whittaker le DSS mmogo e bontshitse maatla a magolwane ka kgonagalo ya 80% ya go kgona go lemoga phetogo e e bonalang mo go noneng ga mefuta ya dimela, dipharologano le kitlano.

MAFOKO A BOTLHOKWA:

Nepagalo, Karoganyo ya tshekeletsa, Go tsaya sampole ya sekgala, Serweboleta sa go tsaya Sampole ya Sekgala, kitlano ya mefuta, pharologano ya mefuta, go nona ga mefuta, Mokgwa wa ga Whittaker

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

Grasslands and savannas occupy more than 40% of the global terrestrial landscape (Chapin, Sala, & Huber-Sannwald, 2001). Huntley & Walker (1985) stated that savannas consist of a discontinuous stratum of trees with a more or less continuous layer of grasses. Despite this apparent structural simplicity, there is a high diversity of both species and life-forms represented within the herbaceous and woody strata of savannas (Wilson, Russell-Smith, & Williams, 1996).

According to Bond & Parr (2010) savanna ecosystems are the result of frequent fire, and without which there would be a dramatic biome shift and loss of biodiversity. The vegetation component of ecosystems developed together with animals, and they occupied it (Bond & Parr, 2010). The African savanna is important for the African culture and economy. Humans alter vegetation through agriculture, development and fencing, and stocking the wrong types of animals (Skarpe, 1992). Savanna plant species provide households with natural elements such as timber, food, medicine, and other products of cultural importance such as African masks, drum and seating benches. The human population living in, and around African savannas has significantly increased leading to the overexploitation of savanna areas.

Large sections of the grassland biome are over-utilised and poorly managed (Oldeman, 1994). At the same time, significant amounts of native forest, shrubland, and woodland have been converted to grassland for food and forage production (DeFries, Field, Fung, Collatz, & Bounoua, 1999). As a result, the conservation and scientifically based ecosystem management of these areas and their species has become important for sustainable development (Kristensen & Lykke, 2003).

Various vegetation survey techniques are applied within conservation areas to determine the nature and extent of vegetation change in grassland and savanna biomes.

This data assists managers make informed decisions on herbivore-stocking rates, implement effective management strategies and to adapt management and monitoring programmes.

Data collection programmes aimed at endangered, highly endangered, and vulnerable species assists in developing specific management programmes for these species. According to Hermoso, Kennard, & Linke (2013), the accuracy of conservation plans that arise from systematic planning depends on the quality of data on biodiversity patterns. Poor-quality data may lead to high uncertainty and poor decision-making. Despite the clear benefit of reducing uncertainties in conservation monitoring and data collection, our capacity to make informed decisions is controlled and limited by the cost and time required to collect data.

Vegetation monitoring techniques are generally grouped into three categories, namely point-based surveys, area-based surveys and semi-quantitative surveys (Fidelibus & Mac Aller, 1993). Point-based techniques including the wheel point technique (Tidmarsh & Havenga, 1955), the nearest plant method (Tainton, Foran, & Booysen, 1978), the benchmark method (Tainton, Edwards, & Mentis, 1980) and the step-point method (Mentis, 1981), have been adopted and variously modified for use in grassland and savanna ecosystems in South Africa. For example, Kiker *at el*. (2014) explored an extensive dataset to establish woody vegetation cover and composition in Kruger National Park for the late 1980s; and Trollope *et al*. (1989) assessed veld condition in the Kruger National Park using key grass species. Subsequently, the key species technique has been developed by Trollope (1990) and is currently used in the Kruger National Park (KNP). This technique was adapted from a technique developed in the Eastern Cape for use by non-botanically trained farmers and extension officers (Willis & Trollope, 1987). Commonly used point-based techniques use between 100 and 200 evenly spaced points placed along a line or randomly within a plot (Trollope *et al*., 2014).

Area-based surveys include area-based vegetation sampling techniques such as the Braun-Blanquet technique (Mueller-Dombois & Ellenberg, 1974). Recently, combinations of point- and area-based sampling techniques have been applied to monitor grass and woody species in the KNP (Zambatis, 2002).

Previous work has focused on the accuracy of different methods for estimating the

density and species composition within a small area (a quadrat). According to Sokal & Rohlf (1981), accuracy is the closeness of a measured value to its true value (reality). The development of effective sampling programmes in different habitats depends on the objectives and which sampling designs are best suited to that particular purpose.

1.2 IMPORTANCE OF SAMPLING METHODS

In grasslands, researchers are using a variety of vegetation sampling techniques (Barbour, Burk, Gilliam, & Schwartz, 1999). Alternative forms of study resolution (combined grain and extent) and sampling frequency affect the estimation of species richness, demanding careful consideration to fulfil an optimum sampling strategy (Pickett & Cadenasso, 1995).

The South African Land Condition Trend Analysis (LCTA) standard has used the point-intercept method, known as a low-resolution approach, as part of its nationwide vegetation sampling procedure (Diersing, Shaw & Tazik, 1992). Land Condition Trend Analysis surveys use a belt-transect approach in combination with the point-intercept method; although point-intercept sampling is rapid and appropriate for some objectives, data resolution can be low in grassland systems with a low number of samples used when doing a survey (Diersing *et al*., 1992).

A second, contiguous quadrat method known as the high-resolution method, allows users to identify the spatial attributes of vegetation such as cover, composition and frequency (Ludwig & Tongway, 1995). The contiguous quadrat method permits researchers to ask several questions about data and is time consuming.

1.3 CHOICE OF SAMPLING METHOD AND SHAPE OF SAMPLING PLOT

The data to be recorded at the identified sampling sites during a survey depends firstly on the objectives, followed by the method of selection, the sampling effort, the spatial arrangement of the sampling units, and the frequency, precision and accuracy of the measurements (Stohlgren, 2007). The sampling methods used should be selected according to the type of vegetation being sampled; for example, mountain bushveld, plains bushveld, sourveld and shrubland (Barbour *et al*., 1999). According to Sorrells & Glenn (1991), other aspects to consider include the number of samples necessary to

represent the community, and the time needed to collect the data.

The sampling method selected plays a paramount role in the number of species recorded in multi-scale species inventories (Keeley & Fotheringham, 2005). Sampling methods that provide multi-scale sampling units use have often been considered to increase the number of species detected in a survey. The difference in these methods lies in the size of the sampling sites and the design of vegetation surveys (Chiarucci, Bacaro, & Scheiner, 2011).

Despite the important implications that the size and shape of the sampling plot have on the sampling method and the overall number of species recorded in large-scale surveys, only a few studies that were done on smaller spatial scales have evaluated the effect of plot shape on the number of plant species recorded, and consistent findings are yet to be found (Bacaro *et al*., 2015).

1.3.1 Whittaker method

The Whittaker method is a nested vegetation sampling method developed by Whittaker (1975) to compare plant species diversity (Whittaker, 1977; Shmida, 1984). The method is a standardized sampling technique for measuring plant diversity, which is needed to assist in resource inventories and for monitoring long-term trends in vascular plant species richness (Stohlgren, Falkner, & Schell, 1995).

The Whittaker method is used for data collection and entails the use of a 20 m x 50 m (1 000 m^2) plot that is subdivided into nested sub-plots of three different sizes: one 10 m x 10 m (100 m^2), two 2 m x 5 m (10 m^2) and ten 1 m x 1 m (1 m^2) subplots. Different parameters of diversity such as differential diversity, point diversity equability and dominance are recorded through the Whittaker method. Supplementary observations data such as plant cover, growth form, phenology and vertical foliage profile are also collected (Shmida, 1984).

The Whittaker method was widely used by Shmida (1984) in Jerusalem to collect species richness data at multiple spatial scales and to investigate species accumulation with increasing area. According to Stohlgren, Falkner, & Schell (1995) based on linear regressions of the subplot data, the Whittaker plot method on average underestimated

plant species richness by 34% when used to estimate the total number of plant species in a 1 000 m^2 plot.

1.3.2 Distance sampling software method

The term ‘‘distance sampling (DS)’’ refers to an assemblage of methods that estimate the absolute density of biological populations, based on accurate distance measurements of all objects close to a line or point being used (Barraclough, 2000). The survey methodologies covered by distance sampling include line transects, point transects, cue counts and trapping webs. However, the main methods of distance sampling are line transects and point transects (also called variable circular plots). From these methods, the density or abundance of objects can be estimated (Thomas *et al*., 2010). The researcher performs a survey along a series of lines or points, looking for objects of interest. For each object he finds, he records the measured distance from the line or point to the object, with the fundamental assumption being that all objects on the line or point are detected (Thomas *et al*., 2010). Barraclough (2000) explains that the advantages of distance sampling include estimating the density for a population, although not every individual is detected per unit area. The same estimation of density for a population can be calculated from data collected by two different observers, even if one of them misses many objects away from the line or point.

Buckland, Anderson, Burnham, & Laake (1993) explained that density estimation can be computed if accurate distances are recorded. It is important that random line or point transects are placed throughout the study area (Buckland *et al*., 1993). The distance sampling software can analyse data from as little as 40 observations and provide reliable analysis (Buckland *et al*., 1993). Possibly one of the most significant disadvantages to this method is the minimum number of observations (40-80) which are important for fitting the detection function.

1.4 COST EFFICIENCY AND EFFECTIVENESS

Cost efficiency and effectiveness should be considered when choosing an appropriate monitoring method to ensure that it is successfully implemented and sustainable. Effectiveness is considered as being output orientated, and a measure of productivity about resources invested in terms of long-term profitability, while efficiency is concerned

with the performance of a given method at the minimum cost of the undertaking (Gaidet-Drapier, Fritz, Bourgarel, & Pierre-Cyril, 2006). Cost efficiency allows proper planning regarding people and time allocation within the budget.

1.5 PROBLEM STATEMENT

Stohlgren, Bull, & Otsuki (1998) explained that scientists should re-evaluate rangeland sampling methods based on three reasons. The first reason is that ecological paradigms have changed, and most vegetation sampling methods have focused on describing perceived homogenous communities (Mueller-Dombois & Ellenberg, 1974). In plant communities, correctly placed sampling transects can reduce potential variance in woody vegetation biomass, foliar cover and species richness measurements due to spatial autocorrelation effects (Fortin, Drapeau, & Legendre, 1989). The second reason is that the objectives of rangeland conservation have also changed, and conservation priorities are now maintaining native plant diversity, detecting exotic species, and monitoring rare species (Randall, 1996). Lastly, the National Research Council (1994) explained that the increase in rangeland inventory and monitoring needs with limited funds to survey rangelands has become important. According to Stohlgren *et al*. (1998), sampling techniques applied in the future must be cost-efficient and information-rich, compared to those used in the past.

According to Brown (1986), science depends largely on the development of new instruments and methods for doing and making things. Different strategies for monitoring vegetation change on reserves and game ranches in South Africa tend to be based on point-survey methods, also known as plot-less methods (Brown, 1986). In these methods, plants are not sampled in a demarcated plot instead sampling points, one-dimensional transect lines, or certain distances within the stand are used (Knapp, 1984) to determine veld condition and frequency of species. These methods (the step-point technique in particular), are efficient in terms of time taken and ease of statistical analyses compared to area-based sampling. In this study the time taken to do distance sampling will be compared to the time taken to do the Whittaker method.

According to Thomas *et al*. (2002) distance sampling is a widely used group of closely related methods for estimating the density and/or abundance of biological populations.

Phama (2012) stated that distance sampling methods have been favoured by some vegetation ecologists and have been applied successfully in a diverse array of taxa including studies on large ungulates (Kruger, Reilly, & Whyte, 2008), small mammals (Stenkewitz, Herrmann, & Kamler, 2010), fish (Ensign, Angermeier, & Dolloff, 1995) birds (Thompson, 2002), tortoises (Swann, Averill-Murray, & Schwalbe, 2002), and butterflies (Brown & Boyce, 1998). A limited number of studies could be found where distance sampling software was applied to vegetation (Beasom & Haucke, 1975; Phama, 2012). This study was initiated due to the limited number of vegetation studies done using distance sampling techniques.

Long-term monitoring is important for conservation since it provides information on management interventions (Singh & Milner-Gulland, 2011). As many protected areas function with limited funds and resources, ecological monitoring is often constrained (Kinahan & Bunnefeld, 2012). Due to the financial limitations encountered by many conservation areas today, identifying cost efficient monitoring protocols has become increasingly important to ensure the long-term sustainability of conservation. A range of factors, such as widespread practice or accuracy often drive the selection of monitoring protocols, but cost efficiency is rarely considered (Kinahan & Bunnefeld, 2012). This makes the cost efficiency of vegetation monitoring techniques particularly important. Investigating the cost efficiency of vegetation survey methodologies can result in significant cost-savings for managers of protected areas.

1.6 AIMS AND OBJECTIVES

The aims of the study are to use the Whittaker method as a baseline to determine the overall accuracy and precision of the Distance Sampling Software (DSS) application in a woody vegetation habitat and comparing DSS to Whittaker results for overall accuracy and efficiency.

The objectives of the study are:

- To compare the density of woody vegetation from DSS to the Whittaker method.
- To quantify and compare woody species composition, species richness and diversity using the Whittaker method as a baseline to DSS for woody vegetation recorded in the study area.

- To determine and compare the accuracy, precision and power to detect change in woody vegetation habitats of DSS to the results from the Whittaker method.
- To ascertain which of the two sampling techniques is most efficient and effective in terms of time and cost.

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CHAPTER 2

STUDY AREA

2.1 GEOGRAPHICAL LOCATION AND SIZE

The Loskop Dam Nature Reserve (LDNR) is located in the Mpumalanga province of South Africa. The reserve covers an area of ~23 612 ha and lies around the Loskop Dam which is ~2 350 ha big (Emery, Lötter, & Williamson, 2002). LDNR is situated 55 km North of Middelburg in the Olifants River valley, at latitude 25°24' to 25°33 South and longitude 29°15' to 29°40 East (Figure 2.1).

Loskop dam supplies water to a vast irrigation scheme in the areas of Loskop, Groblersdal and Marble Hall. The construction of the Dam was initiated in 1938 and the rising of the dam wall was completed in the 1970's. The LDNR's elevation varies from 1 450 to 1 990 m.a.s.l. Four perennial streams pass through the reserve (Fontein Zonder End, Scheepersloop, Kerkplaasloop and Krantzspruit) as well as the Olifants River (Filmalter, 2010).

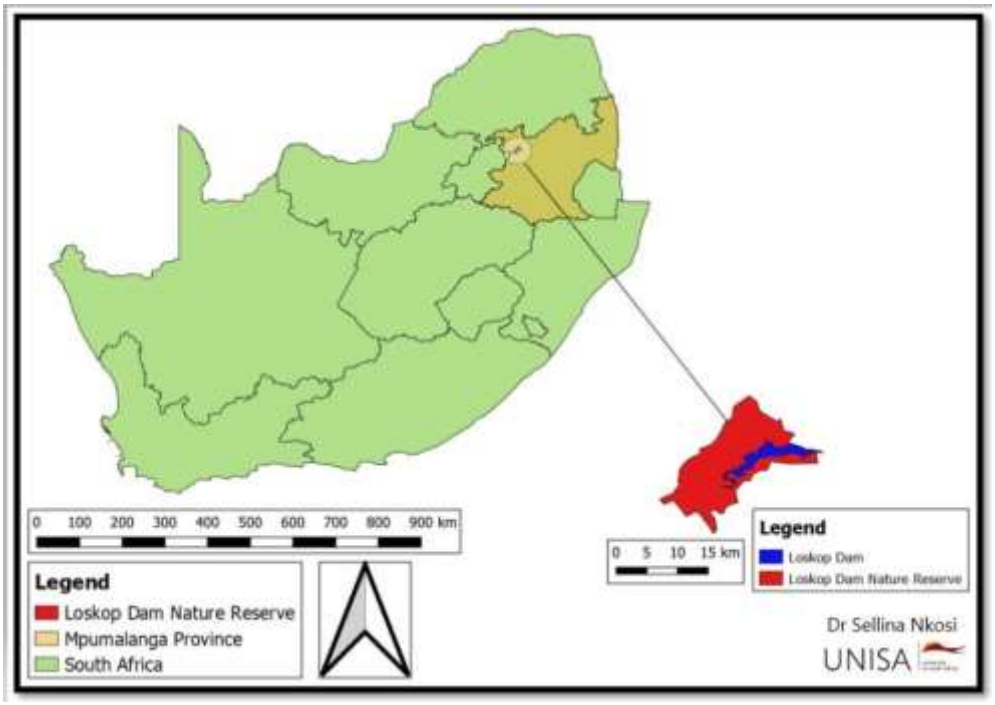

Figure 2.1: Location of Loskop Dam Nature Reserve (LDNR) in South Africa.

2.2 TOPOGRAPHY AND GEOLOGY

The topography ranges from incised plateaus on the higher-lying areas, through steep cliffs and a variety of slope types, to deep valleys and relatively flat valley bottoms. Filmalter (2010) explains that the nature reserve is edged by the Waterberg Plato on the southern and south-eastern sides, forming a continuous band of steep cliffs that constitute a clear border towards the north of the reserve (Figure 2.2). According to Theron (1973), seasonal streams and their associated hygrophytic tree- and shrub communities are found in the narrow ravines situated between the adjoining mountains.

The largest part of the LDNR consists of broken terrain with an extensive network of drainage lines. The geology of the largest part of the reserve is made of the Waterberg System, Loskop System and Rooiberg felsite. Local intrusions of dolerite and granite porphyry are also present, while the valley floor is overlain by alluvium and surface drift (Eksteen & Borman, 1990).

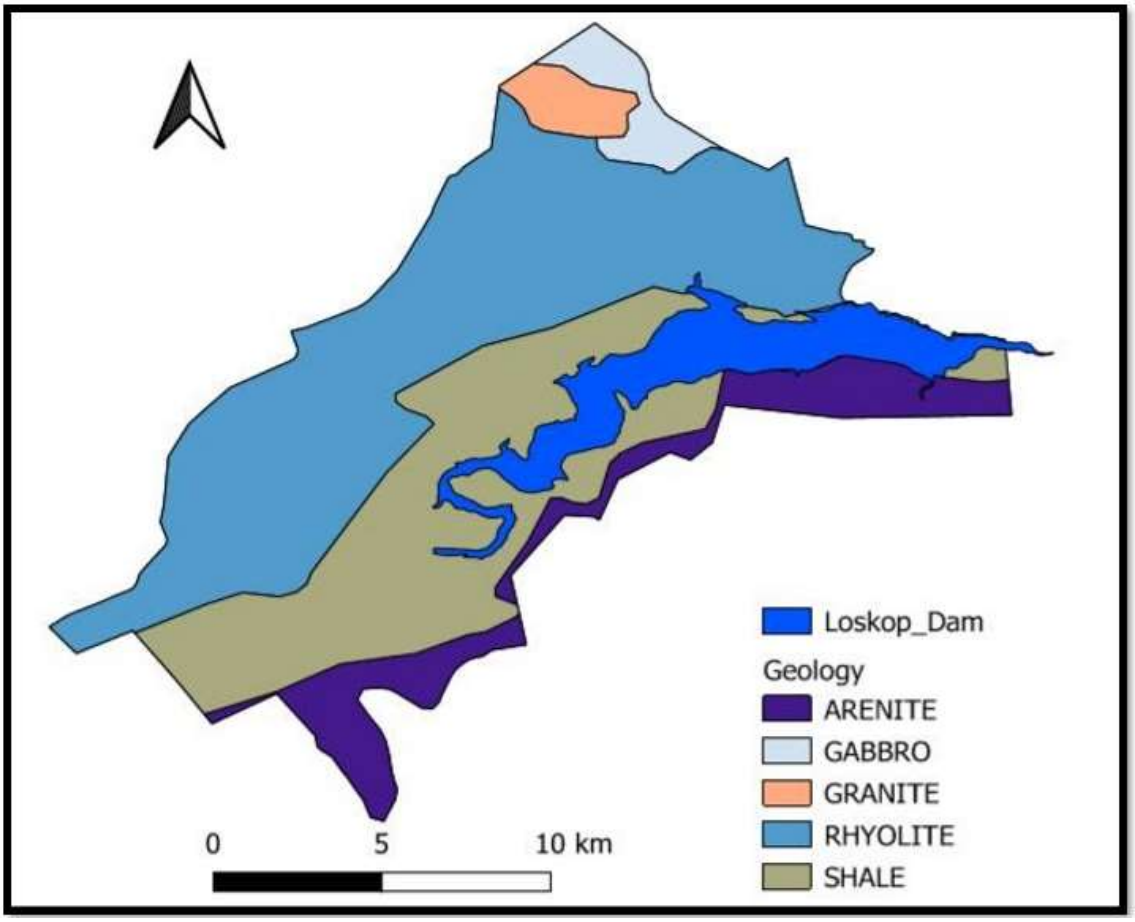

Figure 2.2: Geology map of Loskop Dam Nature Reserve (Nkosi, 2021).

2.2.1 The Rooiberg Group

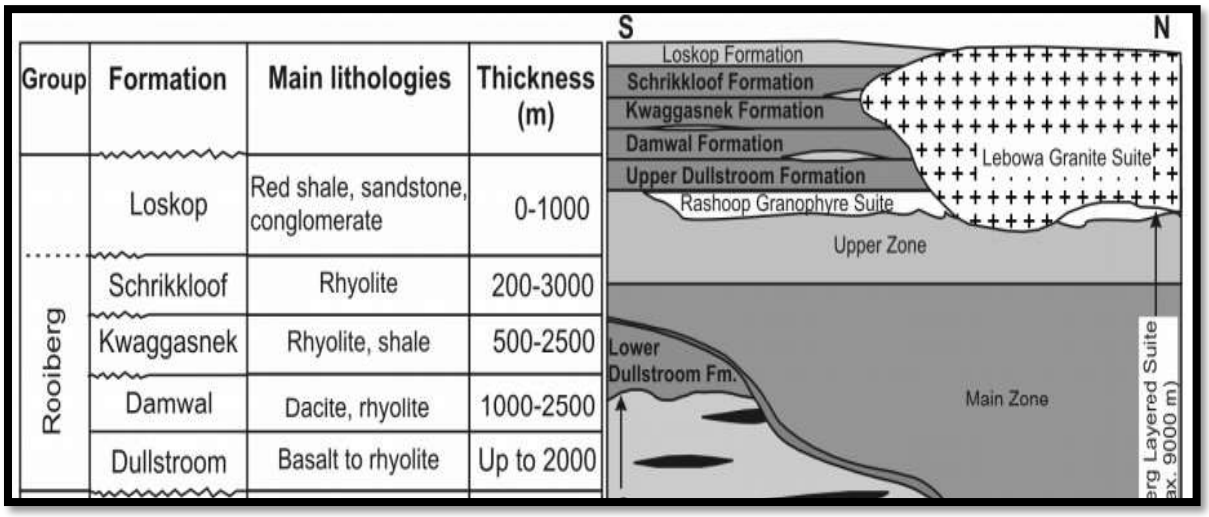

Figure 2.3: Schematic presentation of geology in the north-south section of the LDNR – Adopted from Lenhardt & Eriksson (2012).

The Rooiberg Group is formed by acid lavas interspersed with intermediate andesitic types that are locally developed (Coertze, Jansen, & Walraven, 1977). The Rooiberg Group consists of basaltic to rhyolitic lava erupted from fissural volcanism with estimated eruption temperatures of the rhyolitic lavas exceeding 1000°C (Lenhardt & Eriksson, 2012). The Rooiberg Group also consists of four formations, the Dullstroom, Damwal, Kwaggasnek and Schrikkloof formations (Figure 2.3). The south-east area of the Rooiberg Group is graded into 1 100 m of red shale intercalated with conglomerate covered by mainly impure recrystallised sandstone of the overlying Loskop Formation; while the northern area of the Rooiberg Group is overlaid by quartzite and sandstone reefs that are characterised by the presence of *Diplorhynchus condylocarpon* (Lenhardt & Eriksson, 2012).

The Rooiberg Group is among the oldest and largest provinces of silicic volcanic rocks known in the Mpumalanga Province and its lithostratigraphic section is dominated by thick lava flows that are intercalated with minor volcaniclastic and siliciclastic layers C (Lenhardt & Eriksson, 2012). Twist (1985) differentiates nine units of lava flows within the sequence, based on colour, texture, phenocryst content, internal structure, and relationship to the intercalated sedimentary units (Table 2.1). Schweitzer, Hatton, & De Waal (1995) assigns the nine lava units of Twist (1985) to the four formations of the Rooiberg Group: (1) the Dullstroom Formation (upper stage) which is correlated with lava units 1-2 of Twist (1985); (2) Damwal Formation, correlated with lava units 3-6; (3)

Kwaggasnek Formation with lava units 7-8; and (4) Schrikkloof Formation, correlated with lava unit 9 (Figure 2.4).

Table 2.1: Description of the nine lava units of the Rooiberg Group in the Loskop Dam region.

Formation	Unit	Description	Rock type
Schrikkloof	9	Sparsely porphyritic to non-porphyritic pinkish-red felsites. Generally, flow-banded, feldspars invariably sericitized.	Low-Mg felsite
Kwaggasnek	8	Very sparsely porphyritic and very flaggy pinkish-red felsite. Commonly flow-banded.	_
	7	Red porphyritic and non-porphyritic lavas.	Low-Mg felsite
Damwal	6	Generally massive porphyritic red felsite with local flow-banding and amygdaloidal layers. Sometimes light greyish to greenish.	_
	5	Brick-red to purple slightly porphyritic felsite. Very flaggy and commonly flow-banded	_
	4	Typically, amygdaloidal and lithophysal dark brown felsites, sometimes with coarse, prominent flow-banding.	Low-Mg felsite
	3	Dense, dark brown, grey and black porphyritic felsites, often glassy with a strong conchoidal fracture. Strongly spherulitic towards the top. Often amygdaloidal.	High Fe-Ti-P andesite
Dullstroom	2	Massive, crystalline microporphyritic black, dark brown and dark green felsites. Sometimes amygdaloidal and flow-banded. Augute phenocrysts are abundant.	High Fe-Ti-P andesite Low-Mg felsite High-Mg felsite High-Ti basalt Basal rhyolite
	1	Massive, dark-red and grey porphyritic felsites, rarely amygdaloidal or flow-banded. Widely spaced spherulites. Typically, hornblende (and chlorite)-bearing, becoming more pervasively	Low-Ti basaltic andesite

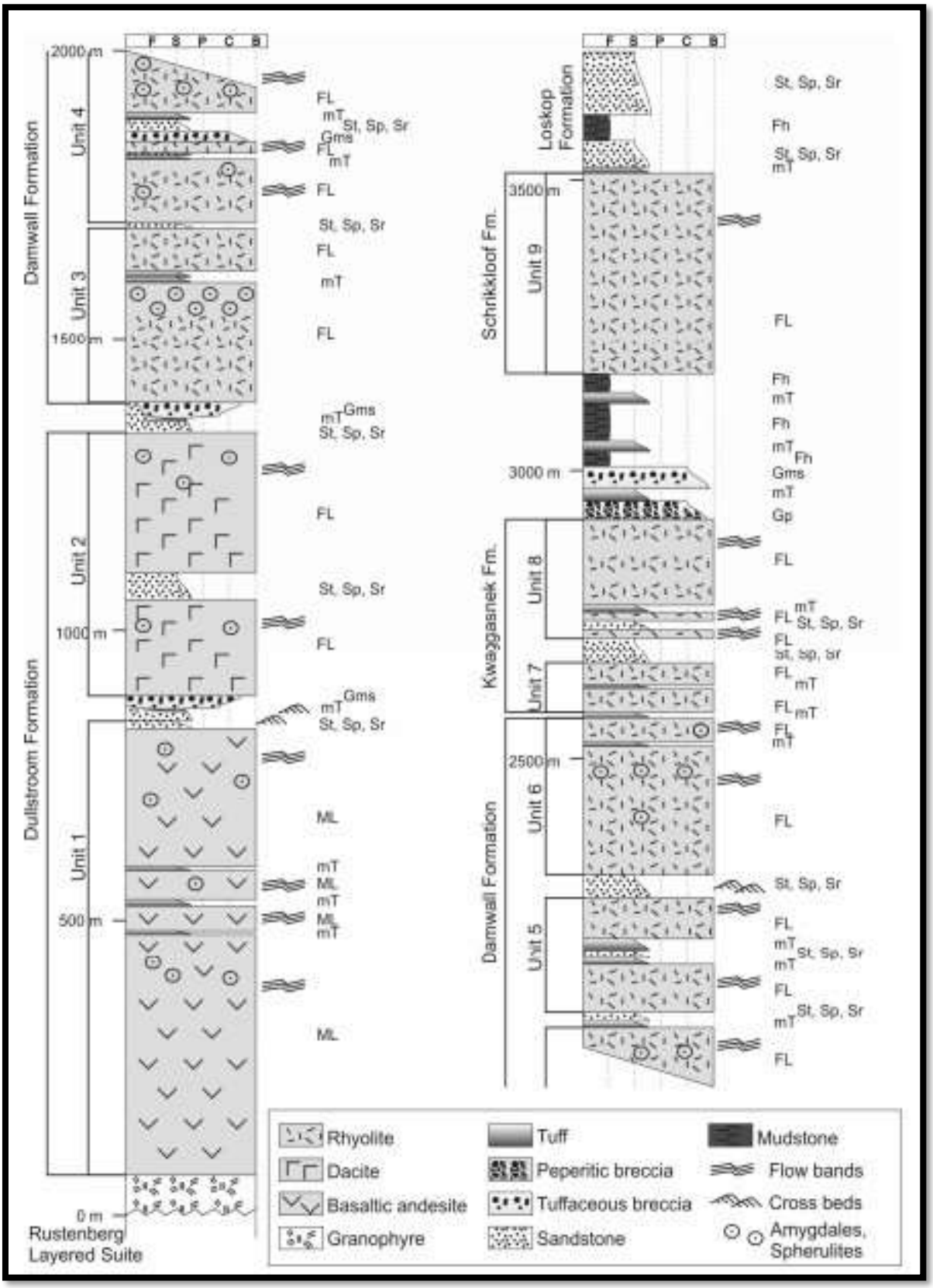

Figure 2.4: Regional stratigraphy of the Rooiberg Group as deduced from lithological and geochemical characteristics – Adopted from Schweitzer et al. (1995).

2.2.2 Granophyre intrusions

Granophyre is a subvolcanic rock that contains quartz and alkali feldspar. The overlying felsite is subjected to temperatures above 1 100°C, significantly higher than their melting temperature; under such conditions, a 1 000 m thick sequence of acid rocks melts during crystallisation of the layered mafic rocks, giving rise to the thick, silt-like occurrence of granophyre, which is frequently found between leptite and felsites (Twist & French, 1983). The thickness and lateral extent of the Rooiberg Felsite suggests that there was an unusually large amount of granitic magma eruption (Twist & French, 1983).

2.2.3 Loskop Formation

The Loskop Formation consists of soft, feldspatic sandstone interlaid with shale and conglomerates. The sediments of this system are mainly found on valley bottoms and weather to form a sandy to sandy-loam, shallow soil (Filmalter, 2010). According to Twist & French (1983), on the north limb of this syncline, the felsites and the conformably overlying Loskop Formation sediments dip southwards at 55-70^{o} (Twist & French, 1983).

Coertze *et al*. (1977) explained that the Loskop Formation shows a different variety of sedimentary rocks than the Wilgerivier Formation. It also contains interbedded lavas and pyroclasts in the lower portion (Figure 2.5). The sedimentary rocks include shale, siltstone, sandstone, quartzite, feldspathic sandstone, conglomerate and breccia. Conglomerate bands with pebbles of quartzite and acid lava occur at various horizons (Coertze *et al*., 1977).

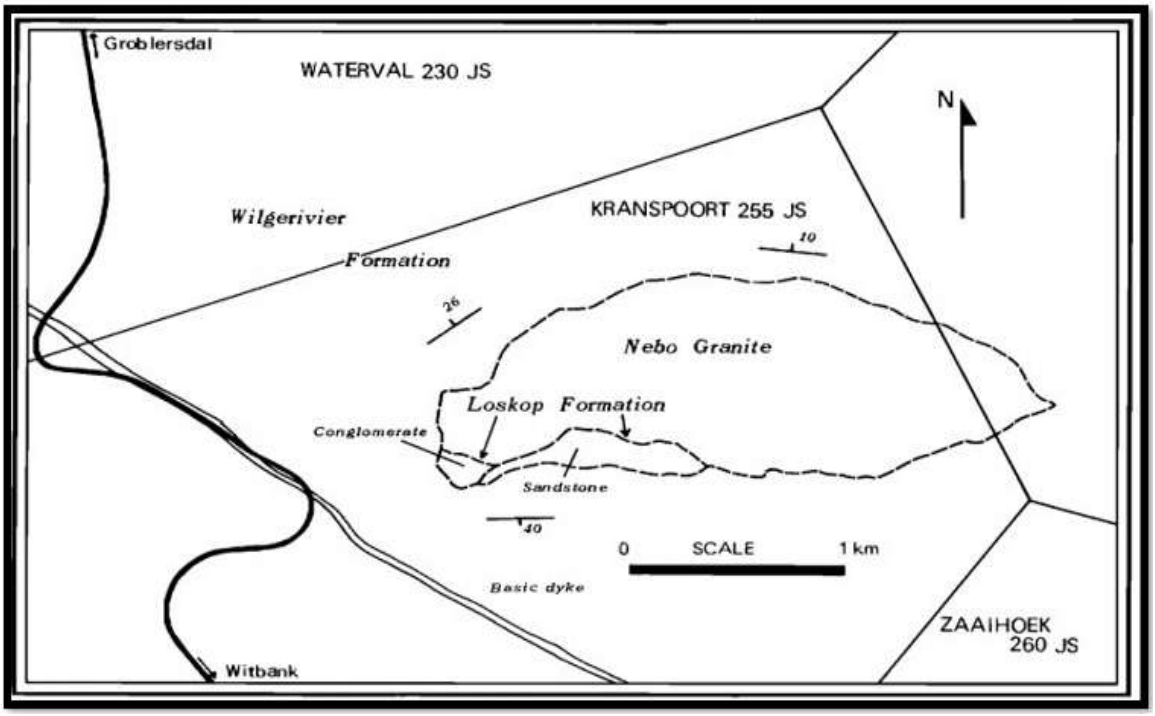

Figure 2.5: Loskop Formation and Wilgerivier Formation - Adopted from Coertze et al. (1977).

The Loskop Formation is represented by grey to red feldspathic sandstone and conglomerate with a large number of pyroclastic fragments. The conglomerate dips towards the west, contrasting with the prevailing attitude of the Wilgerivier Formation, which dips to the south. The sandstone occurs at the east of the conglomerate and overlies the granite with an intrusive contact (Coertze *et al*., 1977).

2.2.4 Waterberg Group

The present structure of Rooiberg Felsite has been determined largely by the intense but localized deformation that accompanied the emplacement of the Bushveld Complex, and the gentler tectonic movements which characterized the Waterberg and post Waterberg periods (Twist & French, 1983).

According to Coertze *et al*., (1977), the sedimentation of the Waterberg Group commenced with relatively small protobasins, called the Nylstroom and Ootse protobasins. In the Ootse basin, the Waterberg sedimentation immediately followed on Transvaal sedimentation and the initial stage of the evolution of the Waterberg basins is described by the Nylstroom protobasin, where the lower portion of the Swaershoek

Formation is laid down. They further explain that at the time of the deposition of the upper portion of the Swaershoek Formation, the Nylstroom protobasin developed gradually into the Alma. In the Cullinan-Middelburg basin, the Waterberg Group is described by the Wilgerivier Formation, which is related to the upper portion of the Swaershoek Formation (Coertze *et al*., 1977). According to Filmalter (2010), the Waterberg Group is comprised of rough-reddish to purple sandstone and patches of quartzite. Conglomerate is encountered in the eastern and south-eastern parts of the reserve, while shale often occurs interlaid with the other layers.

2.2.5 Dolerite

The composition of the different rocks, which are the parent materials for the mineral rich soils used as licks by various animals at Loskop Dam are situated at the base of a dolerite intrusion. Minerals in dolerite consist of sodium, calcium, and magnesium which represent the elements that occur in the licks in higher amounts than in the surrounding soils (Eksteen & Borman, 1990).

2.3 SOIL

According to Eksteen (2003), the topography and weathering of the different geological substrate types result in a complex system of soil patterns with a large variety of soil types that vary over short distances. The underlying Sandstone and Rhyolite rock types have given rise to acid soils. The types of soils vary from a sloping mass of loose rocks at the base of a cliff to soils just below the ridges, and very shallow soils on the steeper slopes and ridges to deeper soils close to the valley bottoms.

Areas of plateau are characterised by relatively shallow, sandy to sandy-loam soils with an acidic pH that varies between 3.5 and 4.5, whilst foothills and valley floors have deeper soils classified as sandy-loam to sandy-clay soils with pH that ranges from 4.5 to 5.5. Soils determine the types of vegetation that will grow in an area. Eksteen (2003) explains that the terrain varies from incised plateaus on the higher- lying areas of the reserve through steep cliffs and a variety of slope types, to deep valleys and relatively flat valley bottoms.

2.4 VEGETATION

The LDNR is situated between the Grassland and Savanna biomes, with the Grassland biome predominantly represented on the higher lying areas and the Savanna biome on the lower-lying areas of the reserve (Eksteen, 2003). According to Emery *et al*. (2002) ~1 115 plant taxa are listed for the reserve, including common woody species such as: *Combretum apiculatum, Burkea africana, Faurea saligna, Englerophytum magalismontanum* and *Vachellia caffra.*

Mucina & Rutherford (2006) classified the Loskop vegetation as Central Sandy Bushveld (SVcb 12), Thornveld (SVcb 14) and Loskop Mountain Bushveld (SVcb 13). Central Sandy Bushveld (SVcb 12) represents 36% of the vegetation in the reserve and is classified as vulnerable. Thornveld (SVcb 14) represents 19% and is also classified as vulnerable. Loskop Mountain Bushveld (SVcb 13) represents 24% of the vegetation and is classified as least threatened and the remaining 21% is covered by water (Dam) (Figure 2.6). Nationally the Central Sandy Bushveld (SVcb 12), and Thornveld (SVcb 14) are both poorly protected, while Loskop Mountain Bushveld (SVcb 13) is moderately protected (Mucina & Rutherford, 2006).

According to Eksteen (2003) the Loskop Thornveld (SVcb 14) and Loskop Mountain Bushveld (SVcb 13), which covers the largest portions of LDNR, are heterogeneous and characterised by a wide range of vegetation variations and transitions. All this is due to the heterogeneous topography and associated environmental factors that include aspect, soil depth and altitude. Eksteen (2003) furthermore adds that in these vegetation types, different plant communities can be identified. Theron (1973) identified twenty-four plant communities for LDNR. These are divided into four main plant communities that comprise of 13 tree-savanna, four tree/shrub savanna, three tree/shrub thickets, and two hygrophilous communities.

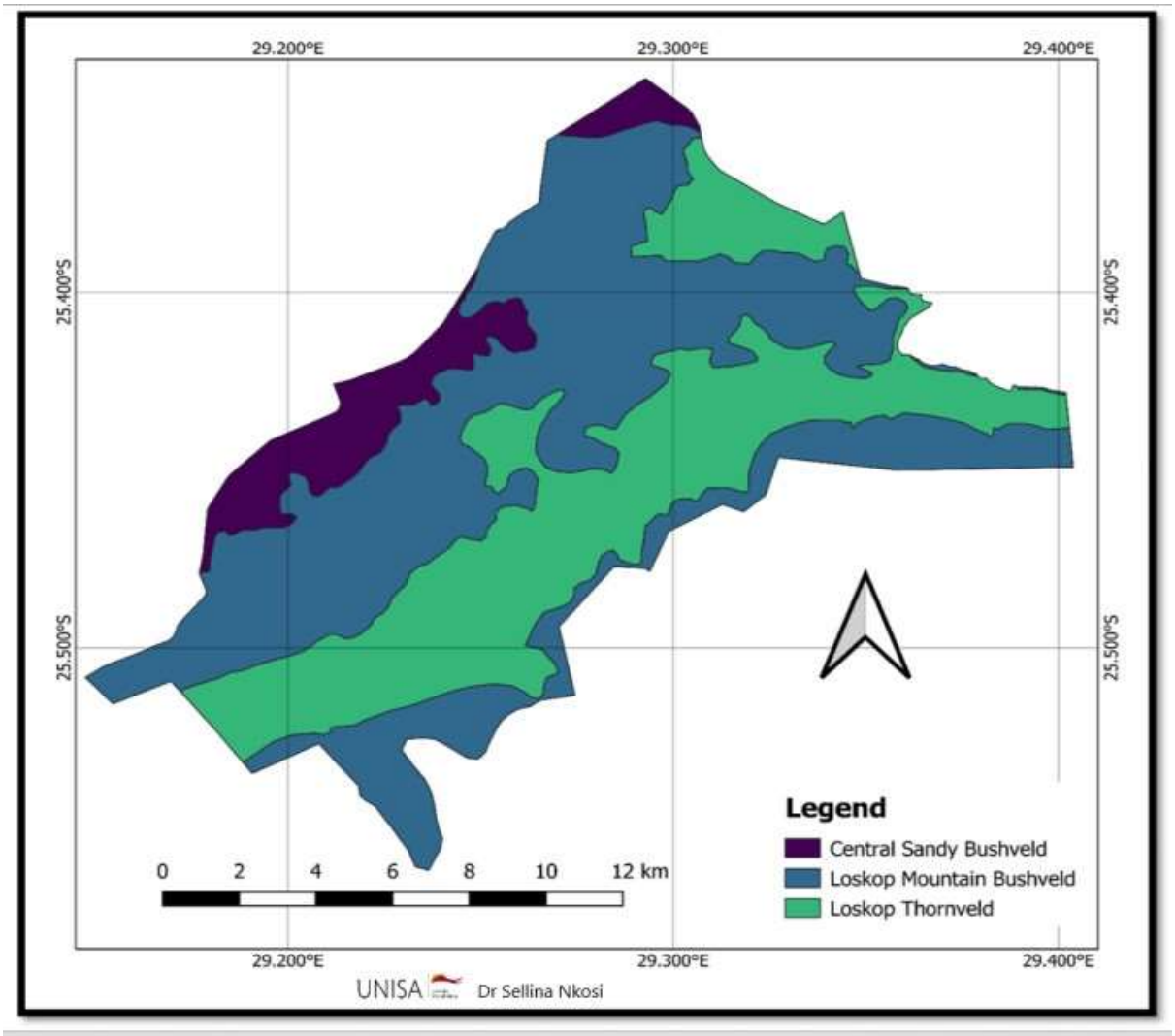

Figure 2.6: Vegetation map of LDNR.

2.5 FAUNA

A variety of animal species are protected on LDNR. These include mammals, birds, amphibians, fish, reptiles, insects and related species. In fact, 367 bird species, 42 reptile, 19 amphibian and 42 fish species (Eksteen, 2003). About 70 species of mammals occur on the reserve including three of the Big five: Buffalo (*Syncerus caffer*), White rhino (*Ceratotherium simum*), and Leopard (*Panthera pardus*). Other fascinating species include Oribi (*Ourebia ourebia*), Sable antelope (*Hippotragus niger*), African wild cat (*Felis silverstris* subsp. *lybica*), Aardvark (*Orycteropus afer*), African civet (*Civettictis civetta*), Aardwolf (*Proteles cristata*), Brown Hyena (*Hyaena brunnea*) and Serval (*Leptailurus serval*). A considerable number of bird species occur on the reserve including the Cape vulture (*Gyps coprotheres*), martial eagle (*Polemaetus bellicosus*), Stanley's bustard (*Neotis denhami*), Caspian tern (*Hydropogne caspia*), African finfoot (*Podica*

senegalensis). Bald ibis (*Geronticus eremita*), Red-billed oxpecker (*Buphagus erythrorhynchus*) and the Blue crane (*Anthropoides paradiseus*).

2.6 CLIMATE

South Africa's climate is mostly semi-arid except along the subtropical east coast. Days are sunny and nights are cool. South Africa has been classified into several climatic zones using primarily rainfall data and supplemented by other climate factors including temperature and humidity (Kruger, Goliger, Retief, & Sekele, 2010).

Kruger (2004) divided South Africa into 24 climatic regions, nine Savanna-type climatic regions, six Grassland-type climatic regions, five Karoo type climatic regions, two Fynbos-type climatic regions, one Forest-type climatic region, and one Desert-type climatic region. The distribution of vegetation within the LDNR is primarily influenced by climate. Bond, Midgley, & Woodward (2003) add that climatic factors such as temperature and moisture are the main factors that control the distribution of vegetation.

Loskop Dam Nature Reserve is situated in the summer rainfall region of South African and is characterised by warm to very hot summers with moderate winters. The wet season in the reserve is during the summer months from November to April. Annual mean long-term rainfall for the reserve is 650 mm that mainly occurs in the form of showers and high-intensity thunderstorms recorded from October to March (Eksteen, 2003). The lower-lying areas are generally frost-free, except for the valley bottoms where temperatures sporadically drop to below 3°C resulting in frost. However, on the higher-lying areas, the frost period extends from May to September with some days of severe frost (Eksteen, 2003).

2.6.1 Rainfall

According to Bredenkamp & Brown (2003) rainfall is the main determining factor in savanna dynamics with the moister savanna moving towards the equilibrium side of the gradient, while arid savanna moves towards the arid State and Transition side. The monthly average rainfall figures for the period 2017 to 2018 are given in Figure 2.8. The average rainfall for the study area during this period was 629.45 mm p.a., with a high of

155.15 mm in December and a low of 0 mm during the month of July, August and September. Figure 2.7 shows that the wet season was from October to April.

2.6.2 Temperature

The significant topographical variation on the reserve has resulted in the variation of climate and temperature across the reserve. A noticeable difference in temperature can be observed between higher and lower lying areas. Eksteen (2003) explains that temperatures on north-facing slopes are above 20°C for longer periods and below 10°C for shorter periods compared to south-facing slopes.

The mean monthly temperatures with their maximum and minimum values for the study period (2017-2018) were recorded by staff from the LDNR Admin Offices and are given in Figure 2.7 below. The maximum and minimum temperatures vary significantly during the wet and dry seasons. The minimum and maximum temperatures observed during the period were 7.1ºC in June and 32.9ºC in January. Average temperatures tend to be high from November to March, which is characterised as the wet summer season and low between June and September which is the dry winter season.

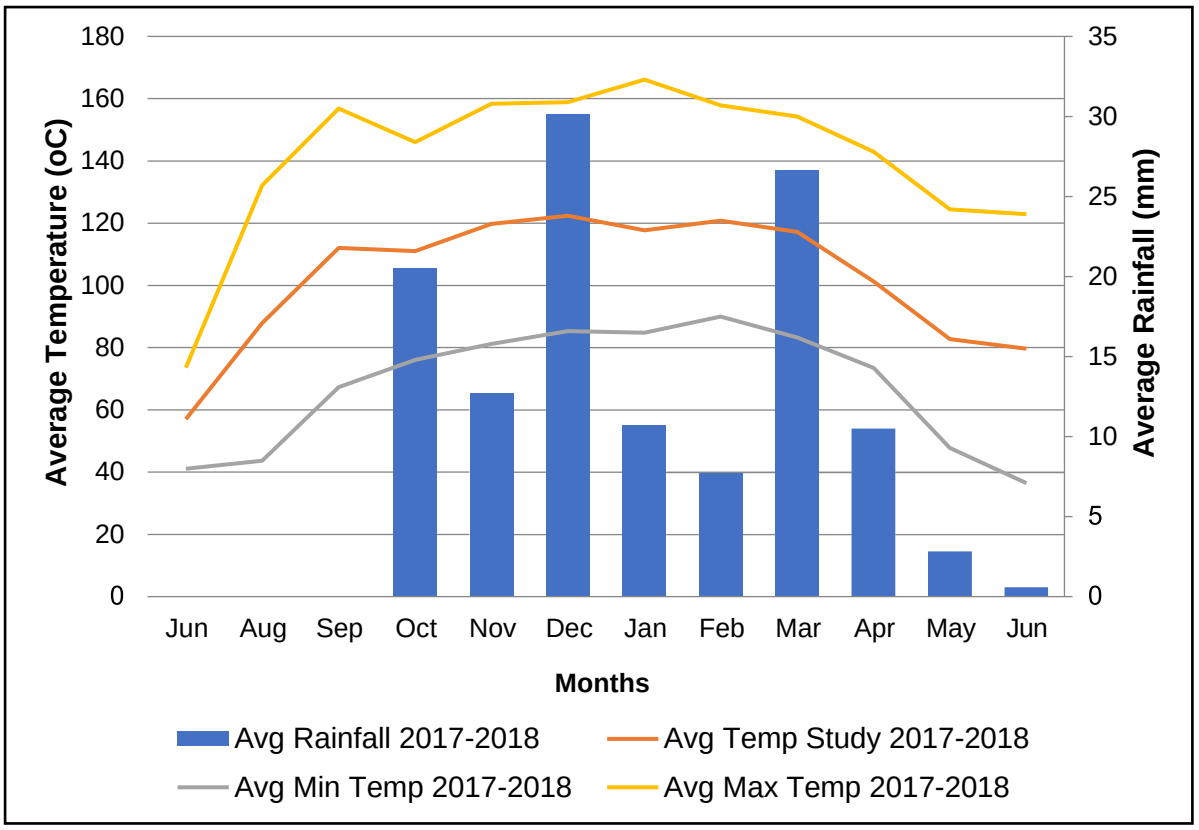

Figure 2.7: Monthly average rainfall, minimum and maximum temperatures for LDNR.

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CHAPTER 3

MATERIALS AND METHODS

3.1 SAMPLING SITE SELECTION AND PLOT SIZE

Four sampling plots were placed in each of two different structural habitats, one characterised by open woody vegetation (which is defined as an area of less woody plant density, with woody plants ≤2 m tall) and the other by closed woody vegetation (which is defined as an area of high woody plant density, with woody plants >2 m tall). The location of the sampling plots was randomly selected using Google Earth and visual observations in the field. The coordinates for each plot recorded on Google Earth, were inserted into a handheld Geographical Position System (GPS) device. After the sampling sites were located on the ground in the study area, using visual observation, two 20 m x 50 m quadrats (as required by the Whittaker method) were demarcated at each site for recording floristic data (tree and shrub) using the Whittaker and DSS methods. We defined a tree as a woody plant that is more than 2m in height with one central stem, and a shrub as a short woody plant that is less than 2m in height having multiple stems.

According to Buckland, Anderson, Burnham, & Laake (1993) estimates of the expected individual plant encounter rates and variability of woody plant species, one can make use of the Whittaker method to determine the amount of survey effort, or the number of points required to obtain a coefficient of variation of abundant woody species estimate. Distance sampling points were randomly placed within the two Whittaker sample plots. It is necessary that the points are randomly placed to effectively record plant species and avoid bias (Barraclough, 2000).

Due to the size of the area, we could only do four (4) replicates for each sampling method (Figure 3.1), giving a total of eight 20 m x 50 m sampling plots surveyed in the study area. Further, due to the sites' distinction and limited available time due to the COVID-19 pandemic, we could not go back to the field for additional surveys, as travelling restrictions were imposed by the government. These restrictions might have

influenced our precision results.

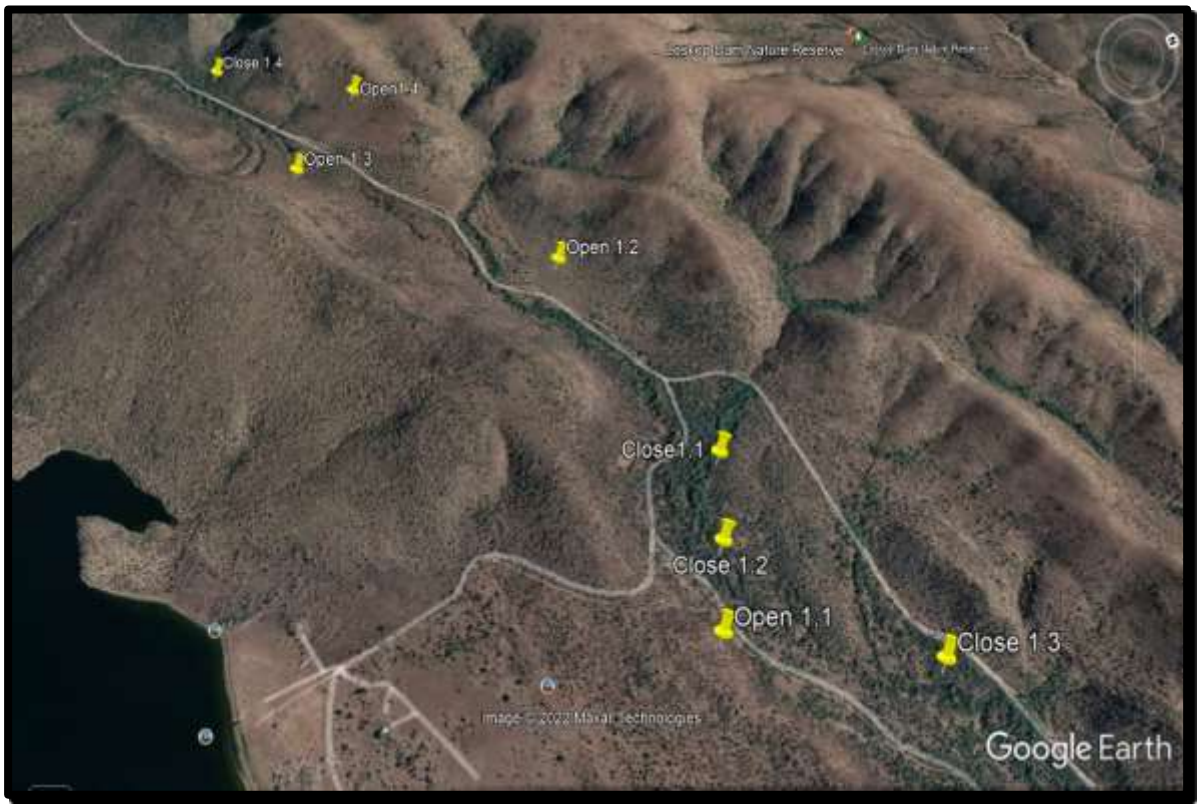

Figure 3.1: Location map of the sampled survey plots in the study area.

3.2 FIELD DATA COLLECTION

3.2.1 Whittaker method

Two researchers collected the field data for this study. One researcher was responsible for data recording on a data collection sheet while the other was doing the plant identification. Data collection was done using a random method. This survey was performed in the closed and open woody vegetation areas, two sample plots were placed in open woody vegetation, and two other plots in closed woody vegetation areas thus four Whittaker plots of 20 m x 50 m (1 000 m^2) were placed in the field. Each sample plot was demarcated using ropes and a measuring tape. Species data sampling involved identifying and counting the numbers of different woody plant species present in 10 contiguous 1 m^2 quadrats, two 10 m^2 (2 m x 5 m) enclosing plots, a 100 m^2 (10 m x 10 m) larger enclosing plot and the 1 000 m^2 (20 m x 50 m) overall enclosing plot (Figure 3.2). The time taken to survey each plot using the Whittaker method was recorded. Woody plants were recorded for two categories (trees and shrubs) per height class (<1 m, 1-2.5 m, >2.5 m) on a data sampling spreadsheet (Appendix A).

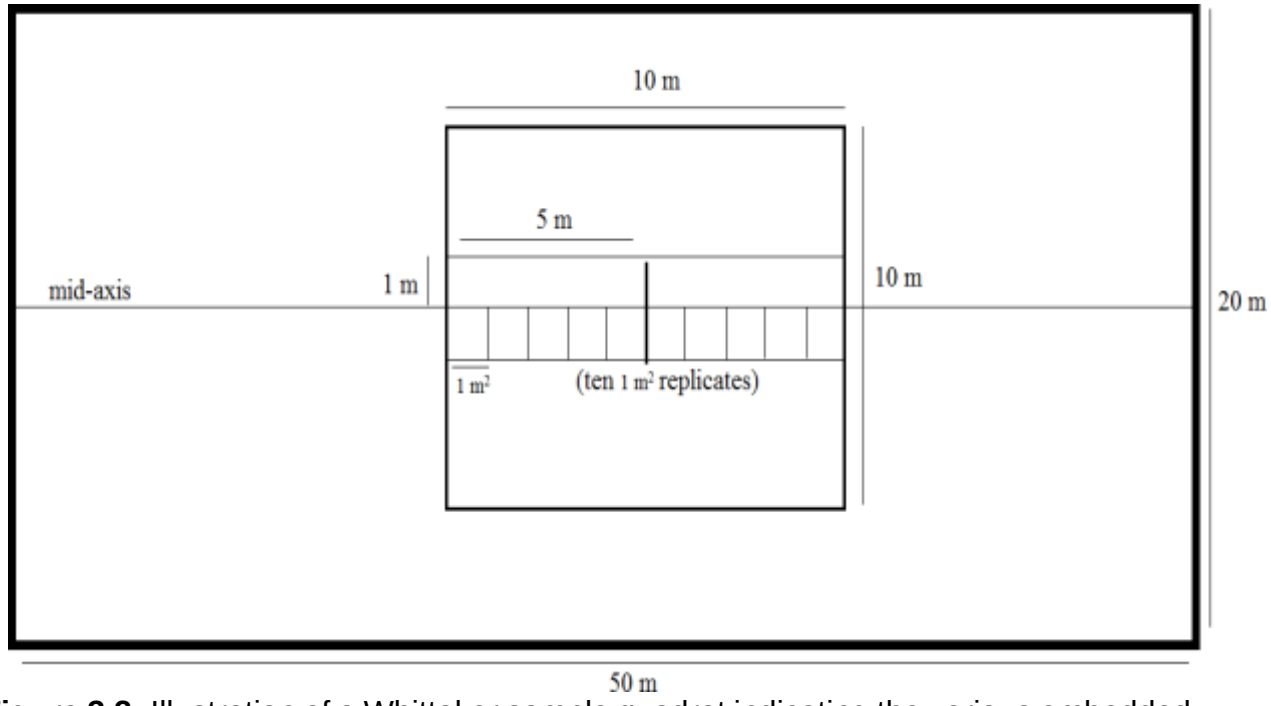

Figure 3.2: Illustration of a Whittaker sample quadrat indicating the various embedded sub-plots.

3.2.2 Distance Sampling (DSS) method

Distance 6.0 V2 is the computer software package, which was developed by Buckland *et al*. (1993) and was again revised by Buckland *et al*. (2004) leading to distance 6.0 V2. The software consists of a Graphical User Interface (GUI) that enables users to enter, import and view data while designing surveys and running analyses (Thomas *et al*., 2010). For this study, the point transects sampling technique, which is a prerequisite for using the Distance software package, was used to collect data.

The Distance 6.0 Release 2 software contains a Project Setup Wizard that is designed to guide users through creating a project and perform analyses. According to Thomas *et al*. (2010), each analysis is based on three components; an initial survey which specifies which data layers to use and the survey methods used; secondly, a data filter which permits subsets of the data to be selected, truncates selected distances and other pre-processing to be done; and lastly a model definition which specifies how the data should be analysed. The first step to analyse distance sampling data is to model the probability of detection. Furthermore, distance contains four increasingly sophisticated analysis algorithms including a Multiple Covariate Distance Sampling (MCDS) algorithm which permits covariates, a Mark Recapture Distance Sampling

(MRDS) algorithm which decreases the assumption of detection at zero distances; a Density Surface Modelling (DSM) algorithm to estimate density and abundance using a detection function, and the Conventional Distance Sampling (CDS) algorithm, which models detection probability as a function of distance from the transect and assumes all objects at zero distance are detected (Thomas *et al*., 2010).

Distance sampling analyses have name-input and results associated with them. It is a progressive procedure that allows users to select options such as the type of survey used (line or point), the number of observers, measurement type (perpendicular or radial distance), observations (clusters or single observations) and the measurement units. All these options are selected in the interface. According to Thomas *et al*. (2010), a distance project has all the data and results of a single study. Moreover, a project is comprised of a project file and an associated data folder; the latter has a data file, geographical shapefiles and a folder which has files generated by analysis algorithm using the statistical software package R.

An important part in the analysis of data is the process where individual algorithms select the model that fits the data. This process involves testing options in the data filter and model-expansion combinations. The data filter manipulates the survey data before analysis and truncates and transforms data that are not grouped into interval data. Model-expansion combinations are important for modelling a detection function and to instruct the program on how the data should be analysed after it has passed through the data filter (Thomas *et al*., 2010).

Finally, according to Buckland *et al*. (1993) the Distance 6.0 Release 2 software program provides a summary of results for each analysis, which includes the following: number of parameters, Akaike Information Criterion (AIC), estimate of density and respective confidence limits, Coefficient of Variation (CV), estimate of population size and respective confidence limits, and the probability of detection point or circular transect technique of distance sampling.

The term point or circular-transect refers to distance sampling that is conducted at a point. Random sampling (random sample with a fixed periodic interval) design was implemented since it is efficient and straightforward. Using this systematic design ensures an overall representative coverage of the area. According to Buckland *et al*.

(1993), the number of points should be at least 20, and preferably substantially more. For this study, within each 20 m x 50 m plot, 50 randomly selected points were identified and the distances between these points and all woody plant species were detected within a 2 m radius of the central point (Figure 3.3). A measuring tape was used to measure distances from the central point to each woody plant species. The names of the woody plant species and their distances to the random point were recorded.

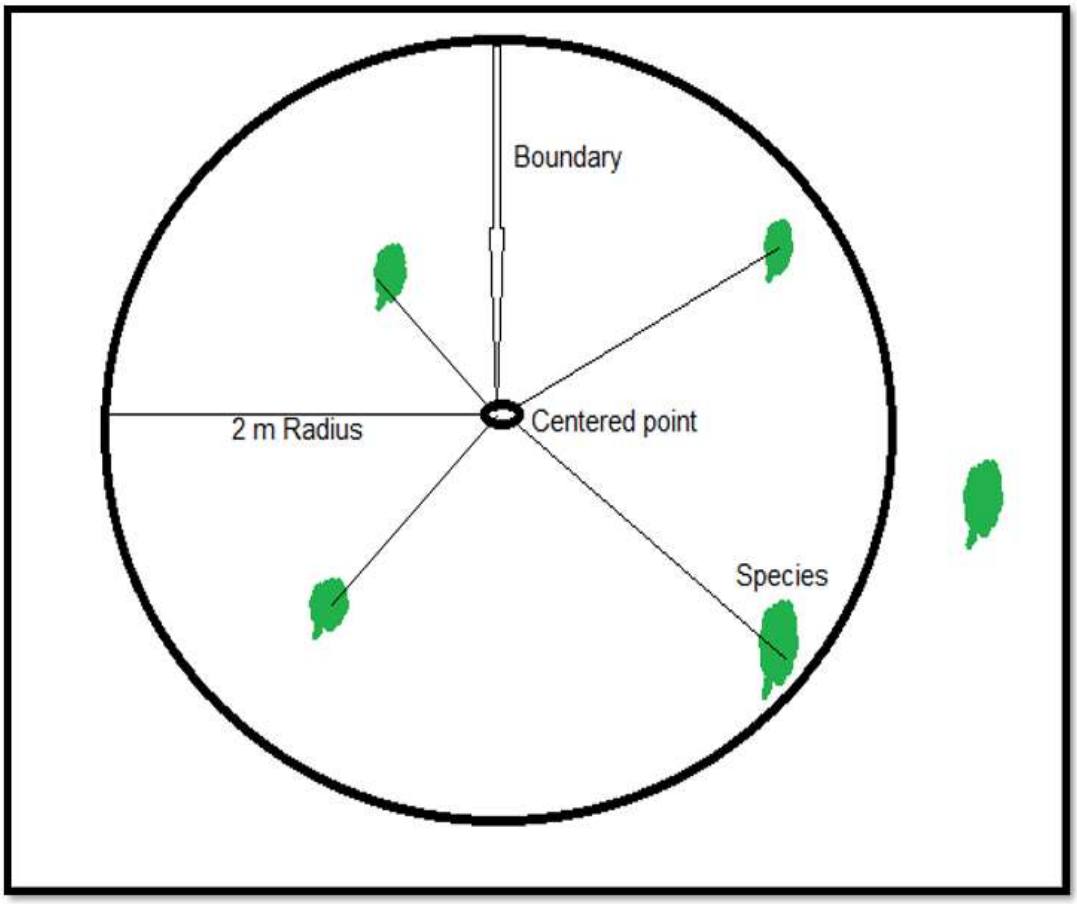

Figure 3.3: Illustration of the distance sampling point transect technique.

According to Buckland *et al*. (1993), using systematically placed sampling points (circles) placed out in a grid format avoids plot overlap. To prevent overlap of the 2 m radius circles in our study, separate equidistant lines were placed perpendicularly to the 50 m tape used for the main plot. Central points for the plots were demarcated along the lines so that the 2 m radius plots did not overlap with one another and were equally spaced from one another along the lines. Adequate spacing between the sampling points reduces the possibilities of double-counting plant species, alleviating biased estimates of density (Phama, 2010). The time to survey each plot using the point transect distance sampling method was also recorded.

3.2.3 Woody vegetation structure

According to Brown (1997), the evaluation of the woody components of a veld type is important to assist in the assessment of the general veld condition. The species composition and the density of woody plants provide valuable information on woody structure that facilitates the management of woody areas (Brown & Bredenkamp, 2004). Data collected at each sample plot about woody plants included the species name and the number of individuals for each species within each of three height classes (<1 m, 1-2.5 m, >2.5 m). The density distribution of woody individuals in the different height classes was also computed.

3.2.4 Plant Identification

Prior to collecting data in the demarcated plots, all sampled plots were scanned, and unknown woody plant specimens were collected, numbered and encoded using vegetative characters for identification. Numbers allocated to previously collected, unidentified specimens were referred to when the species were encountered in subsequent plots to prevent collecting multiple samples of the same plant. Field naming was done using Van Wyk & Van Wyk (1997), and when a plant remained unidentified, a field name was assigned to that plant specimen. All field names, whether scientific or unidentified plants were recorded with a short description of the plant alongside. As fieldwork progressed, fieldworkers were able to refer to the vegetative description and characteristics of the plants when unsure of the identification of plants. Unidentified plant species collected were put into a plant press for later identification with the ecologist on the reserve.

3.2.5 Time and cost efficiency and effectiveness

The time duration taken to do the Whittaker method and DSS surveys were measured independently. Time cost (setting-up plots and observation time) measurements incorporated the time taken to complete the survey using each method. The effective time to carry out woody plant counts during the survey from start to end for each plot was measured. The mean observation period for each method in the two study sites (open and closed woody vegetation areas) was determined. The equipment costs for

each sampling method, which included all necessary expenditures for setting and demarcating the sampling plots, were also considered.

3.3 DATA ANALYSIS

3.3.1 Species composition – Whittaker method and DSS

Woody species composition constituted the list of woody species recorded using each of the two methods. Woody plant species composition was compared between the two sampling methods.

3.3.2 Species richness and diversity – Whittaker method and DSS

The woody species richness as determined by each sampling technique is indicated by the number of woody species encountered in the sample plot. The diversity of woody species per sample plot was determined using the Shannon-Wiener Diversity Index (H') and the Equitability/evenness index (J) (Kent & Coker, 1992). The Shannon-Wiener diversity index is the most widely used measure of species diversity as it combines species richness with species evenness in a plant community or sample plot, also known as relative abundance (Kent & Coker, 1992). The Shannon-Wiener diversity index (H') was calculated using the following equation:

$$H' = -\sum_{n=1}^{S} \mathrm{PiLnPi}$$

Where:

H’ = Shannon-Wiener diversity index, s = the number of species,

Pi = the proportion of individuals of the i^{th} species expressed as a proportion of total cover in the sample,

ln = the natural logarithm.

The Shannon evenness index (J) was also calculated using the following equation:

$$\mathrm{J} = \frac{\mathrm{H}'}{\mathrm{H}'\mathrm{max}} = \frac{\mathrm{H}'}{\ln \mathrm{s}}$$

Where:

J = Shannon equitability or evenness

index, H' = Shannon-Wiener diversity

index,

H' max = the maximum level of diversity possible within a given population, which equals In s,

s = the number of

species, In = the natural

logarithm.

Index values obtained from diversity index calculations were insufficient for further statistical analysis and were converted into effective numbers. The effective number of species is a standard diversity index that gives the idea of stability and also the standard number of species for a particular value (for index) of an ecosystem (Islam, Siddeqa, Hasan, & Islam, 2018). An ANOVA test was used to determine whether there were significant differences between the woody vegetation in terms of effective numbers of species (diversity).

The effective number of species was calculated as per Islam *et al*. (2018) using the following equation:

$$EXP\ (H')$$

EXP = Exponential

3.3.3 Density distribution

Density is the number of plants of a certain species per unit area (Tilahun, Soromessa, & Kelbessa, 2015). Woody density data from both open and closed woody vegetation areas was obtained from four 20 m x 50 m sampling plots in each vegetation area. For each sampling method, woody density was determined for the open and closed woody vegetation areas and compared across the surveyed areas. Further, the overall woody density of the study area was determined and compared for the Whittaker method and DSS. The woody density of plants in the different height classes was also determined and compared for the two sampling methods. The density of woody species was expressed as individuals per hectare ($ind.ha^{-1}$).

The formula used to calculate woody density is:

$$\text{Woody density} = \frac{\text{Total number of woody plants per plot}}{\text{Total size of sample plots } (m^2)} \times 10\,000$$

3.3.4 Accuracy

The accuracy of DSS compared to the Whittaker method was estimated by calculating chi square (x^2) (Sparks, Masters, & Payton, 2015) for species richness, species diversity and species density. Accuracy of DSS within each woody vegetation area was estimated and compared across woody vegetation habitats. Further, data for both woody vegetation areas (open and closed) were combined, giving data for the study area, for which accuracy of DSS was estimated. The chi square (x^2) test results were analysed using ANOVA to determine whether there were significant differences in the accuracy of DSS. All statistical analyses were conducted using Microsoft Excel.

3.3.5 Precision and Power to detect change

Precision was estimated using the Coefficients of variation (CV) for species richness, species diversity and species density (Godinez-Alvarez, Herrick, Mattocks, Toledo, & Van Zee, 2009). Precision of each sampling method within each woody vegetation area was estimated and compared across woody vegetation areas. Further, data for both woody vegetation areas (open and closed) were combined, giving overall data for the study area, for which precision was estimated and compared across sampling methods. Coefficients of variation were analysed with likelihood ratio tests (ANOVA) to determine whether there were significant differences between methods (Verrill & Johnson, 2017).

For this study, precision for each of the survey methods was computed as a percentage by dividing the standard deviation of woody species encountered by their mean ($\bar{x}$) number, giving the Coefficient of Variation (CV).

$$P = \frac{S}{\bar{x}} \times 100$$

Where:

P = precision

S = woody standard deviation

$\bar{x}$ = the mean number of woody plant species encountered in the sample plots.

According to Plumptre (2000), the power to detect change is the likelihood to detect a given percentage change in population size. This is measured using the resolution of a density estimate (R), which is defined as the percentage change that will be detected between two surveys (Plumptre, 2000). Therefore, given a resolution of a density estimate of 0.2 (using the coefficient of variation of the survey estimate), the population would have to increase or decrease by 20% between two surveys for the changes to be detectable. Typically, 80% of power to detect change is used (Plumptre, 2000). To determine 80% power to detect change, the resolution (R) was calculated using:

$$R = 3.96\left(\frac{D1}{D2}\right) = 3.96\left(\frac{\mathrm{CV}}{100}\right)$$

Where:

R = resolution

CV = coefficient of variation between the samples,

SE = standard error,

D1 and D2 = density estimates at time t and t+1

3.96 = constant

3.3.6 Analysis of distance sampling software data

The analysis of distance data for this study was performed using the Distance software program Distance 6.0 Release 2, which provides a range of models that have been proven to perform well in the analysis of distance data (Barraclough, 2000). Before performing any analysis, data was captured and stored in a Microsoft Excel file. Each data file was exported from MS Excel to a Tab delimited Text file and imported into Distance 6.0. The data for each site were analysed as separate Distance 6.0 projects. Distance 6.0 Release 2 Software contains a Density Surface Modelling (DSM) algorithm for estimates density and abundance.

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CHAPTER 4

WOODY PLANT SPECIES DIVERSITY, STRUCTURE, AND PRECISION OF THE WHITTAKER METHOD

4.1 INTRODUCTION

Loss of biodiversity is a major concern, and many researchers (Bascompte & Rodríguez, 2001) have been devoted to understanding the consequences of reduction in niche diversity due to the loss of landscape complexity and ecological integrity, known as ecosystem simplification (Kowalchuk, Buma, Boer, Klinkhamer, & Veen, 2002). According to Maestre (2004), the prevalent role that biodiversity has for the proper functioning of Earth's ecosystems, as well as its intrinsic value was emphasized by Ghilarov (2000) and Loreau *et al*. (2001). Understanding factors that are affecting plant species richness and diversity has become an important issue in ecology and conservation biology (Maestre, 2004).

To determine the patterns of woody species composition and diversity, much emphasis has been placed on the determination of diversity gradients (Ter Steege *et al*., 2003). The diversity of plant life plays a significant role in reinforcement of plant ecosystems (Rahman, Hossain, Hossain, & Haque, 2017). According to Whittaker (1975), species diversity can be observed at three spatial scales, the landscape or cover type level (gamma diversity), the between-stand level (beta diversity), and the within-stand or habitat level (alpha diversity). According to Schoonmaker (2019), some ecologists such as Harger & Tustin (1973) have predicted that diversity will increase through succession, while some such as Brunig (1973) have observed such increases and others such as Pielou (1966) have predicted that diversity might decrease during a successional sequence.

A study conducted by Hossain, Hossain, Alam, & Uddin (2015) in Bangladesh forest reveals that woody species diversity may serve as a preliminary indicator for all plant

forms in an ecosystem type. Moreover, information on floristic composition, plant quantitative structure, and diversity are important to understanding the functioning and dynamics of ecosystems (Reddy, Shilpa, Giriraj, Reddy, & Rao, 2008). Higher numbers of tree species in forest increase the number of associated species such as understory plants and animals (Forest, 2019). Specific information about the flora of an area is important for sustainable end-use and management activities.

According to Gerrodette, Perryman, & Oedekoven (2018), assessing the precision of sampling techniques is important. If plants are to be estimated accurately on average, there is measurement error associated with plant estimates. Variability associated with plant estimates are important for proper assessment of uncertainty. If measurement error is not included, variance of estimates of abundance and other quantities that depend on plant estimates will be too small.

The Whittaker sampling method was one of the methods for evaluation used during this study as it is known to measure plant diversity quickly and easily across a wide range of habitat types (Nath, Pelissier, & Garcia, 2009). An ideal sampling method should provide accurate and representative information about the population studied, while also being geometrically compact and requiring the least amount of field effort (Scott & Gove, 2002). Very often, studies focus on assessing efficiency of monitoring techniques in terms of the precision of sample estimates (Bryant *et al*., 2004).

In this chapter, the results obtained by application of the Whittaker Method on woody species composition, richness and diversity for the open area and the closed area structural habitat, woody density and the height classes are presented and also explored for the entire study area.

4.2 FLORISTIC COMPOSITION AND RICHNESS ACCORDING TO THE WHITTAKER METHOD

Knowledge about the floristic composition and structure of vegetation in nature reserves is useful for identifying important elements of plant diversity so that species that are threatened or of economic importance can be monitored and protected (Ssegawa & Nkuutu, 2006).

4.2.1 Species composition and richness

The species composition and richness found in the study area (both open and closed vegetation areas) with their respective plant family names are listed in Appendix B & C1. The species composition and richness of both open and closed woody vegetation areas are given in Appendix C2. A total of 47 species of woody plants, belonging to 19 plant families and 34 genera were recorded from eight sampling plots (1 000 m^2 each) in the study area of which four were placed in open woody vegetation area and four in closed woody vegetation area. Several woody species were found to have the highest number of individual species in the open and closed woody vegetation areas as well as in the entire study area.

Figure 4.1 shows the most dominant families by proportion in the study area. Anacardiaceae (23.40%), Fabaceae (17.02%), Malvaceae (10.64%) and Burseraceae (6.38%) are the four dominant plant families in the study area, with all other plant families being low in abundance.

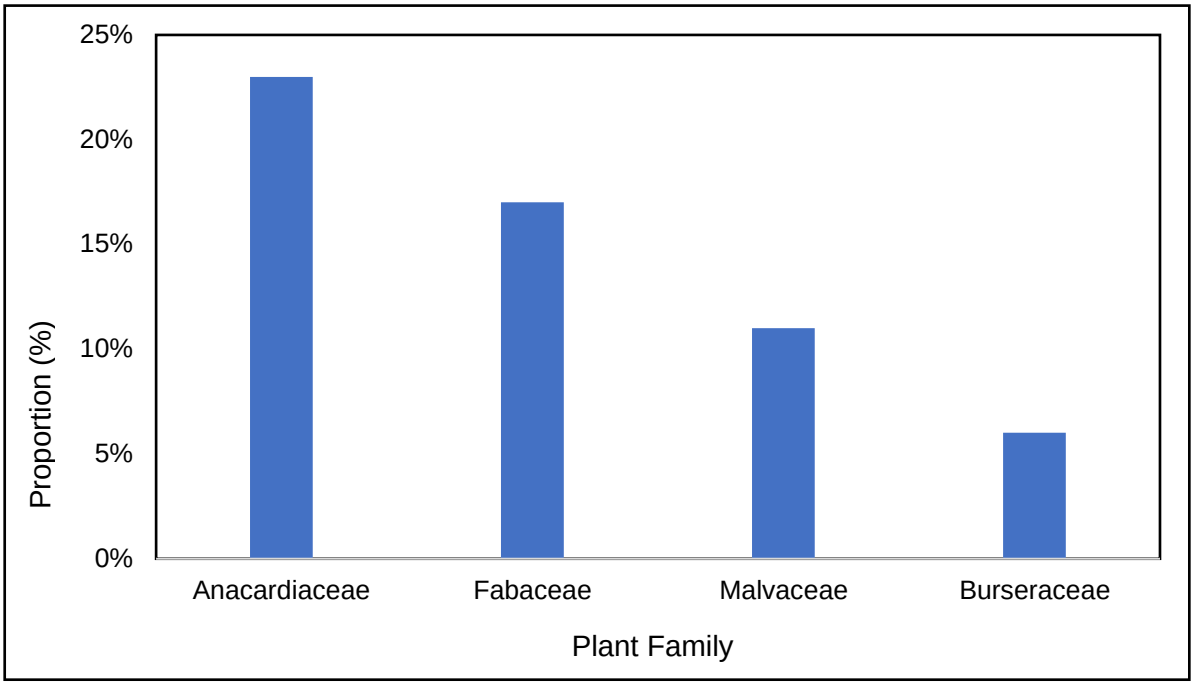

Figure 4.1: Proportional representation of dominant woody plant families in the study site.

Table 4.1 shows the family richness observed in the study area. The families with the highest number of species were Anacardiaceae, represented by 11 species (23.40%)

belonging to nine (9) genera, followed by Fabaceae represented by eight (8) species (17.02%) belonging to five (5) genera. The next dominant family was Malvaceae, comprising five (5) species (10.64%) belonging to three (3) genera, followed by three (3) species from Burseraceae (6.38%) belonging to three (3) genera. The least represented plant families include Rhamnaceae, Sapindaceae, Celastraceae, Combretaceae and Loganiaceae, represented by two (2) species and together accounting for 21.27% of the total identified woody species from the eight sample plots. The remaining species belong to 10 plant families (21.27%) with each family represented by a single species.

Table 4.1: Diversity, evenness, density and percentage of each family in the entire study area.

Family	No. of Species	% Family	Density (ind.ha^{-1})	H'	J'	EN
Anacardiaceae	11	23,40	27.5	0.34	0.14	1.41
Fabaceae	8	17,02	20	0.30	0.14	1.35
Malvaceae	5	10,64	12.5	0.24	0.15	1.27
Burseraceae	3	6,38	7.5	0.18	0.16	1.20
Celastraceae	2	4,26	5	0.13	0.19	1.14
Combretaceae	2	4,26	5	0.13	0.19	1.14
Loganiaceae	2	4,26	5	0.13	0.19	1.14
Rhamnaceae	2	4,26	5	0.13	0.19	1.14
Sapindaceae	2	4,26	5	0.13	0.19	1.14
Apocynaceae	1	2,13	2.5	0.08	N/A	1.08
Capparaceae	1	2,13	2.5	0.08	N/A	1.08
Ebenaceae	1	2,13	2.5	0.08	N/A	1.08
Erythroxylaceae	1	2,13	2.5	0.08	N/A	1.08
Olacaceae	1	2,13	2.5	0.08	N/A	1.08
Phyllanthaceae	1	2,13	2.5	0.08	N/A	1.08
Proteaceae	1	2,13	2.5	0.08	N/A	1.08
Salicaceae	1	2,13	2.5	0.08	N/A	1.08
Santalaceae	1	2,13	2.5	0.08	N/A	1.08
Annonaceae	1	2,13	2.5	0.08	N/A	1.08

*H' – Diversity Index, J' – Evenness, EN-Effective Number

4.2.2 Growth form

Data collected for the plant species in both open and closed woody vegetation areas indicate that in the open woody vegetation area, trees had a proportion of 64.52% (n = 12 species recorded) and shrub had a proportion of 35.48% (n = 9 species recorded),

as opposed to the closed woody vegetation area where tree had a proportion of 52.83% (n = 18 species recorded) and shrub had a proportion of 47.17% (n = 17 species recorded). However, this resulted in n = 22 species of trees recorded and n= 25 species of shrub recorded in the entire study area. The proportion of the growth form of woody plant species recorded in the entire study area (open and closed areas) is represented in Figure 4.2. According to figure 4.2 the closed area had a higher proportion of trees to shrub species than the open areas.

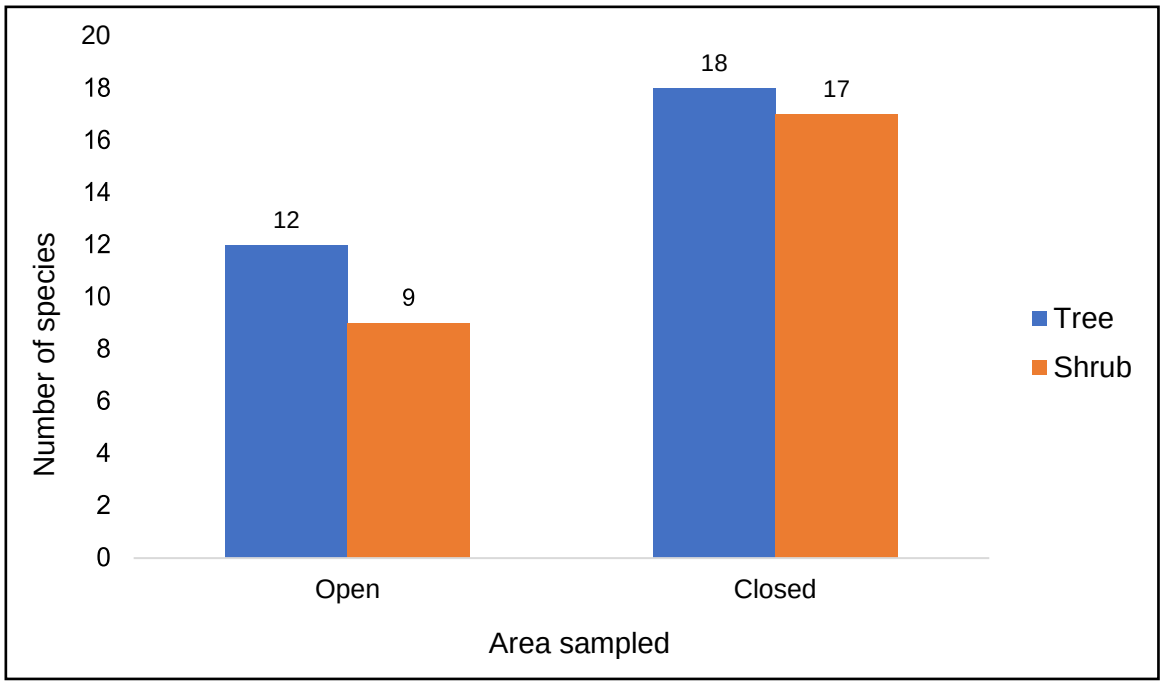

Figure 4.2: The proportion of growth form for collected woody plant species in the study area using Whittaker method.

4.3 DIVERSITY AND EVENNESS ACCORDING TO THE WHITTAKER METHOD

4.3.1 Floristic diversity and evenness

The Shannon Wiener diversity index values and evenness values for all woody plant species recorded in each vegetation area (closed and open) from the Whittaker method are given in Appendices D & E. The diversity was analysed per woody vegetation area and was converted into effective numbers (Table 4.1). Overall, results reveal that the effective numbers for Anacardiaceae, Fabaceae and Malvaceae were 1.41, 1.35 and 1.27 respectively and evenness values were 0.14, 0.14 and 0.15 respectively (Table 4.1). This suggests that the families of dominant species are equally diverse and remain evenly distributed in the study area except for the Malvaceae.

Shannon Wiener diversity index, effective numbers and evenness of both open and closed vegetation areas from Whittaker method are given in Table 4.2. Furthermore, the diversity and the evenness of each species recorded in the study area is given in Appendix F.

The results reveal that the effective number of the open woody vegetation area is more than the effective number of the closed woody vegetation area. These results infer that the open woody vegetation area is more diverse compared to the closed woody vegetation area. Results from an ANOVA test to compare the effective number between both vegetation areas indicate that there was a significant difference between the two woody vegetation areas (one-way ANOVA: $F = 8.11$, df = 3, $p = 0.03$).

Table 4.2: Species richness, diversity and evenness.

Area	No. of Species	Diversity (H')	Effective Number	Evenness (J')
Open	21	0.37	1.45	1.12
Closed	35	0.22	1.25	0.06

The results indicate that the fewer the woody plant species, the higher the effective woody plant species number and the higher the effective woody plant species number, the fewer the woody plant species. Further, both open and closed woody areas have woody plant species that are unevenly distributed.

4.4 WOODY VEGETATION STRUCTURE ACCORDING TO THE WHITTAKER METHOD

4.4.1 Floristic density

A complete list of woody plant species recorded in the open and closed vegetation areas, as well as in the entire study area together with their density and their percentages of occurrence is given in the Appendix C (C1 & C2). *Dichrostachys cinerea, Sclerocarya birrea* subsp*. caffra, Ziziphus mucronata*, *Dombeya rotundifolia, Euclea crispa* and *Senegalia caffra* had high numbers of individuals per hectare with a density of 10 ind.ha^{-1} (4.76%) each. Some species with lowest density such as

Berchemia zeyheri, Carissa bispinosa, Combretum apiculatum, Commiphora edulis, Commiphora harveyi, Crotalaria monteiroi var. galpinii, Dovyalis caffra, Elephantorrhiza elephantina, Hippocratea parvifolia, Lannea edulis, Mundulea sericea, Osyris lanceolata Pappea capensis, *Grewia oxyphylla, Grewia occidentalis, Gymnosporia buxifolia* and *Strychnos henningsii* had the lowest density of 2.5 ind.ha^{-1} (1.19%) each. Of all the collected and identified families of woody plant species in the study area, Anacardiaceae was found to have the highest number of woody plants per hectare, with57.5 ind.ha^{-1} (23.40%) followed by Fabaceae 47.5 ind.ha^{-1} (17.02%), Malvaceae 27.5 ind.ha^{-1} (10.64%) and Rhamnaceae 12 ind.ha^{-1} (4.26%). Four families, namely Apocynaceae, Olacaceae, Salicaceae and Santalaceae had the lowest number of individuals per hectare with 2.5 ind.ha^{-1} (2.13%) each (Table 4.1).

The two woody vegetation areas (open and closed) from which woody plants were sampled had different densities. The closed woody vegetation area had a density of 265 ind.ha^{-1}, contributing to 63% of the total area, and the open woody vegetation area had a density of 155 ind.ha^{-1}, contributing to 37% of the total area (Table 4.3).

Table 4.3: Population density and percentage estimates of woody species at the different study sites.

Area	No. of Species	No. of Individual	Density (ind.ha^{-1})	Percentage (%)
Open	21	31	155	37
Closed	35	53	265	63

4.4.2 Height-class distribution

The results reveal that in the open woody vegetation area, the number of woody plants for the lower, middle and upper height classes is 20, 9 and 2 respectively. The overall height class distribution of woody plants in the open woody vegetation area shows higher number of woody plants in the lower class, suggesting that the number of woody plants gradually decreases from the lower class towards the middle and upper classes indicating continuous representation of woody plants in all height classes. This density distribution gives rise to a reverse J-shape pattern (Tilahun *et al*., 2015) (Figure 4.3a), which indicates a decrease in the number of woody plant while increasing with height

classes (Table 4.4). The proportion of individuals in the open woody vegetation area was 65%, 29% and 6% for lower, middle and upper height classes respectively.

However, in the closed woody vegetation area, the number of woody plants is 13, 19 and 21 respectively for the lower, middle and upper height classes, suggesting that the number of woody plants gradually decreases from the upper class towards middle and lower classes. This density distribution indicates a J-shape (Tilahun *et al*., 2015) (Figure 4.3b), which shows a decrease in density and in the height class (Table 4.4). The woody plants in the upper height class and their percentage distribution are 40%, indicating that the woody plant in the upper height class area dominating the area.

In the overall study area, similarly to the open woody vegetation area, the number of individuals decreases from the lower towards the middle and the upper height classes, which shows a decrease in density with increasing height classes. The highest density was found to be 165 ind.ha^{-1} (33%) representing the lower height class.

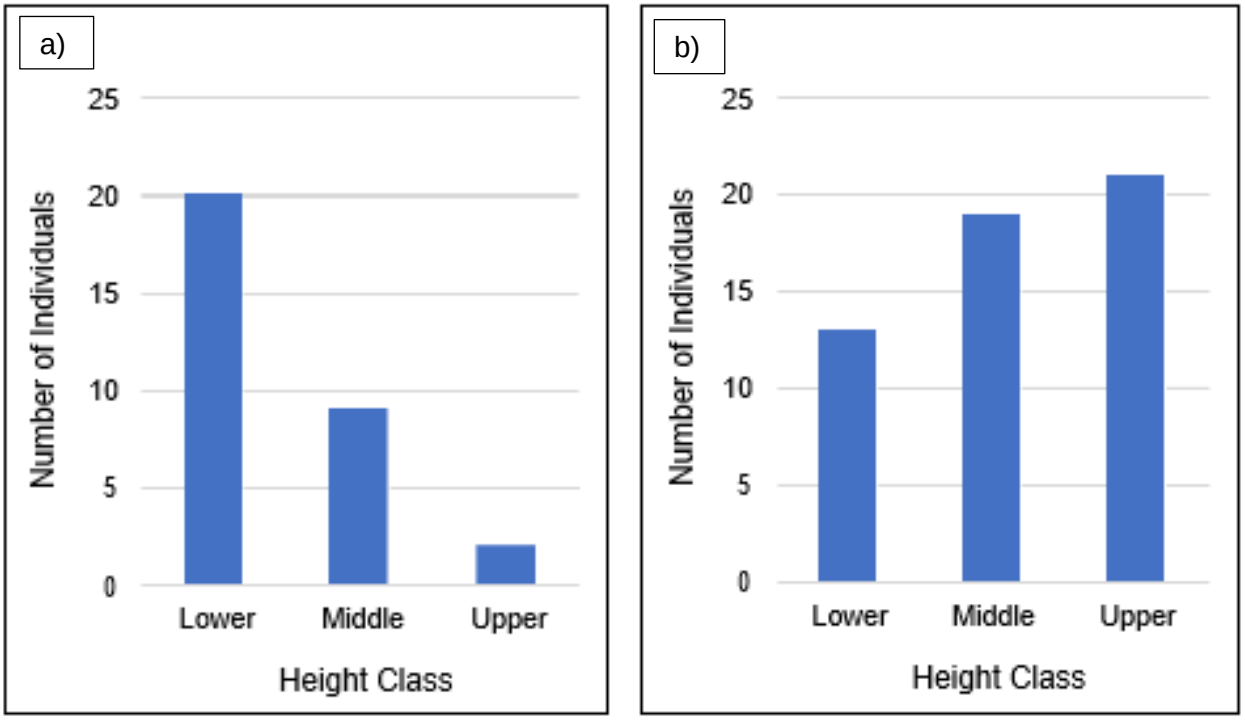

Figure 4.3: Height classes versus number of Individuals for the a) the open and b) the closed vegetation study areas.

Results indicate that in the open woody vegetation area, 35% of individuals per hectare belong to the middle and the upper height classes and 65% belong to the lower height class, while 76% of individual per hectare in the closed woody vegetation area belong

to the middle and the upper height classes and 24% belong to the lower height class. Therefore, 61% of individuals per hectare in the middle and the upper height classes and 39% to the lower height class in the overall study area, suggest that the study area is dominated by woody plants above 1 m in height.

Table 4.4: Density, percentage (%) density and number of species per height class using the Whittaker method.

#	Open vegetation			Closed vegetation		
Storey	Density (ind.ha^{-1})	Density %	No. of Individual	Density (ind.ha^{-1})	Density %	No. of Individual
Lower	100	65	20	65	24	13
Middle	45	29	9	95	36	19
Upper	10	6	2	105	40	21

4.5 PRECISION AND POWER TO DETECT CHANGE OF THE WHITTAKER METHOD IN WOODY VEGETATION AREAS

4.5.1 Precision and power to detect change of the Whittaker method in species richness

The analysis of the Whittaker method data reveals that the method has different coefficient of variation (CV) for the two sampling plots surveyed within the open vegetation area (plot 1: 28% CV and plot 2: 47% CV). A smaller CV indicates greater precision. These results indicate that in the open woody vegetation area, the Whittaker method is more precise in sampling plot 1 than in sampling plot 2 (for precision determination the four plots in the open habitat were randomly combined into two sets of data comprising two plots each). Different results were obtained from the closed woody vegetation area. In the closed woody area, the two sampling plots (combined in a similar way as for the open plots) showed similar values of coefficient of variation (plot 1: 17% CV and plot 2: 20% CV), resulting in similar precision of the Whittaker in detecting species richness in both sampling plots.

Further, the results of the overall open and closed woody vegetation areas as well are provided in Table 4.5. At a 95% confidence level, both woody vegetation areas present different values of Standard Error (SE). The results further indicate a similar

repeatability of both the open woody vegetation area (22.84 %CV) and closed woody vegetation area (24 %CV), resulting in similar precision in detecting species richness in the open and closed woody vegetation areas. The Whittaker method can be said to be equally precise in species richness detection in the open and closed woody vegetation areas.

Furthermore, both open (22.84 %CV) and closed (24 %CV) woody vegetation areas resulted in two resolutions $R_O = 0.9$ and $R_C = 0.95$ or an 80% probability of being able to detect a 90% and 95% change in species richness in both open and closed woody vegetation areas respectively. In the light of these results, one could potentially say that the Whittaker method has a high capacity to detect change in the number of species (species richness) in the open and closed woody vegetation areas.

Table 4.5: Descriptive statistics of Whittaker method in species richness.

#	Open	Closed
Mean	15.5	26.5
Standard Error	2.5	4.5
Median	15.5	26.5
Standard Deviation	3.54	6.36
Variance	12.5	40.5
Range	5	9
Sum	31	53
95% Confidence Interval	16.27 – 47.27	**4.68 - 38.68**

4.5.2 Precision and power to detect change of Whittaker method in density

For precision determination the eight plots in the open and close habitat were randomly combined into four sets of data comprising two plots for the open habitat and two plots for the closed habitat.

The precision of the Whittaker method in determining the number of individuals per hectare was compared using the coefficient of variation (%CV). Results reveal a significant difference in precision between the sampling plots surveyed. In the open woody vegetation area, the coefficient of variation in the sampling plot 1 (10.89%CV) was almost twice that of sampling plot 2 (6% CV), implying that Whittaker method has about twice more variation between species density in sampling plot 1 than in sampling

plot 2. This suggests that the Whittaker method is more precise in detecting species density in the sampling plot 2 than in sampling plot 1. However, in the closed woody vegetation area, the Whittaker method was more precise in sampling plot 1 (8.43% CV) than in sampling plot 2 (14.13% CV).

Precision for the overall open and closed woody vegetation areas was compared. Results obtained are provided in Table 4.6 below. The results indicate a difference in the coefficient of variation. The closed woody vegetation area has a higher variation between species density and lower repeatability with 16.77% CV as opposed to the open woody vegetation area (11.96% CV), which has a lower variation between the species density and a greater repeatability. This result suggests that the Whittaker method is more precise at detecting species density in the open woody vegetation.

Further, both open (11.96% CV) and closed (16.77% CV) woody vegetation areas resulted in two resolutions R_O = 0.47 (open) and R_C = 0.66 (closed) or an 80% probability of being able to detect a 47% and 66% change in species density in both open and closed woody vegetation areas respectively. These results infer that the Whittaker method has a greater capacity to detect change in species density in the closed woody vegetation area. This implies therefore that the Whittaker method is missing some species density and provides an underestimate of the true population density (Table 4.6).

Table 4.6: Descriptive statistics of Whittaker method precision in density

#	Open	Closed
Mean	71	88.5
Standard Error	6	10.5
Median	71	88.5
Standard Deviation	8.49	14.85
Variance	72	220.5
Range	12	21
Sum	142	177
95% Confidence Interval	5.23 – 147.23	44.92 – 221.92
%CV	11.96	16.77

4.5.3 Precision and power to detect change of the Whittaker method in species diversity

The comparison of precision across sampling plots was not considered as the sampling plots have a very low effective number of woody species, which resulted in extremely low results. As a result, only precision across woody vegetation areas is taken into account.

Both open and closed woody vegetation differ in terms of species diversity estimate, which resulted in the open woody vegetation area being more diverse than the closed woody vegetation area. The analysis of data using descriptive statistics (Table 4.7) to compare precision reveals that both areas have a similar repeatability with 27.42% CV (open) and 26.04% CV (closed), indicating similar precision. The open woody vegetation area (27.42% CV) resulted in R_O = 1,09 or an 80% probability of being able to detect a 109% change in species diversity in the open woody vegetation area.

The closed woody vegetation area generated a 26.04% CV, resulting in R_C = 103 or an 80% probability of being able to detect a 103% change in species diversity estimate in the closed woody vegetation area. This indicates that the Whittaker method has over 100% capacity to detect change in species diversity in either of the woody vegetation areas. The results indicate that the Whittaker method is equally precise and exhibits a greater power to detect change in species diversity in the open and closed vegetation areas.

Table 4.7: Descriptive statistics of Whittaker method precision in species diversity.

#	Open	Closed
Mean	7.44	3.38
Standard Error	1.44	0.63
Median	7.44	3.38
Standard Deviation	2.04	0.88
Variance	4.15	0.78
Range	2.88	1.25
Sum	14.88	6.75
95% Confidence Interval	9.86 – 24.74	4.56 – 11.32

4.6 ECONOMIC VALUES OF THE WHITTAKER METHOD

Only economic value may permit adequate planning such as the number of people, time allocated and sample size within budgetary and technical constraints (Gaidet-Drapier *et al*., 2006).

4.6.1 Sampling and time efficiency

Table 4.8 shows that the time to sample the woody vegetation areas using the Whittaker method varied according to the woody vegetation area in which the survey was completed. The time to sample the closed woody vegetation area was higher than the time to sample the open area. The Whittaker method was significantly lower in the open than in the closed woody vegetation area (*t*-test: $t = 2.92$, df = 3, $p \leq 0.05$).

Table 4.8: Mean sampling effort for the Whittaker method in a 0.2 ha sampling.

Area	Total Area (ha)	Sampling time (h)	No. species
Open	0.4	3h02	31
Closed	0.4	3h35	53

The average time to complete the survey in the open and closed woody vegetation areas was 3h02 (SE = 0.99) and 3h35 (SE = 1.28) respectively. The sampling time of the two woody vegetation areas increased with the number of species recorded in the plot. Our results are in line with a study done by Shmida (1984), who found using the

Whittaker plot to survey plants for up to 4 hrs. in the rich Southern Hemisphere, Tropical vegetation and temperate North American vegetation. The difference in woody species recorded within both vegetation areas could be attributed to the difference in density of woody plants occurring in the two vegetation areas. The denser the area, the more time is required to set the sampling plot and complete the species counts.

4.6.2 Sampling effort and cost efficiency

Table 4.9 below shows the field resources needed to survey both open and closed woody vegetation areas using the Whittaker method. Results reveal that Whittaker method uses different resources to set a sampling plot within a sampling area. In addition, the total cost associated with each resource varied according to the number of units and not according to the area sampled. This resulted in a total cost of R1 258 to establish a Whittaker sampling plot in the open and closed woody vegetation areas and complete a woody plant survey.

Table 4.9: Breakdown of the total field resources required to implement the Whittaker method effectively, and their cost in South African Rand (ZAR).

Material	No. of Unit	Cost Unit	Total Cost per Unit (R)
Measuring tape (50 m)	3	139	417
Rope (20 m)	8	30	240
Hammer	1	76	76
Pegs (50 cm)	35	15	525
Total cost (R)			**1258**

CONCLUSION

According to our findings, the Whittaker method is an efficient method in recording species composition, species richness, species diversity and density. A variation of species composition, species richness, species diversity and density between both woody vegetation areas was found. Plants from the following families, Anacardiaceae (23.40%), Fabaceae (17.02%) and Malvaceae (10.64%) were found to be the most dominant, having more species richness and diversity than the other families. The

results show that the Whittaker method had two patterns of height class distribution. In the open woody vegetation area, density distribution gives rise to a reverse J-shape pattern, indicating a decrease in the number of individual woody plants with a decrease in height classes. In contrast, in the closed woody vegetation area the density distribution formed a J- shape, indicating an increase in the number of individual woody plants with increasing in height class.

The results reveal that the Whittaker method has a similar precision in detecting species richness and species diversity in both open and closed woody vegetation areas except in detecting species density, where the method was more precise in the open woody vegetation area. We showed that the power to detect a change in species richness and species diversity was high, with an 80% probability of being able to detect a 90% (open) and 95 % (closed) change in species richness and 109% (open) and 103% (closed) change in species diversity. The Whittaker method however shows a moderate power to detect change in species density, with an 80% probability of being able to detect a 47% (open) and 66% (closed) change in species density.

The Whittaker method is effective and efficient in achieving the monitoring objectives and is suitable for repeated surveys. The Whittaker method is time and cost efficient and reveals important insights for future monitoring schemes that may result in drastic cost savings over the long term. Although the method requires less equipment to complete a woody plant survey, the time to complete the survey will vary according to the characteristics of the woody vegetation area to be sampled and the size of the sampling plot(s).

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CHAPTER 5

WOODY PLANT SPECIES DIVERSITY, STRUCTURE AND PRECISION OF DISTANCE SAMPLING SOFTWARE

5.1 INTRODUCTION

The ability to monitor plant species abundance has become important with the growing concerns over biodiversity loss through anthropogenic changes. These concerns brought together political leaders to the World Summit on Sustainable Development in Johannesburg in 2002 to discuss ways to significantly reduce the current rate of biodiversity loss by the end of 2010 (Buckland, Summers, Borchers, & Thomas, 2006). New methodologies are needed to estimate the abundance of a number of vulnerable species to reliably quantify the rate and extent of biodiversity change. The first step to address these concerns is to develop adequate monitoring methods, to quantify the rate of biodiversity loss, which enables the success of management actions that will be assessed by their impact on the rate of change of biodiversity (Buckland *et al*., 2006).

A common strategy is to estimate smoothed trends in abundance for each of a number of species (Fewster, Buckland, Siriwardena, Baillie, & Wilson, 2000) from which biodiversity changes may be quantified (Buckland, Magurran, Green, & Fewster, 2005). A widely used tool for such monitoring is distance sampling, in which distances of detected species from a point are modelled, to estimate detectability and hence species abundance (Buckland *et al*., 2006). Distance sampling provides a flexible set of tools for estimating abundance of a wide variety of species, from which trends can be quantified (Buckland *et al*., 2001).

Distance sampling is a widely used technique for estimating the size or density of biological populations and many distance sampling designs and most analyses use the software Distance (Thomas *et al*., 2010). Distance contains three increasingly sophisticated analysis engines, which estimate density and/or abundance of species

with associated measures of precision. Distance sampling is a key method for producing abundance and density estimates in challenging field conditions. The theory underlying the method continues to expand to cope with realistic estimation situations in natural ecosystems (Thomas *et al*., 2010).

Sahu, Pani, Ranjan Mohanta, & Kumar (2019) consider rangelands to be natural ecosystems that are genetically rich with a variety of plant species and high overall biodiversity. According to Mekonen, Ayele, & Ashagrie (2015) plant species composition and diversity assist with effective decision making for biodiversity management. Biodiversity in rangeland ecosystems is sustained by vegetative properties of plants and overall species diversity (Noori, Gholinejad, & Jonaidi, 2014). Vegetation in these ecosystems is threatened by anthropogenic disturbances, which often require management intervention to maintain an overall sustainable level of biodiversity (Kumar, Marcot, & Saxena, 2006).

Plant community composition is monitored for three main reasons; to record the abundance of individual dominant species and groups of plants, to provide information for managing plant communities, and to track ecosystem health (Symstad, Wienk, & Thorstenson, 2006). Rapid loss of vegetation is often due to the over-exploitation of resources, bush encroachment and overgrazing, which are recognised as some of the biggest environmental and economic problems in rangelands (Sahu *et al*., 2019).

A primary objective of many ecological monitoring methods is to detect changes in ecosystem functions and processes (Niemi & McDonald, 2004). Vegetation cover and composition are two of the indicators used for detecting change in many terrestrial ecosystems. The objectives of this chapter are to evaluate and compare the precision of DSS for both the open and closed vegetation areas.

5.2 FLORISTIC COMPOSITION AND RICHNESS ACCORDING TO THE DISTANCE SAMPLING SOFTWARE

5.2.1 Species composition and richness

The overall list of woody plant species and their richness for the entire study area, with their respective family names using DSS are given in Appendices G & H. An indication

of species richness of both open and closed vegetation areas, together with the list of species are given in Appendix I.

Using DSS, a total of 36 woody plant species represented by 15 woody plant families and 25 genera were identified in the study area. The study area included an open and a closed woody vegetation areas in which eight sampling plots of 1000 m^2 each were placed. The results indicate that the closed vegetation area had a higher number of species and families (n = 27 and n = 11 respectively) compared to the open vegetation area (n = 14 species and n = 9 families). The results show that some species have a higher number of individuals compared to others. *Dichrostachys cinerea* (n = 49)*, Sclerocarya birrea* (n = 15)*, Combretum collinum* (n = 12)*, Vachellia karroo* (n = 10) and *Dombeya rotundifolia* (n = 9) were the dominant species with the highest number of individuals in the closed vegetation area; while in the open vegetation area *Dichrostachys cinerea* (n = 35), *Sclerocarya birrea* (n = 18), *Senegalia caffra* (n = 11), *Lannea edulis* (n = 9) and *Faurea galpinii* (n = 7) were the most frequent with the highest number of individuals. (n = 9).

The family richness and the number of individual species recorded in the study area are given in the Table 5.1. DSS the recorded the lowest number of individuals from the following families, Santalaceae and Rubiaceae with an equal percentage of 0.69%.

The results reveal that Anacardiaceae was the family with the highest number of species (n = 11), belonging to 9 genera. Species belonging to the Anacardiaceae occupied 30.60% of the study area (Table 5.1). Other plant families with high numbers of species include Fabaceae (n = 9, 25%) with 5 genera and Malvaceae (n = 4 species, 11.11%) with 5 genera (Table 5.1).

Figure 5.1 below presents the proportional representation of the most prominent plant families in the study area using DSS. The occupational proportion of Malvaceae family is about half the proportion of Fabaceae and about one-third of Anacardiaceae in the study area, making Malvaceae the least dominant family in the study area. The high representation of species from Anacardiaceae may be attributed to the family's efficient and successful dispersal strategies as well as its perfect adaptation to a wide range of ecological conditions (Forest, 2018).

Table 5.1: Species richness, diversity, effective number, evenness, density and plant family using DSS.

Family	No. of Species	No. of ind.	Density (ind.ha^{-1})	Family %	H'	EN	J'
Fabaceae	8	342	310	42.76	0.33	1.39	0.16
Anacardiaceae	10	152	180	24.83	0.36	1.43	0.16
Malvaceae	4	84	52.5	7.24	0.24	1.27	0.17
Phyllanthaceae	1	34	35	4.83	0.10	1.11	N/A
Combretaceae	1	31	30	4.14	0.10	1.11	N/A
Rhamnaceae	2	17	20	2.76	0.16	1.17	0.23
Ebenaceae	1	48	17.5	2.41	0.10	1.11	N/A
Proteaceae	1	21	17.5	2.41	0.10	1.11	N/A
Burseraceae	1	1	12.5	1.72	0.10	1.11	N/A
Celastraceae	1	8	12.5	1.72	0.10	1.11	N/A
Loganiaceae	2	8	10	1.38	0.16	1.17	0.23
Sapindaceae	1	8	10	1.38	0.10	1.11	N/A
Annonaceae	1	9	7.5	1.03	0.10	1.11	N/A
Rubiaceae	1	2	5	0.69	0.10	1.11	N/A
Santalaceae	1	3	5	0.69	0.10	1.11	N/A

*EN-Effective Number, H' – Diversity, J' – Evenness

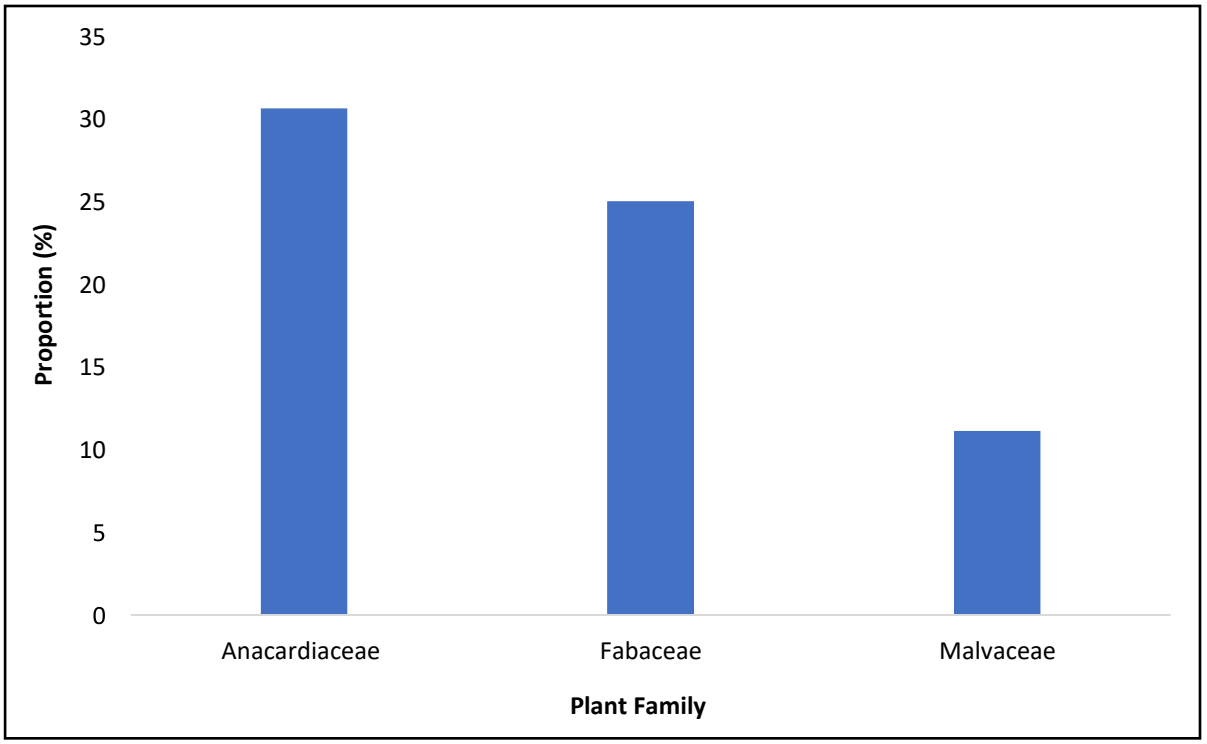

Figure 5.1: Proportional representation of dominant woody plant families in the study area using DSS.

5.2.2 Growth form

Plant growth forms determine the spatial geometry of vegetation (Edwards, 1983). The collected species data, using DSS were grouped into two different growth forms, which included trees and shrubs (Appendix G). The results indicate that in the open woody vegetation area, trees and shrubs had an equal proportion of 50% (n = 7 species recorded in each area), while in the closed woody vegetation area where trees had a proportion of 55.56% (n = 15 species were recorded) and shrubs had a proportion of 44.44% (n = 12 species recorded). However, this resulted in an equal number of both trees and shrubs (n = 18) recorded in the entire study area. The proportion of woody plant species per growth form recorded in the entire study area (open and closed areas) is represented in Figure 5.2.

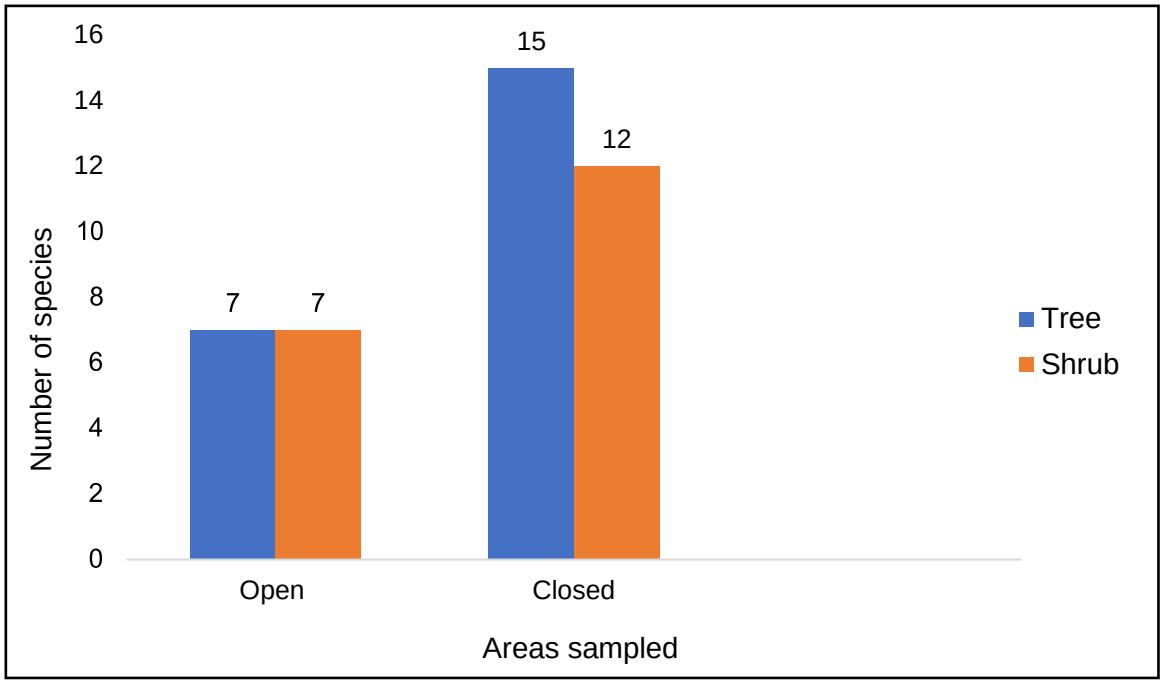

Figure 5.2: The number of different trees and shrubs for recorded woody plant species in the open and closed areas using DSS.

5.3 FLORISTIC DIVERSITY AND EVENNESS ACCORDING TO THE DISTANCE SAMPLING SOFTWARE

5.3.1 Floristic diversity and evenness

The Shannon Wiener diversity index values and evenness values for all woody plant species recorded in both closed and open vegetation areas using the DSS method are given in Appendices J & K. *Dichrostachys cinerea* and *Senegalia caffra* have the highest diversity index and are the most evenly distributed species in both woody vegetation areas (Appendix L). In addition, Table 5.1 shows the diversity index, effective number values and the evenness values for each woody plant family. Results reveal that diversity index value for Anacardiaceae was 0.36 with an effective number of 1.43, Fabaceae was 0.33 with an effective number of 1.39, and Malvaceae was0.24 with an effective number of 1.27 (Table 5.1). Besides the three most diverse families, others with similar effective numbers include Phyllanthaceae, Combretaceae, Ebenaceae, Proteaceae, Burseraceae, Celastraceae, Sapindaceae, Annonaceae, Rubiaceae and Santalaceae suggesting similar diversity (Table 5.1).

The Shannon Wiener diversity index, effective species number and evenness of both open and closed vegetation areas are given in Table 5.2. Both open and closed woody vegetation areas had a similar effective number of woody species and evenness, suggesting that the open area (effective number of 1.50) is equally diverse to the closed area (effective number of 1.3), and both are not evenly distributed. The analysis of results using ANOVA tests to compare the effective numbers between both vegetation areas indicate that there was a non-significant difference between the two woody vegetation areas (one-way ANOVA: $F = 0.03$, $df = 1$, $p > 0.05$). Furthermore, the diversity, effective number and the evenness of each species recorded in the study area is given in Appendix L.

Table 5.2: Species richness, diversity, effective number and evenness using DSS.

Area	No. of Species	No. of Ind.	Diversity (H')	Effective Number	Evenness (J')
Open	14	206	0.37	1.50	1.15
Closed	27	531	0.28	1.30	0.09

5.4 WOODY VEGETATION STRUCTURE OF DISTANCE SAMPLING SOFTWARE (DSS)

Vegetation structure is defined as the organization in space of individual plants that form a stand (Dansereau, 1957). According to Edwards (1983), vegetation structure is based solely on vegetation characteristics. Vegetation structure is complementary to floristic composition, habitat and ecological classifications. For this study, vegetation structure has been limited to density and height class attributes of the woody species in the study area.

5.4.1 Floristic density

Densities of different woody plant species recorded in the study area are given in Appendix H. Results indicate a significant variation in species densities and percentage representation. The four most important species based on their densities are *Dichrostachys cinerea* with 447.5 ind.ha^{-1} (24.29%), *Senegalia caffra* with 295 ind.ha^{-1} (11.87%), *Sclerocarya birrea* with 220 ind.ha^{-1} (5.76%) and *Dombeya rotundifolia* with 142.5 ind.ha^{-1} (4.32%). Species with the lowest densities include *Crotalaria monteiroi var. galpinii, Mundulea sericea, Pyrostria hystrix, Strychnos henningsii* with 5 ind.ha^{-1} (0.72%) and *Commiphora edulis* with 2.5 ind.ha^{-1} (0.36%). Floristic density findings indicate that *Dichrostachys cinerea* (indicator of bush encroachment) together with *Senegalia caffra* are dominant.

From the identified families of woody plant species in the study area, Fabaceae was found to have the highest number of individuals per hectare, with 855 ind.ha^{-1} (44.53%) followed by Anacardiaceae 380 ind.ha^{-1} (19.79%) and Malvaceae 210 ind.ha^{-1} (10.94%). Two families, Santalaceae and Rubiaceae were found to have the lowest number of individuals per hectare with 7.5 ind.ha^{-1} (0.39%) and 5 ind.ha^{-1} (0.26%) each (Table 5.1). The density of woody species found in the Fabaceae family is twice the density of woody species found in the Anacardiaceae family, and four times the density of woody species found in the Malvaceae family. This indicates that the Fabaceae family is dominant among other families in the study area. A few families such as Rubiaceae and Santalaceae have similar woody plant species density. Low densities could be

attributed to prevalent environmental conditions and competition from dominant species or families in the study area.

The woody plant species collected from the two vegetation areas (open and closed) showed differences in the number of individual woody plants per hectare. The closed woody vegetation area had a total density of 2 655 ind.ha^{-1}, contributing to 72% of the study area and the open woody vegetation area had 1 030 ind.ha^{-1} contributing to 28% of the study area (Table 5.3), indicating that the density of the closed woody area is more than twice the density of the open woody vegetation area.

Table 5.3: Population density and occurrence estimates of woody species at the different study sites.

Area	No. of Individuals	Density (ind.ha^{-1})	Percentage (%)
Open	206	1 030	28
Closed	531	2 655	72

5.4.2 Height-class distribution

Plant height is an important component of a plant's strategy to compete for light (Moles *et al.*, 2009). Plant height also plays an important part of a coordinated suite of life-history traits such as seed mass, time to reproduction, longevity and the number of seeds a plant can produce per year (Mole & Leishman, 2008). These life-history traits determine how a species lives, grows and reproduces (Mole & Leishman, 2008).

Plant species recorded in the study area were divided into three different height classes, lower (<1 m), middle (1-2.5 m) and upper (>2.5 m). Table 5.4 indicates that in the open woody vegetation area, the number of individuals in the lower height class was the highest and decreased toward the upper height classes. Whereas the number of individuals in the middle height class of the closed vegetation area was highest and decreased towards the upper and lower height classes. These results suggest that the open woody vegetation area was dominated by plants in the lower height class, which is an indication of functional regeneration. Some species in the lower height classes

are by nature smaller (e.g., shrub species) and are already adults that cannot grow taller, while others are young plants/trees that will eventually reach tree size.

In the open woody vegetation area, the density distribution of woody plants in different height classes indicates a reverse J-shape pattern (Tilahun, Soromessa, & Kelbessa, 2015) (Figure 5.3a), which shows a type of distribution in which a number of woody plants in the lower class was high and decreases towards the middle and upper classes. It shows a decrease in density with increasing height classes (Table 5.4). This is because of the higher number of individuals in the lower height class and a gradual decrease towards the middle and upper height classes, indicating continuous representation of plants in all height classes. This could be an indication of bush encroachment, depending on the species. The highest number of individuals per hectare was found to be 785 ind.ha^{-1} (76.47%) representing the lower height class. Height can be used as an indicator of the age of the woody plant (Teshager, Argaw, & Eshete, 2018).

Table 5.4: Density, percentage (%) density and number of species per high class using DSS.

#	**Open vegetation**			**Closed vegetation**		
Storey	No of individuals	Density (ind.ha^{-1})	Density %	No of individuals	Density (ind.ha^{-1})	Density %
Lower	157	785	76.21	165	825	31.07
Middle	33	165	16.02	264	1320	49.72
Upper	16	80	7.77	102	510	19.21

In the closed woody vegetation area, the density distribution of woody plants in different height classes indicate a Bell-shape pattern (Teshager *et al*., 2018) (Figure 5.3b), which shows a type of distribution in which a number of woody plants in the middle height class is high and decreased towards the lower and upper height classes. It shows a decrease in density with decreasing (lower) and increasing (upper) height classes (Table 5.4). This is because of the higher number of woody plants in the middle class and a gradual decrease towards the lower and upper classes indicating continuous representation of woody plants in all height classes. The highest density was found to be 1 320 ind.ha^{-1} (49.68%) representing the middle height class. This means that the

woody plants of the middle height class occupied half of the closed woody vegetation area. The old woody plants are found in in the upper height class and their percentage distribution is 19.11%.

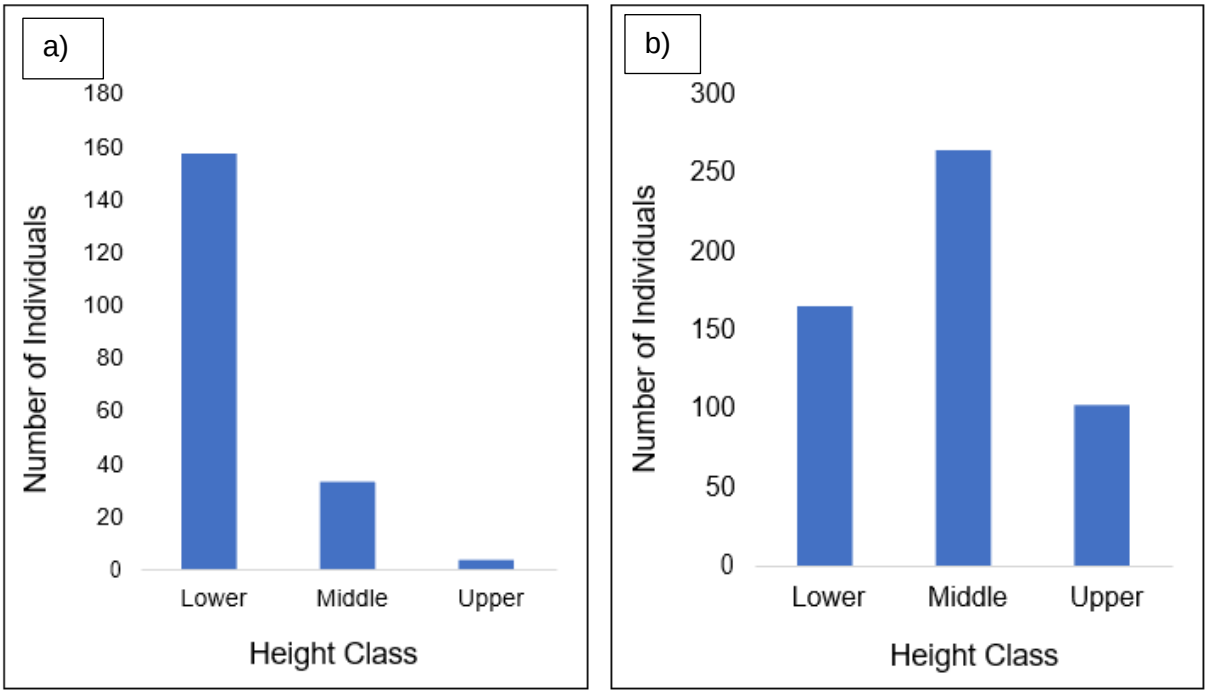

Figure 5.3: Height class versus number of individuals in a) the open, and b) the closed vegetation areas.

5.5 PRECISION AND POWER TO DECTECT CHANGE IN ABUNDANCE AND DENSITY ESTIMATION

The analysis of distance sampling data in DSS, using the half-normal/cosine model, reveals that DSS provides different coefficients of variation (%CV) for abundance and density estimation in the open and closed woody vegetation areas. DSS had 5.71% (df = 588) and 8.31% (df = 460) coefficient of variation for open and closed vegetation areas respectively (Table 5.5). The %CV for the closed woody vegetation area was greater than for the open woody vegetation area, indicating that the precision of DSS in the open woody vegetation area is higher than the precision of DSS in the closed woody vegetation area.

Further, DSS's power to detect change in abundance and density in the open and closed woody vegetation areas resulted in $R_O = 0.23$ and $R_C = 0.33$ respectively or an 80% probability of being able to detect a 23% and 33% change in abundance and

density within the open and closed woody vegetation areas respectively. This result suggests that DSS has less power to detect change in the open woody vegetation area compared to the closed woody vegetation area. This can be attributed to the lower number of individuals recorded in the open woody vegetation area.

Results indicate that when the abundance and density estimates were low, the standard error (SE) and precision was low and when the abundance and density estimates were high, the SE and precision was high. It can infer that the precision of DSS in both open and closed woody vegetation areas was dependent on the density and abundance of the species measured. Differences in abundance and density among vegetation types tends to cause variation in precision (Symstad, Wienk, & Thorstenson, 2008). Our findings suggest that DSS could potentially be used in woody vegetation monitoring.

Distance sampling software provided computed estimate values of density and abundance for combined data from both woody vegetation areas (Table 5.6). Results indicate that the combined woody density and abundance means ($\bar{x}$) falls within the confidence interval of density mean (95% CI, 2.27 to 2.52) and abundance mean (95% CI, 10911 to 12089). One could infer that DSS provides sufficient information on the precision estimate of density and abundance in the study area. The lesser the confidence level (95%), the more precise the estimate is, and the wider the confidence level (99%), the less precise the estimate tends to be (Hawkins, 2005). According to Fowler, Cohen & Phil (2009), the 95% confidence interval is more precise than the 99% confidence interval.

Table 5.5: Precision estimates of abundance and density in the open and closed woody vegetation area using DSS.

#	**Open Area**		**Closed Area**	
Parameters	Density	Abundance	Density	Abundance
Estimate	2.37	3787	2.35	4505
SE	0.14	216.09	0.21	478.51
%CV	5.71	5.71	8.31	8.31
df	588	588	460	460
95% CI	2.12 - 2.65	3386 - 4236	1.93 - 2.89	4210 - 5141

***CV: Coefficient of Variation *CI: Confidence Interval**

Distance sampling resulted in R = 0.37 or an 80% probability of being able to detect a 37% change in density and abundance in the whole study area. Monitoring methods should also detect small changes in vegetation (Havstad & Herrick, 2003). This capacity to detect small changes depends on the precision of estimates of density and abundance, estimates with high precision are less variable and more repeatable (Brady, Michell, Bonham, & Cook, 1995). Furthermore, vegetation monitoring methods should provide the necessary information on the highest possible number of individuals in the shortest time (Floyd & Anderson, 1987). Our findings suggest that DSS could potentially be effective for decisions on management intervention in rangelands.

Table 5.6: Precision estimates of abundance (N) and density (D) in study area.

Parameter	Estimate	%CV	df	95% CI	
Half-normal/Cosine					
D	2.39	9.34	1461	2.27	2.52
N	11485	9.34	1461	10911	12089

Similar to Kinahan & Bunnefeld (2012), we found that the confidence limits of both woody vegetation areas are linked to the number of woody plants recorded. Contrary to Wegge & Storaas (2009) who explained that low plant species numbers result in wider confidence intervals and higher species numbers in narrower confidence intervals; we found that higher numbers of woody plant recorded wider confidence intervals and lower number narrow confidence intervals. Distance sampling software yields a higher number of individual species in the study area. The difference in precision and power to detect change in abundance and density between woody vegetation areas vary due to woody abundance recorded in each woody vegetation area.

5.6 ECONOMIC EFFICIENCY OF DISTANCE SAMPLING SOFTWARE (DSS)

5.6.1 Sampling and time efficiency

The standardisation of sampling techniques allows researchers and conservationists worldwide to implement effective and accurate surveying programmes. Table 5.7 shows the mean time required to sample both open and closed woody vegetation areas. The time to sample the closed woody vegetation area was higher than the open woody vegetation area. Distance sampling software took significantly less time to do in the open woody vegetation area than in the closed woody vegetation area. Results from a t-test revealed that there was a statistically significant difference between the mean survey times of both woody vegetation areas (t-test: $t = 5.91$, df = 2, $p \leq 0.05$).

On average, the field technician spent 4h27 (SE = 1.5) and 6h15 (SE = 0.37) to complete the survey in the open and closed woody vegetation areas respectively (Table 5.7). Distance Sampling survey recorded 14 species and 206 individuals in the open woody vegetation area and recorded 27 species and 531 individuals in the closed woody vegetation area. The number of species recorded in the closed woody vegetation area was almost twice the number of species recorded in the open woody vegetation area and the number of individuals in the closed woody area was more than twice in the open woody vegetation area (Table 5.7). This clearly shows that more species are found in the closed woody vegetation area.

This difference in detection could be due to difference in abundance and density of woody plants occurring in both areas. This suggests that DSS is more efficient at detecting species abundance and species richness in the closed woody vegetation area because woody species in the closed area tend to be close to one another and as a result, this reduces the possibility of uncertainty at detecting the woody species. Further because there are more woody plants in the closed vegetation.

Table 5.7: Mean sampling effort for the DSS in a 0.4 ha sampling area.

Method	Total area (ha)	Total observation time (h)	Number of species	No. of Individuals
Open	0.4	4h27	14	206
Closed	0.4	6h15	27	531

5.6.2 Sampling effort and cost efficiency

Table 5.8 below shows the field resources needed to survey both open and closed woody vegetation areas using DSS. Distance sampling software (DSS) uses different resources to set a sampling plot within a sampling area (Table 5.8). In addition, the total cost of each resource needed varies according to the number of units and not according to the area sampled. This resulted in a total cost of R513 to establish a DSS plot in the open and closed woody vegetation areas and complete the woody plant survey (Table 5.8).

Table 5.8: Breakdown of the total field resources required to implement DSS effectively, and their cost in South African Rand.

Materials	No. of Unit	Cost Unit	Total Cost per Unit (R)
Measuring tape (50 m)	2	139	278
Soler tape (2 m)	1	24	24
Rope (20 m)	2	30	60
Hammer	1	76	76
Pegs (50 cm)	5	15	75
Total cost (R)			**513**

CONCLUSION

Although mostly used for animal monitoring, DSS tends to be a suitable method for recording woody species abundance, composition, density, richness and diversity. A high variation in terms of species composition, richness and diversity for both open and closed woody vegetation areas was observed within and between the open and closed

woody areas.

This study shows that the study area contains a diversity of woody plant species comprising a total of 36 woody plant species belonging to 25 genera and 15 families, of which Anacardiaceae is the family with the most species. Distance Sampling resulted in a species richness of 14 and 27 respectively for the open and closed woody vegetation areas. The closed woody vegetation area had a large list of species and the highest species richness. Families with least species abundance were less dominant in the open woody vegetation area. Distance Sampling Software efficiently detected sufficient individuals of species present for data analysis that resulted in useful information for conservation and management decision making.

Distance Software only analyses data related to species abundance and density. Although DSS was found to be precise in both woody vegetation areas, we conclude that DSS remains more precise in closed woody vegetation area. Distance sampling's precision was significantly different in both woody vegetation areas. The precision of both closed and open woody vegetation areas was found to be dependent on density and abundance of species recorded. When the abundance and the density values were low, precision was also low. The ability of DSS to detect change in density and abundance was higher in the closed woody vegetation area. However, DSS was unable to determine the precision and power to detect change in species richness and diversity.

Using DSS, one requires minimal equipment to establish sampling plots. The method tends to be cost efficient and the cost to sample a plot is independent of the area being sampled. Although the time to complete a survey varies according to the woody vegetation in the sample area, DSS took on average 5h20 to complete the survey in the study area using a 20 x 50 m^2 sampling plot.

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CHAPTER 6

COMPARISON OF DISTANCE SAMPLING SOFTWARE AND THE WHITTAKER METHOD

6.1 INTRODUCTION

Grasslands provide many ecosystem services required to support human well-being and are home to a diverse fauna and flora. Degradation of grasslands due to agriculture and other forms of land use threaten biodiversity and ecosystem services (Egoh *et al*., 2011). Noori *et al*. (2014) describes rangelands as natural ecosystems that contains high sources of genetic material, plant species diversity and biodiversity. Biodiversity in rangeland ecosystems has been influenced by vegetative properties and plant species diversity that guarantee the sustainability of these ecosystems amidst environmental and biological instability (Noori *et al*., 2014).

Various efforts are underway around the world to stem these declines. The Grassland Programme has been initiated in South Africa and aims at safeguarding both biodiversity and ecosystem services (Egoh *et al*., 2011). Many vegetation sampling methods have been developed and used to describe shrubland and grassland communities (Seefeldt & Booth, 2006). Some vegetation sampling methods attempt to efficiently quantify plant diversity, species distribution, rare plant occurrence, seeded species establishment, and vegetation cover (Pilliod & Arkle, 2013). These components are important indicators of rangeland conditions associated with grazing, erosion potential, wildlife habitat quality, the resistance of habitats to exotic species invasion, and resilience to changing climates (Herrick *et al*., 2012).

In vegetation studies, selecting an adequate sampling method is paramount for optimizing the performance of vegetation monitoring. An efficient sampling method leads to reduced variance and time of sampling. The selection of an appropriate sampling technique depends on the objectives for the study, the type of data needed, the size of the sampling site and available manpower (Noori et al., 2014).

According to Symstad *et al*. (2006)**,** there is no standardization of methods used in vegetation sampling and analysis. Symstad *et al*. (2006) stated that there have not been many changes to standardization of methods over the years although several investigators have made use of Daubenmire's (1959) described methodology. One main reason for this is because the most appropriate method for measuring the various properties or traits of a plant community depends on the objective of the project for which the measurements are done and the type of vegetation being measured (Symstad *et al*., 2006).

Previous studies have compared traditional observation techniques for qualitative methods for estimating cover and composition of vegetation (Godínez- Alvarez, Herrick, Mattocks, Toledo, & Van Zee., 2009). Some quantitative sampling methods, such as point- and line-intercept sampling, have shown to provide greater accuracy and precision than other methods.

In this chapter, the results of DSS were compared to that of the Whittaker.

6.2 FLORISTIC AND STRUCTURAL COMPARISON OF DISTANCE SAMPLING SOFTWARE TO WHITTAKER METHOD

6.2.1 Comparison of DSS to Whittaker method in woody species composition and species richness detection

The two methods showed a difference in the list of species recorded in the study area (Appendices B & F). Results indicate that only 77% of DSS species list is found in the Whittaker methods species list. It is therefore inferred that applying the DSS method, resulted in the identification and recording of less species compared to the Whittaker method. This difference can be attributed to the shape of the sampling plot or the design of each method for collecting woody species related information in the study area. The Whittaker method is based on square subplots, whereas DSS in this study is based on point transects. Further, DSS and Whittaker methods recorded different woody species in the study area (Appendices B & G). The Whittaker method recorded a total of 19 woody plant families whilst DSS recorded 15 woody plant families in the study area. Further, both sampling methods recorded exactly the same dominant families: the

Fabaceae, Anacardiaceae and Malvaceae. The Whittaker method recorded Anacardiaceae, Fabaceae and Malvaceae family dominating with 11, 8 and 5 woody species respectively compared to DSS, where Anacardiaceae, Fabaceae and Malvaceae family dominated with 10, 7 and 5 woody species respectively. The results showed that the Whittaker method recorded more woody families (and species) than DSS in the study area.

In total, 83 woody plant species were recorded for the study area using both methods. The Whittaker method yielded a total of 47 species whilst DSS had a total of 36 species. This indicates that DSS recorded less species than the Whittaker method. In both open and closed woody vegetation areas, there were differences between the two methods in estimating the total number of species in all sub-plots. The Whittaker method returned significantly higher species richness than DSS (Anova: $F = 6.2$, df = 3, $p \leq 0.05$). We found a large difference between the number of species recorded in the eight 20 m x 50 m plots for both closed and open vegetation areas. The results in Table 6.1, reveal that the highest species richness in all cases was found in the Whittaker plots. Both vegetation sampling methods have delivered different estimates of species richness as the pooled number of species recorded in 1 000 m^2 by the Whittaker method (47 species) was higher than in DSS (36 species).

Table 6.1: Descriptive data for the combined dataset, the Whittaker method (WM) and DSS.

	Whole dataset	**WM**	**DSS**
No of Plots	8	8	8
No of Subplots and/or points	240	40	200
Total Species Richness	83	47	36
Mean No of Species per Plot	10.38	5.88	4.5
Mean No of Species per Subplot	0.35	1.18	0.18

The correlation between species richness and plot size differs for the two methods across the two woody vegetation areas (Whittaker $r = 0.94$ vs. DSS $r = 0.85$). Plot size was significantly related to species richness for both methods (Whittaker: $F = 14.02$, DSS: $F = 3.40$, df = 3, $p > 0.05$), suggesting that the number of species recorded was

proportional to the plot size.

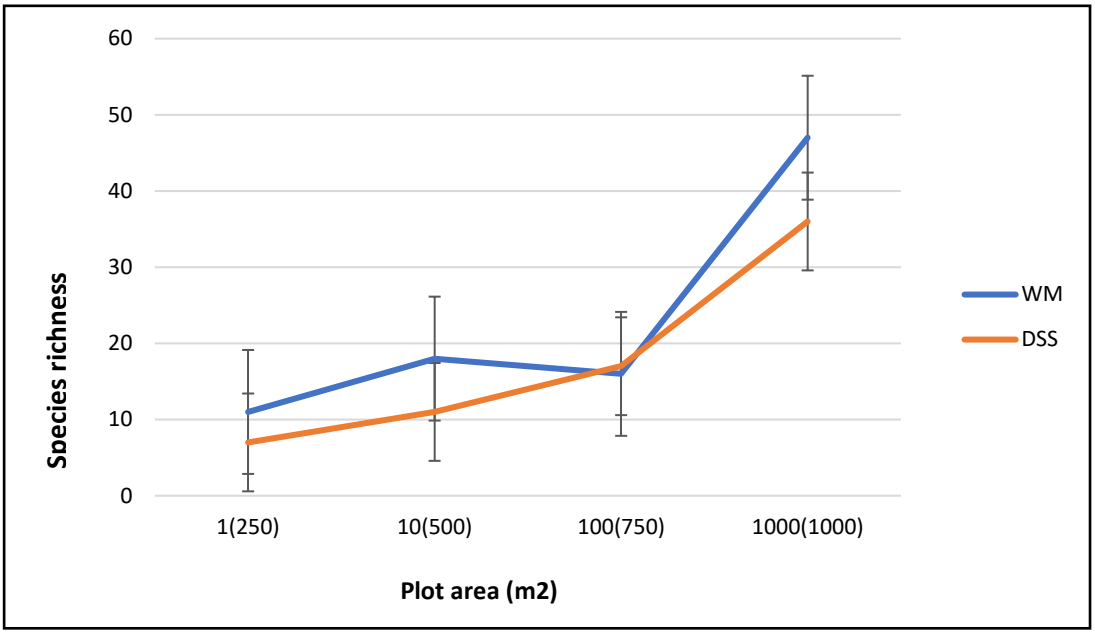

Figure 6.1: Accumulative species richness per subplots and plot of the Whittaker method and distance sampling technique.

The difference in the mean ($\bar{x}$) number of species recorded in sub-plots using the different sampling strategies was high for the Whittaker method (Figure 6.1). The total number of species recorded using both sampling methods in both open and closed woody vegetation areas differed. Walker *et al*. (2015) explains that if woody plant species in an area have a different abundance or spatial distribution, then the probability of species detection may vary not only with regard to sampling method and effort but also differ between the woody plant components in the area. As a result, the sampling methods will produce different ratios in the numbers of woody species per sample area.

We can infer that the spatial arrangement of subplots and their shape within each sampling plot have affected or influenced the overall number of species recorded. The shape and spatial arrangement of the sampling unit affect the cumulative number of plant species recorded in a vegetation survey (Bacaro *et al*., 2015). The Whittaker method's subplots have less overlap than the subplots (points) within the DSS plot; this difference may have been less influenced by spatial arrangement (Stohlgren, Falkner, & Schell, 1995). Systematic placement of subplots in the Whittaker sampling plot made its design reasonably easy to use during the survey, although DSS also provides quality data, it takes more time to sample, but results in detecting less species.

Another possible explanation of the difference in species richness between the two methods may be because both methods greatly differ in their application. The Whittaker plots are square and rectangular whereas, distance sampling software requires a central point to start from within a circular plot. According to Ghorbani, Taya, Shokri, & Naseri (2011), one of the advantages of nested sampling design is to determine the relationship between species richness and plot area, which has been considered as a species-area curve and also allows for more accurate determination of species diversity. In all species-area relationships, the species lines showed that the greatest difference in subplots between the two methods is in sub-plots 1(250) and 10(500) for both methods (Figure 6.1).

Variability among both methods increased with increasing numbers of species in a plot. The Whittaker method detected more species than DSS. The similarity between the two methods due to the species recorded improved the correlation between the number of species and the plot size. We found that the species richness of the two sampling methods increased as the number of plots increased.

The strong positive correlation observed between both species richness and the plot size could be explained by the overall measures of composition, which suggest that the two survey methods capture more or less the same information about the woody plant species occurring in the study area. However, multivariate cluster analysis demonstrated that vegetation survey methods that assessed species composition produced different results at the plot scale most of the time (Kercher *et al*., 2003).

6.2.2 Comparison of DSS to Whittaker method in woody species diversity detection

Biodiversity measurement is mostly centered on the species level and species diversity, which is one of the most important indices used for the evaluation of ecosystems at different scales (Ardakani, 2004). The specific environmental conditions and altitude of the study areas are responsible for its unique species composition and richness.

The woody plant species in open and closed woody vegetation areas resulted in significant variations of diversity and evenness indices (Table 6.2). Our results indicate

that the diversity and evenness provided by the Whittaker method in both open and closed vegetation areas are similar to that of DSS. According to Gotelli & Colwell (2001) the species richness of the sampling area affects estimates of species diversity because the fundamental accumulation of the number of species sampled, lead to species accumulation with sampling effort.

The diversity was analysed per area and was converted into effective numbers (Table 6.2). Results reveal that DSS was similar in terms of diversity to the Whittaker method in both woody vegetation areas, as well as in the entire study area. Results from the ANOVA test to compare the effective numbers indicates that there were no significant differences between the two methods in detecting species diversity (one-way ANOVA: $F = 3.25$, df = 3 $p > 0.05$). After calculating the Shannon-Wiener index, it was found that there were 1.45 EN woody species in the open area and 1.25 EN woody species in the closed woody vegetation areas using the Whittaker method. With the DSS where 1.45 EN woody species in the open and 1.32 EN woody species in the closed woody vegetation area.

Table 6.2: Comparison of the Whittaker method and DSS in species diversity for the woody areas and the overall study area, indicating the Shannon-Wiener index (H'), Evenness (J') and the calculated effective numbers (EN).

	Whittaker				**DSS**			
Area	**Species richness**	**H'**	**EN**	**J'**	**Species richness**	**H'**	**EN**	**J'**
Open	21	0.37	1.45	1.12	14	0.37	1.45	1.14
Closed	35	0.22	1.25	0.06	27	0.28	1.32	0.09
Study Area	47	0.15	1.16	0.04	36	0.11	1.12	0.03

The evenness for the Whittaker was 1.12 (open area) and 0.06 (closed area). This means that every woody species in respective area is evenly distributed. Similarly, DSS, had an evenness of 1.14 (open) and 0.09 (closed).

6.2.3 Comparison of DSS to Whittaker method in woody species density detection

In the open woody vegetation area, the Whittaker method recorded 31 individuals, resulting in 155 ind.ha^{-1} (37%) as opposed to DSS which recorded 206 individuals, resulting in 1 030 ind.ha^{-1} (28%). In the closed woody vegetation area, the Whittaker method recorded 53 individuals, resulting in 265 ind.ha^{-1} (63%) compared to DSS which recorded 531 individuals, resulting in 2 655 ind.ha^{-1} (72%). This suggests that overall DSS recorded a total of 737 individuals, resulting in 1 843 ind.ha^{-1} compared to the Whittaker method that recorded a total 84 individuals, resulting in 210 ind.ha^{-1} in the study area.

Both methods differed in species composition and species richness between the open and closed woody vegetation areas. This is because the two areas represent different structural habitats. Lubke, Morris, Theron, & Van Rooyen (1983) explained that the woody vegetation layer of savanna varies not only in species composition from one area (open) to another (closed) but also in structure, density and biomass. These differences can be attributed to local microclimate, edaphic variation, fire and macroclimatic variations over the period of time.

The decision on which vegetation sampling method to implement will depend on whether the priority is to monitor the number of woody species or not because the objectives of the survey are the key components to the determination of which method to use when conducting vegetation monitoring.

6.2.4 Height class distribution

The woody plants in the study area could be conventionally divided into three height classes (lower, middle and upper). The overall height class distribution of woody plants for the two methods shows a higher number of woody plants in the lower height class and gradually decreases towards the middle and upper height class, indicating continuous representation of woody plants in all height classes (Tilahun, Soromessa, & Kelbessa, 2015). Woody plants in middle and upper height classes together make a density of 255 ind.ha^{-1} for the Whittaker method and 2 075 ind.ha^{-1} for DSS. Although

both methods reveal that the study area is dominated by woody plants above 1 m height, however, DSS recorded a higher density of woody plants than the Whittaker method.

The analysis of density distribution by height classes of woody plants resulted in similar patterns (Figure 6.2). The density distribution of woody plants in different height classes shows a reversed J-shape (Tilahun *et al*., 2015), which shows a distribution in which a number of individual plants in the lower classes are high and decrease towards the middle and upper height classes. This pattern shows a decrease in density with increasing height classes. This means that there is a higher number of woody plants in the lower height class and a gradual decrease towards the middle and upper height classes, indicating a normal distribution of woody plants. According to Tilahun *et al.* (2015) this pattern represents good reproduction status and regeneration potential of woody plants in the study area.

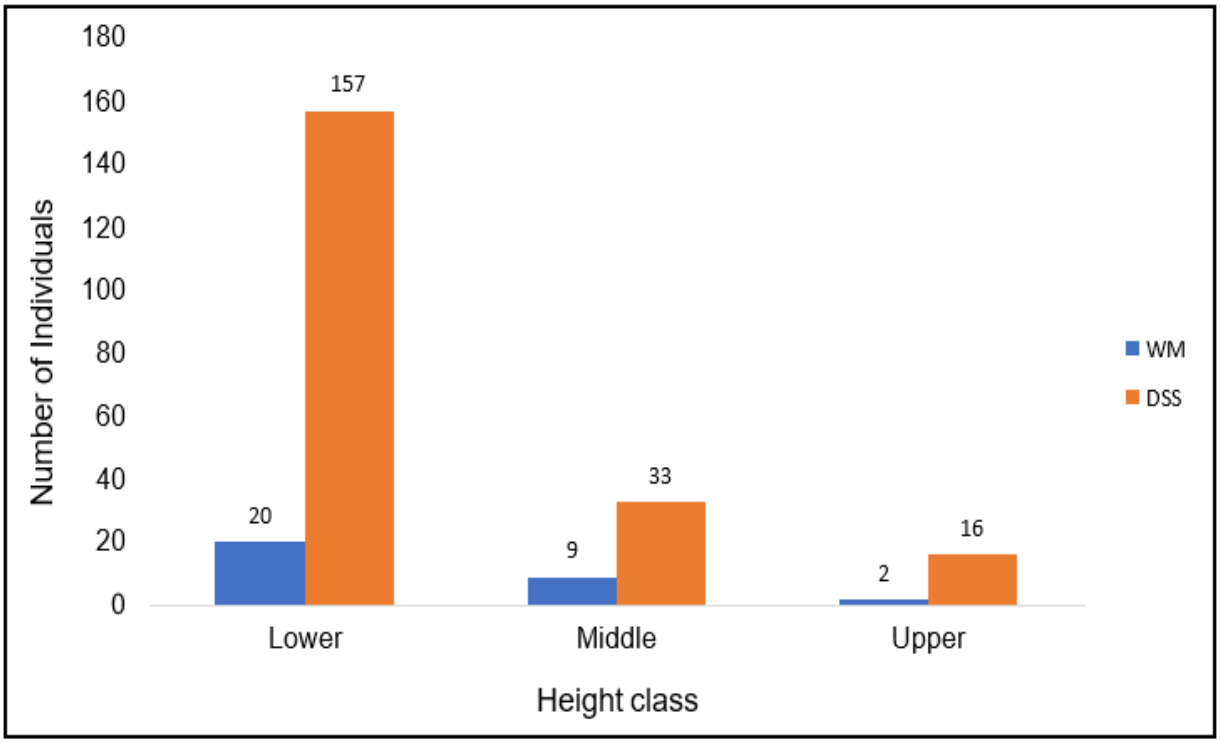

Figure 6.2: Number of plants versus height classes in the study area using Whittaker method (WM) and Distance Sampling Software (DSS).

6.3 COMPARING ACCURACY OF DSS TO RESULTS FROM THE WHITTAKER METHOD

6.3.1 Comparing the accuracy of DSS to Whittaker results in species richness detection

Analysis was performed for DSS and Whittaker data using Microsoft Excel in order to compare their accuracies. In the open woody vegetation areas, the Whittaker method which recorded 31 species (species richness) performed better than DSS, which recorded 14 species. Similarly, in the closed woody vegetation area the Whittaker method recorded 53 species and DSS recorded 27 species.

The results reveal that there were non-significant differences between the Whittaker method and DSS in detecting species richness in the open (Anova: $F = 3.26$, df = 3, $p > 0.05$) and closed (Anova: $F = 2.31$, df = 3, $p > 0.05$) woody vegetation areas. Chi- square test results indicate that in both the open woody vegetation area ($x^2 = 4.31$, df = 1, $p \leq 0.05$) and the closed woody vegetation area ($x^2 = 3.39$, df = 1, $p \leq 0.05$), the accuracy of DSS is significantly lower than the results of the Whittaker method. Overall, the accuracy of DSS ($x^2 = 6.19$, df = 3, $p \leq 0.05$) is significantly lower than the Whittaker method's results for the study area. These results suggest that DSS is less accurate in determining species richness in both open and closed woody vegetation areas.

This difference can be attributed to the difference in the number of species recorded in the study area. The Whittaker method yielded higher number of species as opposed to DSS. This is said to be caused by the fact that the Whittaker method focuses on recording species composition, which results in a higher number of species (species richness). We found that the accuracy increases as the number of species increases, meaning that the higher the number of species the higher the accuracy. The accuracy of DSS to detect species richness is dependent on the number of species recorded. The lower performance of DSS in terms of accuracy in detecting species richness could also be due to the fact that the method requires no sub-plot setup, instead the field technician can navigate to the random point of interest. However, the systematic placement of the Whittaker method's sampling plots could have possibly impacted or influenced the number of species recorded. According to Noori *et al*. (2014), plot

placement and distribution could also influence overall species richness, while according to Stockwell & Peterson (2002), the local ecological adaptation of species is a major phenomenon that decreases the accuracy of species detection.

6.3.2 Comparing accuracy of DSS to Whittaker results in species diversity detection

The analysis of data reveals that DSS is similar to the Whittaker method as both methods yield a similar effective number (diversity) in both open and closed woody vegetation areas. To determine the significant difference, we performed a parametric ANOVA test (Hawkins, 2005). Therefore, the results show that there is non-significant difference between the Whittaker method and DSS in detecting species diversity in the open (Anova: $F = 3.80$, df = 3, $p > 0.05$) and closed (Anova: $F = 2.04$, df = 3, $p > 0.05$) woody vegetation areas.

We also performed a chi-square test to compare the accuracy of DSS to the Whittaker method in each woody vegetation area. We found that there is non-significant difference between the accuracy of DSS to the Whittaker results in detecting species diversity in the closed and open woody vegetation areas. In both the open woody vegetation area ($x^2 = 4.04$, df = 1, $p \leq 0.5$) and the closed woody vegetation area ($x^2 = 2.02$, df = 1, $p \leq 0.05$), the accuracy of DSS is close to the Whittaker method's results. Overall results in the study area ($x^2 = 3.21$, df = 3, $p \leq 0.05$) show that the accuracy of DSS is close to the Whittaker method in detecting woody species diversity.

We found that the accuracy of DSS method depends on the effective number of woody species scored. The higher the effective number of DSS, the more accurate DSS is. The lower number of woody species (species richness) recorded by the DSS method did not influence its ability to score accuracy values similar to the Whittaker methods results in detecting species diversity in the study area. We conclude that the number of species recorded by the DSS method does not have an impact on the method's accuracy in detecting species diversity, compared to the results of the Whitaker method, in the study area.

6.3.3 Comparing accuracy of DSS to Whittaker results in species density detection

Distance sampling software was most efficient because it detected the greatest number of individuals per unit area (density) at both woody vegetation areas and provides great interpretive power because woody plant observations included the same spatial scales. However, we did not find any significant difference between the Whittaker method and DSS in detecting species density in the study area (ANOVA: F= 7.52, df = 3, $p > 0.05$). Further, we compared the accuracy of DSS to the Whittaker results in determining density in the study area using the chi-square. The result reveals that there is no significant difference between the two methods in detecting species density. The chi-square value of DSS (x^2 = 65.50, df = 3, $p > 0.05$) is greater or equal to the chi-square value of the Whittaker method (x^2 = 30.93, df = 3, $p > 0.05$) in the study area. This suggests that the accuracy of DSS is close to the results from the Whittaker method in determining species density in the entire study area.

DSS remains as efficient as the Whittaker method in detecting the number of individuals per unit area as we found no significant difference. The similarity in accuracy of DSS to the results of the Whittaker method at determining species density is potentially attributed to its ability to record a high number of individuals (abundance).

6.4 COMPARING PRECISION AND POWER TO DETECT CHANGE OF DSS TO THE WHITTAKER METHOD

6.4.1 Comparing precision and power to detect change in species richness of DSS to Whittaker method

In the open woody vegetation area, the comparison of data between the two methods reveals that there is no significant difference between the precision of the Whittaker method and DSS in determining species richness (ANOVA: F = 18.50, df = 3, p > 0.05). We found that the Whittaker method (22.84% CV) has a similar coefficient of variation with DSS (21.43% CV) in the open woody vegetation area. This result indicates that the Whittaker method and DSS have similar repeatability. One could potentially infer that both methods are equally precise in the open woody vegetation area. However, we found that in the closed woody vegetation area the Whittaker

method (13.68% CV) has a higher coefficient of variation than DSS (7.11% CV). The coefficient of variation of the Whittaker method is about twice the coefficient of variation of DSS, suggesting that the repeatability of the Whittaker method is about twice lower than the repeatability of DSS. This implies that DSS has less variation in species richness detection and therefore yields greater confidence in the repeatability of the sampling plots. We can infer that DSS is more precise than the Whittaker method at determining species richness in the closed woody vegetation area.

Further, we compared precision of both the Whittaker method and DSS in the study area and results are provided in Table 6.3. No statistical significance difference in precision was found between the Whittaker method and DSS in determining species richness in the study area (ANOVA: $F = 5.47$, df = 3, $p > 0.05$). We found that Whittaker method (35.32% CV) has a higher coefficient of variation than DSS (43.76% CV), suggesting that the Whittaker method has a higher repeatability and a lower variation between species richness detection in the study area. This indicates that the Whittaker method is more precise than DSS in the study area.

Table 6.3: Comparison of descriptive statistics of the Whittaker method and DSS for species richness in the study area.

#	**Whittaker method**	**DSS**
Mean	28	21
Standard Error	7	6.5
Median	28	20.5
Standard Deviation	9.89	9.19
Variance	98	84.5
Range	14	13
Sum	56	41
95% Confidence Interval	88.94	82.59

The lower variability of Whittaker method among sampling plots within the closed woody vegetation area, made the Whittaker method more precise in determining species richness. Although it is difficult to attribute this difference to any one factor, it is possible that a large part of it was caused by the larger number of species recorded by the Whittaker method. Whatever the cause of this difference, it did not substantially affect the precision obtainable by the two methods. Both sampling methods proved to

be equally good at obtaining precise measurements of species richness in the study area.

The analysis of results reveals that in the open woody vegetation area, the Whittaker method (22.84% CV) and DSS (21.43% CV) resulted in two similar resolutions R_W =0.90 (Whittaker method) and R_D = 0.85 (DSS) or an 80% probability of being able to detect a 90% and 85% change in species richness between the sampling plots of the open woody vegetation areas respectively. However, in the closed woody vegetation area the Whittaker method (13.68% CV) and DSS (7.11% CV) resulted in two different resolutions R_W = 0.54 (Whittaker method) and R_D = 0.28 or an 80% probability of being able to detect a 54% and 28% change in species richness between the sampling plots of the closed woody vegetation areas respectively.

These results indicate that both the Whittaker method and DSS have the same capacity to detect change in species richness in the open woody vegetation area. Whereas in the closed woody vegetation area the Whittaker method exhibits a greater power to detect change in species richness as opposed to DSS, which is missing some species and therefore is more likely to provide an underestimate of the true number of woody species in the closed woody vegetation area. We found that the higher the precision, the lower the power to detect change in species richness and the lower the precision the higher the power to detect change in species richness.

We also compared the power to detect change in species richness between the two woody vegetation areas for both sampling methods in the study area. Overall, the Whittaker method (35.32% CV) and DSS (43.76% CV) resulted in two different resolutions R_W = 1.40 and R_D = 1.73 or an 80% probability of being able to detect a 140% and 173% change in species richness between the open and closed woody vegetation areas of the study area respectively. Both the Whittaker method and DSS exhibit a greater power to detect change in species richness as they both have over 100% capacity to detect change in species richness between the open and closed woody vegetation areas. This suggests that both sampling methods are efficient, reliable and nature conservationists should consider taking them into account when monitoring woody vegetation areas.

6.4.2 Comparing precision and power to detect change in species diversity of DSS to Whittaker method

A test of difference was performed using ANOVA to find a significant difference between both methods. We found that there is statistically a non-significant difference between DSS and Whittaker method's precision in detecting species diversity in the closed woody vegetation area (ANOVA: $F = 11.10$, df = 3, $p > 0.05$). However, we found a significant difference in precision between DSS and Whittaker method in detecting species diversity in the open woody vegetation area (ANOVA: $F= 15.83$, df = 3, $p \leq 0.05$).

The findings indicate that in the open woody vegetation area, the Whittaker method (7.98% CV) has a higher coefficient of variation than DSS (2.13% CV) and in the closed woody vegetation area. Whittaker method (15.68% CV) still has a higher coefficient of variation than DSS (6.22% CV). These results show that in the open and closed woody vegetation areas, the Whittaker method has a higher coefficient of variation than DSS, suggesting that DSS has a higher repeatability among the sampling plots, whereas the Whittaker method shows a wide variation among the sampling plots. These results indicate that DSS is more precise than the Whittaker method in detecting species diversity between the sampling plots of both open and closed woody vegetation areas.

Overall, the comparison of both sampling methods reveals that the Whittaker method (10.37% CV) outperforms DSS (6.47% CV) in terms of variation between the open and closed woody vegetation areas. Results are provided in Table 6.4. This indicates that Whittaker variation is higher than the variation of DSS in the study area, suggesting that DSS shows greater confidence in the repeatability of the survey than the Whittaker method. This implies that DSS is more precise in detecting species diversity than the Whittaker method. Further analysis reveals that no significant difference was found between the precision of the Whittaker method and the precision of DSS in detecting species diversity in the study area.

We also found that the precision of DSS increases with increasing species diversity, whereas the precision of the Whittaker method decreases with decreasing species diversity. In other words, the higher the species diversity estimate, the higher the

precision and the lower the species diversity estimate the lower the precision. This difference can be attributed to each sampling method's ability to record species richness. In addition to increasing precision, adding sampling plots would, in most cases, increase the number of species quantitatively sampled by either method (Symstad *et al*., 2006). Species-sample number curves show that this increase would be greater for the DSS. Floyd & Anderson (1987) found that sampling more plots will increase precision. With any of the methods, adding more sampling plots would require more sampling time at an individual plot.

Table 6.4: Comparison of descriptive statistics of the Whittaker method and DSS for species diversity in the study area.

#	**Whittaker method**	**DSS**
Mean	1.35	1.39
Standard Error	0.1	0.07
Median	1.35	1.39
Standard Deviation	0.14	0.09
Variance	0.02	0.01
Range	0.2	0.13
Sum	2.7	2.77
95% Confidence Interval	1.27	0.83

Furthermore, the power to detect change in species diversity for both methods was compared in both woody vegetation areas as well as in the study area. In the open woody vegetation area, the Whittaker method (7.98% CV) and DSS (2.13% CV) resulted in different resolutions $R_W = 0.32$ and $R_D = 0.08$ or an 80% probability of being able to detect a 32% and 8% change in species diversity respectively between the sampling plots of the open woody vegetation area. Whereas in the closed woody vegetation area, the Whittaker method (15.28% CV) and DSS (6.22% CV) resulted in different resolutions $R_W = 0.61$ and $R_D = 0.25$ or an 80% probability of being able to detect a 61% and 25% change in species diversity respectively between the sampling plots of the closed woody vegetation area.

However, overall, the Whittaker method (10.37% CV) and DSS (6.47% CV) resulted in two different resolutions $R_W = 0.41$ and $R_D = 0.26$ or an 80% probability of being able to detect a 41% and 26% change in species diversity between the open and the closed

woody vegetation areas of the study area respectively. This implies that DSS has a lower power to detect change in species diversity and therefore is more likely to provide an underestimate of the true species diversity. Further, the Whittaker method requires a large change in species diversity between the open and closed woody vegetation areas before it can be detected in the study area.

6.4.3 Comparing precision and power to detect change in woody density of DSS to Whittaker method

In the open woody vegetation area, the comparison of data between both sampling methods indicates that there is no significant difference between the precision of the Whittaker method and DSS in determining woody species density (ANOVA: $F = 2.16$, df = 3, $p > 0.05$). The Whittaker method (13.69% CV) has a lower variation compared to DSS (24.71% CV) in the open woody vegetation area. We also found that in the closed woody vegetation area the Whittaker method (13.34% CV) has a higher repeatability among the sampling plots than DSS (31.28% CV). These results suggest that the Whittaker method is more precise than DSS in determining woody plant density in the open and closed woody vegetation area.

Further, we also compared both the Whittaker method and DSS in the study area and results are provided in Table 6.5. The test of difference indicates that there was no significant difference between the precision of the Whittaker method and DSS in determining species density in the study area (ANOVA: $F = 5.46$, df = 3, $p > 0.05$). We found that the Whittaker method (37% CV) has a higher repeatability than DSS (62% CV) between both open and closed woody vegetation areas of the study area, suggesting the Whittaker method is more precise than DSS in determining species density. We found that despite the difference in species density recorded, the precision of each sampling method at detecting species density did not differ in any woody vegetation area as well as in the study area. We can say that the density recorded did not influence the precision of DSS and Whittaker method.

Table 6.5: Comparison of descriptive statistics of Whittaker method and DSS for species density in the study area.

#	Whittaker method	DSS
Mean	210	1843
Standard Error	55	813
Median	210	1843
Standard Deviation	77.78	1149
Variance	6 050	1 320 313
Range	110	1620
Sum	420	3685
95% Confidence Interval	658.84	10324.79

The analysis of results reveals that in the open woody vegetation area, the Whittaker method (13.69% CV) and DSS (24.71% CV) resulted in two different resolutions R_W = 0.54 (Whittaker method) and R_D = 0.98 (DSS) or an 80% probability of being able to detect a 54% and 98% change in species density in the open woody vegetation areas respectively. On the contrary, in the closed woody vegetation area the Whittaker method (13.34% CV) and DSS (31.28% CV) resulted in two different resolutions R_W = 0.53 (Whittaker method) and R_D = 1.24 or an 80% probability of being able to detect a 53% and 124% change in species density in the closed woody vegetation areas respectively. Results indicate that the Whittaker method and DSS have different capacities to detect change in species density in the open as well as closed woody vegetation areas.

Further, findings indicate that the Whittaker method as well as DSS have an equal capacity (value estimates) to detect change in both open and closed woody vegetation areas respectively. In other words, the Whittaker method has the same (percentage) power to detect change in species density in the open and closed woody vegetation area. Nevertheless, DSS in all cases has the highest capacity to detect change in the open and closed woody vegetation area and is therefore a suitable method for monitoring.

We also compared the power to detect change in species density for both sampling methods in the study area. Overall, the Whittaker method (37% CV) and DSS (62%

CV) resulted in two similar resolutions R_W = 1.47 and R_D = 2.47 or an 80% probability of being able to detect a 147% and 247% change in species density in the study area respectively. Both the Whittaker method and DSS have over 100% capacity to detect change in species density, suggesting that both Whittaker method and DSS are equally capable of detecting change in species density in a woody vegetation area.

6.5 COMPARISON OF ECONOMIC VALUE OF DSS TO WHITTAKER METHOD

With the growing concern of biodiversity, long-term ecological monitoring is important for conservation as it provides essential information on the effectiveness of management interventions (Singh & Milner-Gulland, 2011). Long-term ecological monitoring reduces uncertainty and forms the basis of decision-making by managers (Bunnefeld, Hoshino, & Milner-Gulland, 2011).

Moore, Balmford, Allnutt, & Burgess (2004) explain that many protected areas have financial constraints and operate with limited funds. As a result, this place emphasis on the development of cost and time efficiency of monitoring methods (Caughlan & Oakley, 2001). Despite the financial problems faced by protected areas, little attention has been paid to cost and time efficiency of vegetation survey methods, although such methods are selected based on their effectiveness in terms of accuracy and precision (Gaidet-Drapier *et al*., 2006). According to Kinahan & Bunnefeld (2012), cost effectiveness is very important in the choice of the appropriate sampling method to ensure its successful implementation and sustainability. Only cost efficiency may permit adequate planning which includes deciding on the number of people, time allocated and sample size within budgetary and technical constraints (Gaidet-Drapier *et al*., 2006).

6.5.1 Sampling and time efficiency

Church, Williams, Hild, & Paige (2011) explained that the initial data collection on a site is to develop a baseline inventory, which provides both ecological and management information about the sampling area. According to Barker (2001) effective monitoring practices enable managers to evaluate the effectiveness of their management actions and develop more appropriate management practices over time. Several factors may have influenced the efficiency of both methods, and this may include the degree of

vegetation heterogeneity, the survey design and the size of the area surveyed. Table 6.6 compares the two methods in terms of time and number of species recorded.

The results showed that the sampling times of the Whittaker method differed across the open and closed woody vegetation areas and were significantly lower than the time obtained from DSS in the open and closed vegetation areas. Further, DSS was significantly faster than the Whittaker method (*t*-test: $t = 2.92$, df = 3, $p \leq 0.05$) in terms of time to conduct the survey. On average, it took 1.48 hours (SE = 0.94 hr.) longer for a two-person team to complete the sampling of four plots with DSS than with the Whittaker method. The significant difference in sampling times between the two methods increased with species richness (Coefficient of determination: $r^2 = 0.08$, df = 3, $p \leq 0.05$).

The Whittaker method is less time consuming (more time-efficient) for doing woody plant surveys in both open and closed woody vegetation areas. It should be noted that the efficiency of the Whittaker method is caused by the fact that the method does not record species abundance, instead it only focuses on species richness. Survey methods should provide information on the highest possible number of species in the shortest time (Godínez-Alvarez *et al*., 2009), because the finances to conduct monitoring programmes are always limited. Survey methods should ideally be objective, precise and time-efficient (Havstad & Herrick, 2003).

Table 6.6: Comparison of mean sampling effort for DSS versus Whittaker method.

Method	Total area (ha)	Total observation time	Number of species
Whittaker	0.4	4h27	47
DSS	0.4	6h15	36

The Whittaker method was significantly faster than DSS, indicating that it takes less time to do a survey, using the Whittaker method. Miller, Witwicki, & Mann (2006) attribute this difference between methods to the greater number of species obtained, which is also consistent with our results as DSS recorded the highest number of species in the study area. The rapidity of the Whittaker method at recording species richness gives this sampling method an advantage over DSS, indicating less sampling effort

required. Rangeland managers are looking for sampling methods that are time efficient and deliver highly accurate results. In this case, we recommend the Whittaker method as a long-term sampling method for woody vegetation.

The greatest difference between the two methods was efficiency, both in terms of the time to complete the survey and in the number of species recorded by each method. The Whittaker method was more efficient and more predictable in terms of time, whereas DSS was more efficient at recording more species (species richness). Species recorded by the Whittaker method but missed by DSS were relatively low in number

6.5.2 Sampling effort and cost efficiency

Our results show that DSS requires more effort in both open and closed woody vegetation areas, compared to the Whittaker method as DSS recorded woody plant species abundance in both vegetation areas, as opposed to the Whittaker method that only records the number of species (species richness). Distance sampling software is less efficient as a survey method, with greater encounter rate of species in the study areas (Table 6.6), which requires more effort. However, the cost to survey both woody vegetation areas was higher for the Whittaker method than DSS. Whittaker method had a survey total cost of R1 258 as opposed to DSS with a total survey cost of R513, because the Whittaker method requires more materials for setting the sampling plot.

Both Whittaker and DSS are useful vegetation monitoring methods (Kinahan & Bunnefeld, 2012). They both have advantages and disadvantages (Table 6.7). According to Symstad, Wienk, & Thorstenson (2008) it is important to look at the advantages and disadvantages when designing a long-term monitoring programme.

Based on the results of this study, we can infer that the Whittaker method, although less cost-efficient than DSS, is still cost-efficient for doing surveys in woody vegetation areas. We recommend that managers should take note of the advantages, limitations, and costs of the Whittaker method and DSS when considering which method to use for monitoring woody vegetation. In this case, the objectives of the sampling or monitoring to be done should dictate what data is required and which method to use.

Table 6.7: Advantages and disadvantages of the Whittaker method and DSS.

	Whittaker Method	DSS
Advantage	-Records species presence (species richness) -Requires less sampling time -Large plot size -Records percentage cover -Records life form (LV) -Records phenological character (flowing, fruiting, growth condition) -Records density (sp.ha^{-1})	-Records species abundance, richness & frequency -Records density (sp.ha^{-1} & ind.ha^{-1}) -Plotless method but can be done in quadrat plot (rectangle, square so forth) -Measures distance -Requires less sampling equipment -Data analysis using distance software -Method includes point transects or circular plot -Cost efficient
Limitations	-Difficult to understand the technical aspect - Requires more sampling equipment	-Analysis engines estimate only density and abundance - Requires more sampling time -Requires more effort -Method does not work well in small survey plots
Similarity	**-**Can be established randomly, systematically, or subjectively -Records density (sp.ha^{-1}) -Measures efficient data -Determines growth form	

Little information on the cost of monitoring methods is available (Gaidet-Drapier *et al*., 2006), and the comparison of costs is difficult because the economic situation of the country varies. Distance sampling software can be widely used for its capacity to cover large areas at low cost, but it requires more effort compared to the Whittaker method. With low cost attached to their implementation, both methods can be less susceptible to budget constraints hence more sustainable in the context of community-based vegetation monitoring programmes (Gaidet-Drapier *et al*., 2006). There are many other methods that we did not take into consideration, that could also be used in certain circumstances, and that might be better than either of the two methods investigated. We recommend further research to investigate these methods.

According to Gaidet-Drapier *et al*. (2006), depending on the type of data needed, in some instances, a simple and low-cost method may be the most suitable method for conducting a vegetation survey in an area. With the increasing need for cost and time efficiency monitoring in various ecological contexts (Walsh & White, 1999), monitoring

techniques should be adapted to site-specific conditions and rely on local facilities rather than being restricted to a standard methodology (Gaidet-Drapier *et al.,* 2006).

6.6 SUITABILITY OF VEGETATION SAMPLING METHODS

The costs of conventional methodologies employed during a vegetation survey are prohibitive for conservation projects that have no financial assistance (Plumptre, 2000). For a vegetation monitoring programme that relies on limited resources, a sampling method should be cost-effective to be used by rangeland managers (Gaidet, Fritz, & Nyahuma, 2003). Sophisticated or expensive sampling methods compared to simple or ordinary ones may, in some instances, provide better estimates of plant species (Peel & Bothma, 1995). In situations where DSS and the Whittaker method involve high costs and/or effort, and where this limits their use in vegetation management, alternative methods such as the Braun-Blanquet method and step point methods can be used, as they have been proposed and implemented with success elsewhere (Mentis et al., 1980 and Shmida, 1984), but it must be emphasized that it depends on what the objectives of the surveys and/or monitoring are.

Many vegetation sampling methods such as DSS require scientific expertise, as the methods produces results that are not quick and easy to interpret (Danielsen, Burgess, Jensen, & Pirhofer-Watzl, 2010). In this study, we did not include the fieldwork and the analysis of data costs by scientific experts because it is hard to estimate the cost of having a quantitative scientist available for a single study (Kinahan & Bunnefeld, 2012). As a result, we only calculated the minimum costs of DSS in this study. The real costs may be higher if we included the services of qualified scientists. The Whittaker method provides cost-saving to rangeland managers, whereas DSS involves significant time and cost for data entry and expertise in its analysis and data interpretation. The Whittaker method is, therefore, more likely to be accepted by rangeland managers to support and improve protected area vegetation monitoring programmes.

Our results show that the DSS was more cost-efficient than the Whittaker method. Despite its limitations, the Whittaker method is preferred for large areas and for determining species composition, due to its ability to record species presence/absence (Shmida, 1984).

6.7 IMPLICATIONS OF USES OF DSS AND WHITTAKER METHOD IN WOODY VEGETATION MONITORING

The evaluation of the Whittaker method and DSS revealed that both methods provided adequate quality data for woody vegetation surveys, but although there is some overlap, they collect different data. The selection and use of a particular method should therefore depend on the objectives of the sampling to be done (Pilliod & Arkle, 2013). We found that both methods were efficient and effective field methods for the characterisation of vegetation or habitat heterogeneity across landscapes of interest. Both methods have limitations, and we emphasize the importance to rangeland managers of keeping these limitations in mind, especially factors which may influence the outcome or results of the sampling, such as low species abundance and low species richness that may influence precision. We found that DSS performed well despite its disadvantages and may be added to other existing woody vegetation monitoring or sampling methods in managed rangeland areas. Nevertheless, both the Whittaker method and DSS were equally good at detecting changes in species richness, species diversity and species density.

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CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Vegetation structure

The results of the present study revealed that the Whittaker method recorded the highest species composition and species richness. However, the two methods result in similar species diversity. The application of both the Whittaker method and DSS indicated the same dominant families, namely Fabaceae, Anacardiaceae and Malvaceae. The total number of woody plants per hectare in the study area was 1 843 ind.ha^{-1} for DSS and 210 ind.ha^{-1} for the Whittaker method. The species population structure showed different dynamics. The majority of woody species recorded were less than 2m. Few woody plants occur in the upper height classes for both sampling methods, showing variation in population size. The overall height class distribution for the Whittaker method and DSS shows a higher number of woody plants in the lower height class and gradually decreases towards the middle and upper height class, indicating a reversed J-shape pattern.

When we compared detection efficiency of both methods, the cheapest method we employed (DSS) recorded the highest numbers of individual plants per hectare. The highest detection efficiency was obtained using the DSS, which only recorded the number of individuals, forcing the observer to survey at a low speed. Gaidet-Drapier *et al*. (2006) explained that plant species density determines the potential encounter rate of species count. The sensitivity of a method to detect individual plant is advantageous in an area of low plant density. At high plant density, a high species encounter rate may compensate for poor detection; therefore, methods offering high species richness should be considered to maximise sample size. Levels of woody species abundance may thus determine the relative efficiency of methods, and plant density is an important factor to consider in the selection of a suitable monitoring method. Dense areas may have imposed a low speed to DSS, thus a faster method like the Whittaker method may be more effective in this context. A vegetation constraint such as dense bush is more problematic for DSS when it is pronounced in areas with high vegetation cover (Jachmann, 2002). Detection efficiency of sampling methods may differ from one

species to another (Reilly & Haskins, 1999). However, in different areas, large differences in detection efficiency are still found between methods (Gaidet-Drapier *et al*., 2006). The application or use of the methods to detect plant species depended on the distribution of species in the area. This suggests that the vegetation structure in our study area played a significant role, especially in explaining the differences in species recorded between slow-moving method (DSS) and fast-moving method (Whittaker method).

According to Gaidet-Drapier *et al*. (2006), the selection of a sampling method has always been a trade-off between the advantages and disadvantages of the method, with respective merits varying according to conditions of the study site. The current study showed that a high sampling effort and low-cost method is more efficient at sampling a woody vegetation area. This was contrary to Gaidet-Drapier *et al*. (2006), who showed that a simple, low speed and low-cost method is in some instances, the most suitable method to monitor an area and collect plant species data. With the increasing need for conservation monitoring in various ecological contexts (Walsh & White, 1999), vegetation sampling methods must be adapted to site-specific conditions and rely on local facilities rather than being restricted to a standard methodology (Hulme & Taylor, 2000).

7.2 Comparing accuracy of DSS to results from the Whittaker method in species detection

The results revealed that the accuracy of DSS is lower to the results from the Whittaker method in determining species richness in both open and closed woody vegetation areas, as well as in the entire study area. The results demonstrate that DSS has a similar accuracy to the results from the Whittaker method in determining woody plant density. However, the results showed that the DSS has a similar accuracy to the results from the Whittaker method in detecting species diversity in the open and closed woody vegetation areas and in the entire study area.

7.3 Precision and power to detect change of DSS to Whittaker method

In this study, the results indicated that there is no significant difference in terms of precision between the Whittaker method and DSS at detecting species richness, species diversity and species density in the entire study area. The results show that both methods are equally precise in the open woody vegetation area. However, DSS shows less variation in species richness detection and therefore yields a greater confidence in the repeatability of the sampling plots, which resulted in DSS being more precise than the Whittaker method at detecting species richness in the closed woody vegetation area. We found that the Whittaker method and DSS are equally precise in detecting species richness in the entire study area.

Further, we demonstrated that DSS has a higher repeatability among the sampling plots, whereas Whittaker method shows a wide variation, concluding that DSS is more precise than Whittaker method in detecting species diversity in the open and closed woody vegetation areas, as well as in the entire study area. We found that Whittaker method is more precise than DSS in the open and closed woody vegetation areas as well as in the entire study area in detecting species density.

At the end of the study, it was found that both methods provide quality data that are beneficial to rangeland managers for vegetation monitoring programmes. The results indicate that Whittaker method and DSS have a greater power with an 80% probability of being able to detect a 90% and 85% change in species richness in the open woody vegetation areas respectively, while in the closed woody vegetation area Whittaker method and DSS have an 80% probability of being able to detect a 74% and 28% change in species richness respectively. This resulted in both Whittaker method and DSS exhibiting a greater power to detect change in species richness with over 100% capacity to detect change in species richness in the study area. We found that Whittaker method and DSS have an 80% probability of being able to detect a 41% and 26% change in species diversity in the study areas respectively, suggesting that DSS has a lower power to detect change in species diversity as opposed to Whittaker method, which shows moderate power. However, Whittaker method and DSS have a higher power with over 100% capacity to detect change in woody plant density, suggesting that both Whittaker method and DSS are equally capable of detecting change in woody plant

density within a woody vegetation area.

7.4 Time and cost efficiency

The greatest difference between the two sampling methods that emerged as we executed them, was the efficiency, both in terms of cost and time to complete the surveys. Whittaker method was more efficient and more predictable in terms of time taken to do the survey; whereas DSS was more effective and cost efficient in achieving the monitoring objective. We found that the average amount of time to complete the Whittaker method was 4h27, whereas it was 6h15 for DSS. Although we did not consider traveling time in this study, we recommend that travel time to sampling plots be taken into account in the final decision, regardless of which method is chosen.

According to Miller *et al*. (2006) the time it takes to reach a sampling site could easily be greater than the amount of time necessary to do the sampling. We found that both the effectiveness and cost-efficiency of DSS revealed important insights for the future monitoring scheme of LDNR and may result in dramatic cost savings. We indicated the importance of including economic costs when comparing monitoring methods in pilot studies so that appropriate recommendations can be provided for economically feasible monitoring plan (Kinahan & Bunnefeld, 2012).

In conclusion, each method has its own strengths and limits. The Whittaker method is intensive, especially when setting up the plot and takes the least amount of time to complete the survey. It requires more equipment to implement compared to DSS. It is effective, creates the least extensive species richness list for rangeland managers to track changes in species over time and does not capture species frequency and abundance. Surveying the woody vegetation using DSS takes more time compared to the Whittaker method. The DSS method requires less equipment. The consistent estimates of cover percentage are easily made. Due to the length time required to complete the survey, personnel might also be exposed to safety issues during the sampling process, especially in a bigger area with any of the ‘big five’ animals present. A finding of this study is that DSS is less effective at capturing species richness. Both methods seem to be effective in areas where the vegetation is homogeneous. There was much more variation between results of the DSS and the Whittaker method,

especially in species richness.

RECOMMENDATIONS

We are aware that our study has limitations. Contrary to the project by Sikkink *et al*. (2013), who assessed five field sampling methods over a long-term and on a broad scale in the Yellowstone National Park, our study only compared one method to another (DSS and Whittaker method) over a short-term. We do, however, recommend that further studies investigate comparing these methods over a longer period and on a broader scale. Nevertheless, we recommend that South African ecologists, consider implementing both DSS and the Whittaker method in their vegetation monitoring programme due to their economic value and ability to record detailed data.

Shmida (1984) and Buckland *et al*. (2001) stated that both the Whittaker method and DSS are valuable tools for quantifying and detecting trends in species richness. Our study confirms this statement. They are both easy to establish, cost-effective and yield abundant and detailed information. Their flexibility may permit them to be combined or used with any other established sampling methods. They detect similar species in a woody vegetation area and allow for statistical comparisons, although only DSS can, provide information on the spatial distribution of species. The Whittaker method can however be modified/adapted to provide spatial information, identify species, and record cover and frequency. To take full advantage of the different strengths of both the Whittaker method and DSS, we recommend that both methods should be used for vegetation monitoring. In addition, combining these methods may increase detection of species with minimal cover that may not be readily detected by DSS neither by Whittaker, which will improve species richness results. If the objective of a study is to determine abundance (individual numbers of species), DSS may be preferred over the Whittaker method. However, because vegetation attributes such as species richness is important to ecosystem function, and because managers have to document vegetation responses to management actions taken over time, the use of DSS alone may not be effective. Due to the ease of use of both methods, it should be possible to integrate either DSS or the Whittaker method into most other sampling methods.

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APPENDIX A

Sampling data sheets.

DATA COLLECTION SHEET								
Method:								
Date:				**Altitude (m)**				
GPS Coordinates	**S:**		**S:**		**S:**		**S:**	
	W:		**W:**		**W:**		**W:**	
Dominant species								
Evidence of fire:			**Present**		**Absent**			
Slope: None (3-8º) Moderate (8-16 º) Steep (16-26 º) Very steep (26->45º)								
Stone cover: 0-20% 21-40% 41-60% 61-80% >80%								
Stone size: Gravel (<10 mm) Small stones (10-50mm) Stones (>50-200mm) Rocks (>200mm)								
Soil erosion: Slight (10-30%) Moderate (30-60%) Severe (>60%)								
Degree of trampling: None Mild Severe								
Evidence of herbivory: Yes No								
Woody plants associated:								
Note								

DATA COLLECTION SHEET								
Sampling Method: Whittaker method								
Dominant species								
Plot size: 20 m x 50 m						**Plot no:**		
Species	**Growth form**	**Presence (sub-plot)**				**Height**		
		1	**10**	**100**	**1000**	**< 1m**	**[1;2.5m[**	**>2.5m**

DATA COLLECTION SHEET									
Sampling Method: DSS									
Dominant species:									
Plot size: 20 m x 50 m							**Plot no:**		
Point	**Species**	**GF**	**Distance**				**Height**		
							< 1m	**[1;2.5m[**	**>2.5m**

APPENDIX B

List of woody plant species found in the study area with their family names.

Species names	GF	Family	Species names	GF	Family
Annona senegalensis	Shrub	Annonaceae	*Hippocratea parvifolia*	Shrub	Celastraceae
Berchemia zeyheri	Tree	Rhamnaceae	*Lannea discolor*	Shrub	Anacardiaceae
Bridelia mollis	Tree	Phyllanthaceae	*Lannea edulis*	Shrub	Anacardiaceae
Burkea africana	Tree	Fabaceae	*Maerua cafra*	Shrub	Capparaceae
Carrisa bispinosa	Shrub	Apocynaceae	*Mundulea sericea*	Shrub	Fabaceae
Combretum apiculatum	Tree	Combretaceae	*Osyris lanceolata*	Shrub	Santalaceae
Combretum collinum	Tree	Combretaceae	*Ozoroa laecans*	Shrub	Anacardiaceae
Commiphora edulis	Tree	Burseraceae	*Ozoroa paniculosa vs. paniculosa*	Shrub	Anacardiaceae
Commiphora harveyi	Shrub	Burseraceae	*Ozoroa sphaerocarpa*	Tree	Anacardiaceae
Crotalaria monteiroi var. *galpinii*	Tree	Fabaceae	*Pappea capensis*	Tree	Sapindaceae
Dichrostachys cinerea	Tree	Fabaceae	*Pyrostria hystrix*	Shrub	Sapindaceae
Dombeya rotundifolia	Tree	Malvaceae	*Searsia keetii*	Shrub	Anacardiaceae
Dovyalis caffra	Shrub	Salicaceae	*Searsia zeyheri*	Shrub	Anacardiaceae
Elephantorrhiza elephantina	Shrub	Fabaceae	*Sclerocarya birrea subsp. caffra*	Tree	Anacardiaceae
Erythroxylum emarginatum	Tree	Erythroxylaceae	*Searsia pyroides*	Tree	Anacardiaceae
Euclea crispa	Tree	Ebenaceae	*Senegalia caffra*	Tree	Fabaceae
Faurea saligna	Tree	Proteaceae	*Strychnos henningsii*	Shrub	Loganiaceae
Flemingia grahamiana	Shrub	Fabaceae	*Searsia leptodictya*	Tree	Anacardiaceae
Grewia bicolor	Shrub	Malvaceae	*Vachellia karroo*	Tree	Fabaceae
Grewia caffra	Shrub	Malvaceae	*Vachellia tortilis*	Tree	Fabaceae
Grewia occidentalis	Tree	Malvaceae	*Ximenia caffra*	Shrub	Olacaceae
Grewia oxyphylla	Shrub	Malvaceae	*Ziziphus mucronata*	Tree	Rhamnaceae
Gymnosporia buxifolia	Shrub	Celastraceae	*Searsia gracillima*	Shrub	Anacardiaceae
			Strychnos madagascariensis	Shrub	Loganiaceae

APPENDIX C1

List of species, their density and percentages in the overall study area according to the Whittaker method.

Species name	Growth form	No. of Ind.	Density (ind.ha^{-1})	Percentage (%)
Dichrostachys cinerea	Tree	4	10	4,7619
Dombeya rotundifolia	Tree	4	10	4,7619
Euclea crispa	Tree	4	10	4,7619
Sclerocarya birrea subsp*. caffra*	Tree	4	10	4,7619
Senegalia caffra	Tree	4	10	4,7619
Ziziphus mucronata	Tree	4	10	4,7619
Combretum collinum	Tree	3	7.5	3,5714
Searsia leptodictya	Tree	3	7,5	3,5714
Bridelia mollis	Tree	2	5	2,3809
Burkea africana	Tree	2	5	2,3809
Erythroxylum emarginatum	Tree	2	5	2,3809
Faurea galpinii	Tree	2	5	2,3809
Annnona senegalensis	Shrub	2	5	2,3809
Flemingia grahamiana	Shrub	2	5	2,3809
Grewia bicolor	Shrub	2	5	2,3809
Grewia caffra	Shrub	2	5	2,3809
Lannea discolor	Shrub	2	5	2,3809
Maerua cafra	Shrub	2	5	2,3809
Ozoroa paniculosa vs*. paniculosa*	Shrub	2	5	2,3809
Searsia zeyheri	Shrub	2	5	2,3809
Searsia pyroides	Tree	2	5	2,3809
Vachellia karroo	Tree	2	5	2,3809
Vachellia tortilis	Tree	2	5	2,3809
Berchemia zeyheri	Tree	1	2,5	1,1904
Carisa bispinosa	Shrub	1	2,5	1,1904
Combretum apiculatum	Tree	1	2,5	1,1904
Commiphora edulis	Tree	1	2,5	1,1904
Commiphora harveyi	Shrub	1	2,5	1,1904
Crotalaria monteiroi var*. galpinii*	Tree	1	2,5	1,1904
Dovyalis caffra	Shrub	1	2,5	1,1904
Elephantorrhiza elephantina	Shrub	1	2,5	1,1904
Grewia occidentalis	Tree	1	2,5	1,1904
Grewia oxyphylla	Shrub	1	2,5	1,1904
Gynosporia buxifolia	Shrub	1	2,5	1,1904
Hippocratea parvifolia	Shrub	1	2,5	1,1904
Lannea edulis	Shrub	1	2,5	1,1904

Mundulea sericea	Shrub	1	2,5	1,1904
Syris lanceolata	Shrub	1	2,5	1,1904
Ozoroa laecans	Shrub	1	2,5	1,1904
Ozoroa sphaerocarpa	Tree	1	2,5	1,1904
Pappea capensis	Tree	1	2,5	1,1904
Pyrostria hystrix	Shrub	1	2,5	1,1904
Searsia keetii	Shrub	1	2,5	1,1904
Strychnos henningsii	Shrub	1	2,5	1,1904
Ximenia caffra	Shrub	1	2,5	1,1904
Searsia gracillima	Shrub	1	2,5	1,1904
Strychnos madagascariensis	Shrub	1	2,5	1,1904

APPENDIX C2

List of species, their densities and percentage in both open and closed woody vegetation areas from the Whittaker method.

Closed woody vegetation area				Open woody vegetation area			
Species name	**No. of Ind.**	**Density (ind.ha^{-1})**	**%**	**Species name**	**No. of Ind.**	**Density (ind.ha^{-1})**	**%**
Burkea africana	2	10	3,7736	*Bridelia mollis*	1	5	3,225
Combretum collinum	2	10	3,7736	*Dichrostachys cinerea*	2	10	6,451
Dichrostachys cinerea	2	10	3,7736	*Dombeya rotundifolia*	2	10	6,451
Dombeya rotundifolia	2	10	3,7736	*Erythroxylum emarginatum*	2	10	6,451
Euclea crispa	2	10	3,7736	*Euclea crispa*	2	10	6,451
Grewia bicolor	2	10	3,7736	*Faurea saligna*	2	10	6,451
Grewia caffra	2	10	3,7736	*Flemingia grahamiana*	2	10	6,451
Lannea discolor	2	10	3,7736	*Sclerocarya birrea* subsp*. caffra*	2	10	6,451
Maerua cafra	2	10	3,7736	*Searsia pyroides*	2	10	6,451
Ozoroa paniculosa vs*. paniculosa*	2	10	3,7736	*Senegalia caffra*	2	10	6,451
Searsia leptodictya	2	10	3,7736	*Ziziphus mucronata*	2	10	6,451
Searsia zeyheri	2	10	3,7736	*Combretum collinum*	1	5	3,225
Sclerocarya birrea subsp*. caffra*	2	10	3,7736	*Elephantorrhiza elephantina*	1	5	3,225
Senegalia caffra	2	10	3,7736	*Grewia oxyphylla*	1	5	3,225
Vachellia karroo	2	10	3,7736	*Hippocratea parvifolia*	1	5	3,225
Vachellia tortilis	2	10	3,7736	*Lannea edulis*	1	5	3,225
Ziziphus mucronata	2	10	3,7736	*Osyris lanceolata*	1	5	3,225
Annona senegalensis	2	10	3,7736	*Pyrostria hystrix*	1	5	3,225
Berchemia zeyheri	1	5	1,8868	*Searsia keetii*	1	5	3,225
Bridelia mollis	1	5	1,8868	*Searsia leptodictya*	1	5	3,225
Carrisa bispinosa	1	5	1,8868	*Strychnos henningsii*	1	5	3,225
Combretum apiculatum	1	5	1,8868				

Commiphora edulis	1	5	1,8868
Commiphora harveyi	1	5	1,8868
Crotalaria monteiroi var. *galpinii*	1	5	1,8868
Dovyalis caffra	1	5	1,8868
Grewia occidentalis	1	5	1,8868
Gymnosporia buxifolia	1	5	1,8868
Mundulea sericea	1	5	1,8868
Ozoroa laecans	1	5	1,8868
Ozoroa sphaerocarpa	1	5	1,8868
Pappea capensis	1	5	1,8868
Searsia gracillima	1	5	1,8868
Strychnos madagascariensis	1	5	1,8868
Ximenia caffra	1	5	1,8868

APPENDIX D

Diversity of species recorded in the open woody vegetation using the Whittaker method (all plots combined).

Species name	No of Individual	n/N	ln(n/N)	-(n/N)*ln(n/N)	Diversity Index (H')	Evenness (J')
Bridelia mollis	1	0,032	-3,434	-0,1107	0,1107	N/A
Combretum collinum	1	0,032	-3,434	-0,1107	0,1107	N/A
Dichrostachys cinerea	2	0,064	-2,741	-0,1768	0,1768	0,25511
Dombeya rotundifolia	2	0,064	-2,741	-0,1768	0,1768	0,25511
Elephantorrhiza elephantina	1	0,032	-3,434	-0,1107	0,1107	N/A
Erythroxylum emarginatum	2	0,064	-2,741	-0,1768	0,1768	0,25511
Euclea crispa	2	0,064	-2,741	-0,1768	0,1768	0,25511
Faurea galpinii	2	0,064	-2,741	-0,1768	0,1768	0,25511
Flemingia grahamiana	2	0,064	-2,741	-0,1768	0,1768	0,25511
Grewia oxyphylla	1	0,032	-3,434	-0,1107	0,1107	N/A
Hippocratea parvifolia	1	0,032	-3,434	-0,1107	0,1107	N/A
Lannea edulis	1	0,032	-3,434	-0,1107	0,1107	N/A
Osyris lanceolata	1	0,032	-3,434	-0,1107	0,1107	N/A
Pyrostria hystrix	1	0,032	-3,434	-0,1107	0,1107	N/A
Searsia keetii	1	0,032	-3,434	-0,1107	0,1107	N/A
Sclerocarya birrea subsp*. caffra*	2	0,064	-2,741	-0,1768	0,1768	0,25511
Searsia leptodictya	1	0,032	-3,434	-0,1107	0,1107	N/A
Searsia pyroides	2	0,064	-2,741	-0,1768	0,1768	0,25511
Senegalia caffra	2	0,064	-2,741	-0,1768	0,1768	0,25511
Strychnos henningsii	1	0,032	-3,434	-0,1107	0,1107	N/A
Ziziphus mucronata	2	0,064	-2,741	-0,1768	0,1768	0,25511

APPENDIX E

Diversity of species recorded in the closed woody vegetation using the Whittaker method (all plots combined).

Species name	No of Individual	n/N	ln(n/N)	-(n/N)*ln(n/N)	Diversity (H')	Evenness (J')
Berchemia zeyheri	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Bridelia mollis	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Burkea africana	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Carisa bispinosa	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Combretum apiculatum	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Combretum collinum	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Commiphora edulis	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Commiphora harveyi	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Crotalaria monteiroi var. *galpinii*	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Dichrostachys cinerea	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Dombeya rotundifolia	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Dovyalis caffra	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Euclea crispa	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Grewia bicolor	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Grewia caffra	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Grewia occidentalis	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Gymnosporia buxifolia	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Lannea discolor	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Maerua cafra	2	0,0377	-3,2771	-0,1236	0,1236	N/A
Mundulea sericea	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Ozoroa laecans	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Ozoroa paniculosa vs. *paniculosa*	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Ozoroa sphaerocarpa	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Pappea capensis	1	0,0189	-3,9702	-0,0749	0,0749	N/A

Searsia gracillima	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Searsia leptodictya	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Searsia zeyheri	2	0,0377	-3,2771	-0,1236	0,1236	N/A
Sclerocarya birrea subsp*. caffra*	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Senegalia caffra	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Strychnos madagascariensis	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Vachellia karroo	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Vachellia tortilis	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Ximenia caffra	1	0,0189	-3,9702	-0,0749	0,0749	N/A
Ziziphus mucronata	2	0,0377	-3,2771	-0,1236	0,1236	0,1784
Annona senegalensis	2	0,0377	-3,2771	-0,1236	0,1236	0,1784

APPENDIX F

Diversity of species recorded in the study area using the Whittaker method (closed and open plots combined).

Species name	No. of ind.	n/N	ln(n/N)	-(n/N)*ln(n/N)	Diversity (H')	Evenness (J')
Annona senegalensis	2	0,024	-3,7377	-0,0890	0,089	0,1283
Berchemia zeyheri	1	0,012	-4,4308	-0,0527	0,052	N/A
Bridelia mollis	2	0,024	-3,7377	-0,0890	0,089	0,1283
Burkea africana	2	0,024	-3,7377	-0,0890	0,089	0,1283
Carisa bispinosa	1	0,012	-4,4308	-0,0527	0,052	N/A
Combretum apiculatum	1	0,012	-4,4308	-0,0527	0,052	N/A
Combretum collinum	3	0,036	-3,3322	-0,1190	0,119	0,1083
Commiphora edulis	1	0,012	-4,4308	-0,0527	0,052	N/A
Commiphora harveyi	1	0,012	-4,4308	-0,0527	0,052	N/A
Crotalaria monteiroi var. *galpinii*	1	0,012	-4,4308	-0,0527	0,052	N/A
Dichrostachys cinerea	4	0,048	-3,0445	-0,1450	0,145	0,1045
Dombeya rotundifolia	4	0,048	-3,0445	-0,1450	0,145	0,1045
Dovyalis caffra	1	0,012	-4,4308	-0,0527	0,052	N/A
Elephantorrhiza elephantina	1	0,012	-4,4308	-0,0527	0,052	N/A
Erythroxylum emarginatum	2	0,024	-3,7377	-0,0890	0,089	0,1283
Euclea crispa	4	0,048	-3,0445	-0,1450	0,145	0,1045
Faurea galpinii	2	0,024	-3,7377	-0,0890	0,089	0,1283
Flemingia grahamiana	2	0,024	-3,7377	-0,0890	0,089	0,1283
Grewia bicolor	2	0,024	-3,7377	-0,0890	0,089	0,1283
Grewia caffra	2	0,024	-3,7377	-0,0890	0,089	0,1283
Grewia occidentalis	1	0,012	-4,4308	-0,0527	0,052	N/A
Grewia oxyphylla	1	0,012	-4,4308	-0,0527	0,052	N/A
Gynosporia buxifolia	1	0,012	-4,4308	-0,0527	0,052	N/A

Hippocratea parvifolia	1	0,012	-4,4308	-0,0527	0,052	N/A
Lannea discolor	2	0,024	-3,7377	-0,0890	0,089	0,1283
Lannea edulis	1	0,012	-4,4308	-0,0527	0,052	N/A
Maerua cafra	2	0,024	-3,7377	-0,0890	0,089	0,1283
Mundulea sericea	1	0,012	-4,4308	-0,0527	0,052	N/A
Osyris lanceolata	1	0,012	-4,4308	-0,0527	0,052	N/A
Ozoroa laecans	1	0,012	-4,4308	-0,0527	0,052	N/A
Ozoroa paniculosa vs. *paniculosa*	2	0,024	-3,7377	-0,0890	0,089	0,1283
Ozoroa sphaerocarpa	1	0,012	-4,4308	-0,0527	0,052	N/A
Pappea capensis	1	0,012	-4,4308	-0,0527	0,052	N/A
Pyrostria hystrix	1	0,012	-4,4308	-0,0527	0,052	N/A
Searsia Keetii	1	0,012	-4,4308	-0,0527	0,052	N/A
Searsia zeyheri	2	0,024	-3,7377	-0,0890	0,089	0,1283
Sclerocarya birrea subsp. *caffra*	4	0,048	-3,0445	-0,1450	0,145	0,1045
Searsia pyroides	2	0,024	-3,7377	-0,0890	0,089	0,1283
Senegalia caffra	4	0,048	-3,0445	-0,1450	0,145	0,1045
Strychnos henningsii	1	0,012	-4,4308	-0,0527	0,052	N/A
Searsia gracillima	1	0,012	-4,4308	-0,0527	0,052	N/A
Vachellia karroo	2	0,024	-3,7377	-0,0890	0,089	0,1283
Vachellia tortilis	2	0,024	-3,7377	-0,0890	0,089	0,1283
Ximenia caffra	1	0,012	-4,4308	-0,0527	0,052	N/A
Ziziphus mucronata	4	0,048	-3,0445	-0,1450	0,145	0,1045
Strychnos madagascariensis	1	0,012	-4,4308	-0,0527	0,052	N/A
Searsia leptodictya	3	0,036	-3,3322	-0,1190	0,119	0,1083

APPENDIX G

List of plant species collected in the study area using DS software.

Species	Growth Form	Family
Crotalaria monteiroi var *galpinii*	Tree	Fabaceae
Annona senegalensis	Shrub	Annonaceae
Berchemia zeyheri	Tree	Rhamnaceae
Bridelia mollis	Shrub	Phyllanthaceae
Combretum collinum	Tree	Combretaceae
Commiphora edulis	Tree	Burseraceae
Dichrostachys cinerea	Tree	Fabaceae
Dombeya rotundifolia	Tree	Malvaceae
Euclea crispa	Tree	Ebenaceae
Faurea galpinii	Tree	Proteaceae
Flemingo grahamiana	Shrub	Fabaceae
Grewia bicolor	Shrub	Malvaceae
Grewia caffra	Shrub	Malvaceae
Grewia occidentalis	Shrub	Malvaceae
Gymnosporia buxifolia	Shrub	Celastraceae
Hippocratea parvifolia	Shrub	Celastraceae
Lannea discolor	Shrub	Anacardiaceae
Lannea edulis	Shrub	Anacardiaceae
Mundulea sericea	Shrub	Fabaceae
Osyris lanceolata	Shrub	Santalaceae
Ozoroa laecans	Tree	Anacardiaceae
Ozoroa paniculosa vs. *paniculosa*	Tree	Anacardiaceae
Ozoroa sphaerocarpa	Shrub	Anacardiaceae
Pappea capensis	Tree	Sapindaceae
Pyrostria hystrix	Shrub	Rubiaceae
Sclerocarya birrea	Tree	Anacardiaceae
Searsia keetii	Shrub	Anacardiaceae
Searsia leptodictya	Tree	Anacardiaceae
Searsia pyroides	Tree	Anacardiaceae
Searsia zeyheri	Tree	Anacardiaceae
Senegalia caffra	Tree	Fabaceae
Strychnos henningsii	Shrub	Malvaceae
Strychnos madagascariensis	Shrub	Loganiaceae
Vachellia karroo	Tree	Fabaceae
Vachellia tortilis	Tree	Fabaceae
Ziziphus mucronata	Tree	Rhamnaceae

APPENDIX H

Species richness, density and percentages of species recorded in the study area using DS software.

Species name	Frequency	No. of Ind.	Density (ind.ha^{-1})	Percentage (%)
Dichrostachys cinerea	84	179	447.5	24.28765
Sclerocarya birrea	33	88	220	11.9403
Senegalia caffra	16	118	295	16.01085
Combretum collinum	12	31	77.5	4.206242
Vachellia karroo	10	17	42.5	2.306649
Dombeya rotundifolia	9	57	142.5	7.734057
Lannea edulis	9	10	25	1.356852
Euclea crispa	7	48	120	6.51289
Faurea galpinii	7	21	52.5	2.849389
Grewia caffra	7	9	22.5	1.221167
Ozoroa paniculosa vs. *paniculosa*	7	7	17.5	0.949796
Vachellia tortilis	7	21	52.5	2.849389
Commiphora edulis	5	1	2.5	0.135685
Ziziphus mucronata	5	9	22.5	1.221167
Lannea discolor	4	4	10	0.542741
Ozoroa laecans	4	12	30	1.628223
Pappea capensis	4	8	20	1.085482
Searsia leptodictya	4	7	17.5	0.949796
Searsia zeyheri	4	7	17.5	0.949796
Annona senegalensis	3	9	22.5	1.221167
Berchemia zeyheri	3	8	20	1.085482
Flemingo grahamiana	3	3	7.5	0.407056
Grewia bicolor	3	13	32.5	1.763908
Gymnosporia buxifolia	3	5	12.5	0.678426
Ozoroa sphaerocarpa	3	5	12.5	0.678426
Searsia pyroides	3	9	22.5	1.221167
Bridelia mollis	2	3	7.5	0.407056
Crotalaria monteiroi var galpinii	2	2	5	0.27137
Grewia occidentalis	2	5	12.5	0.678426
Hippocratea parvifolia	2	3	7.5	0.407056
Mundulea sericea	2	2	5	0.27137
Osyris lanceolata	2	3	7.5	0.407056
Pyrostria hystrix	2	2	5	0.27137
Strychnos henningsii	2	2	5	0.27137
Strychnos madagascariensis	2	6	15	0.814111
Searsia keetii	1	3	7.5	0.407056

APPENDIX I

List of species, their densities and percentage in both open and closed woody vegetation areas from the DSS software.

Closed woody vegetation area				Open woody vegetation area			
Species name	**No. of Ind.**	**Density (ind.ha^{-1})**	**%**	**Species name**	**No. of Ind.**	**Density (ind.ha^{-1})**	**%**
Dichrostachys cinerea	49	245	27.374	*Dichrostachys cinerea*	35	175	16.990
Sclerocarya birrea	15	75	8.379	*Euclea crispa*	2	10	0.970
Combretum collinum	12	60	6.703	*Faurea galpinii*	7	35	3.398
Vachellia karroo	10	50	5.586	*Flemingo grahamiana*	3	15	1.456
Dombeya rotundifolia	9	45	5.027	*Hippocratea parvifolia*	2	10	0.970
Grewia caffra	7	35	3.910	*Lannea edulis*	9	45	4.368
Ozoroa paniculosa vs. *paniculosa*	7	35	3.910	*Osyris lanceolata*	2	10	0.970
Vachellia tortilis	7	35	3.910	*Pyrostria hystrix*	2	10	0.970
Commiphora edulis	5	25	2.793	*Searsia keetii*	1	5	0.485
Euclea crispa	5	25	2.793	*Searsia pyroides*	3	15	1.456
Senegalia caffra	5	25	2.793	*Sclerocarya birrea*	18	90	8.737
Lannea discolor	4	20	2.234	*Senegalia caffra*	11	55	5.339
Ozoroa laecans	4	20	2.234	*Strychnos henningsii*	2	10	0.970
Pappea capensis	4	20	2.234	*Ziziphus mucronata*	2	10	0.970
Searsia zeyheri	4	20	2.234				
Searsia leptodictya	4	20	2.234				
Annona senegalensis	3	15	1.675				
Berchemia zeyheri	3	15	1.675				
Grewia bicolor	3	15	1.675				
Gymnosporia buxifolia	3	15	1.675				
Ozoroa sphaerocarpa	3	15	1.675				
Ziziphus mucronata	3	15	1.675				
Bridelia mollis	2	10	1.117				

Grewia occidentalis	2	10	1.117
Crotalaria monteiroi var galpinii	2	10	1.117
Mundulea sericea	2	10	1.117
Strychnos madagascariensis	2	10	1.117

APPENDIX J

Diversity value of species recorded in the closed woody vegetation using DS software.

Species name	No. of Ind.	n/N	ln(n/N)	n/N*LN(n/n)	Diversity Index	Effective number	Evenness
Dichrostachys cinerea	49	0.2737	-1.2956	-0.35465201	0.35465201	1.42568444	0.091128
Sclerocarya birrea	15	0.0838	-2.4793	-0.20776555	0.20776555	1.23092455	0.076721
Combretum collinum	12	0.067	-2.7025	-0.18117179	0.18117179	1.19862107	0.072909
Vachellia karroo	10	0.0559	-2.8848	-0.16116205	0.16116205	1.17487534	0.069992
Dombeya rotundifolia	9	0.0503	-2.9902	-0.1503433	0.1503433	1.16223317	0.068424
Grewia caffra	7	0.0391	-3.2415	-0.12676162	0.12676162	1.13514639	0.065143
Ozoroa paniculosa vs. *paniculosa*	7	0.0391	-3.2415	-0.12676162	0.12676162	1.13514639	0.065143
Vachellia tortilis	7	0.0391	-3.2415	-0.12676162	0.12676162	1.13514639	0.065143
Commiphora edulis	5	0.0279	-3.5779	-0.09994268	0.09994268	1.10510757	0.062098
Euclea crispa	5	0.0279	-3.5779	-0.09994268	0.09994268	1.10510757	0.062098
Senegalia caffra	5	0.0279	-3.5779	-0.09994268	0.09994268	1.10510757	0.062098
Lannea discolor	4	0.0223	-3.8011	-0.08494059	0.08494059	1.08865239	0.061272
Ozoroa laecans	4	0.0223	-3.8011	-0.08494059	0.08494059	1.08865239	0.061272
Pappea capensis	4	0.0223	-3.8011	-0.08494059	0.08494059	1.08865239	0.061272
Searsia zeyheri	4	0.0223	-3.8011	-0.08494059	0.08494059	1.08865239	0.061272
Searsia leptodictya	4	0.0223	-3.8011	-0.08494059	0.08494059	1.08865239	0.061272
Annona senegalensis	3	0.0168	-4.0888	-0.06852693	0.06852693	1.07092947	0.062376
Berchemia zeyheri	3	0.0168	-4.0888	-0.06852693	0.06852693	1.07092947	0.062376
Grewia bicolor	3	0.0168	-4.0888	-0.06852693	0.06852693	1.07092947	0.062376
Gymnosporia buxifolia	3	0.0168	-4.0888	-0.06852693	0.06852693	1.07092947	0.062376
Ozoroa sphaerocarpa	3	0.0168	-4.0888	-0.06852693	0.06852693	1.07092947	0.062376
Ziziphus mucronata	3	0.0168	-4.0888	-0.06852693	0.06852693	1.07092947	0.062376

Bridelia mollis	2	0.0112	-4.4942	-0.05021496	0.05021496	1.0514971	0.072445
Grewia occidentalis	2	0.0112	-4.4942	-0.05021496	0.05021496	1.0514971	0.072445
Mundulea sericea	2	0.0112	-4.4942	-0.05021496	0.05021496	1.0514971	0.072445
Strychnos madagascariensis	2	0.0112	-4.4942	-0.05021496	0.05021496	1.0514971	0.072445
Crotalaria monteiroi var *galpinii*	2	0.0112	-4.4942	-0.05021496	0.05021496	1.0514971	0.072445

APPENDIX K

Diversity values of species recorded in the open woody vegetation using DSS software.

Species Name	No. of Species	n/N	ln(n/N)	n/n*LN(n/n)	Diversity Index	Effective number	Evenness
Dichrostachys cinerea	35	0.3535	-1.0398	-0.36759609	0.36759609	1.44425857	0.103392
Sclerocarya birrea	18	0.1818	-1.7047	-0.3099542	0.3099542	1.36336267	0.107237
Senegalia caffra	11	0.1111	-2.1972	-0.24413606	0.24413606	1.27651801	0.101813
Lannea edulis	9	0.0909	-2.3979	-0.21799048	0.21799048	1.24357523	0.099212
Faurea galpinii	7	0.0707	-2.6492	-0.18731786	0.18731786	1.20601056	0.096262
Flemingo grahamiana	3	0.0303	-3.4965	-0.10595477	0.10595477	1.1117716	0.096444
Searsia pyroides	3	0.0303	-3.4965	-0.10595477	0.10595477	1.1117716	0.096444
Euclea crispa	2	0.0202	-3.902	-0.07882773	0.07882773	1.08201791	0.113724
Hippocratea parvifolia	2	0.0202	-3.902	-0.07882773	0.07882773	1.08201791	0.113724
Osyris lanceolata	2	0.0202	-3.902	-0.07882773	0.07882773	1.08201791	0.113724
Pyrostria hystrix	2	0.0202	-3.902	-0.07882773	0.07882773	1.08201791	0.113724
Strychnos henningsii	2	0.0202	-3.902	-0.07882773	0.07882773	1.08201791	0.113724
Ziziphus mucronata	2	0.0202	-3.902	-0.07882773	0.07882773	1.08201791	0.113724
Searsia keetii	1	0.0101	-4.5951	-0.04641535	0.04641535	1.04750941	N/A

APPENDIX L

Diversity values of species recorded in the study area using DSS Software.

Species name	No. of Ind	n/N*LN(n/n)	H’	EN	J’
Dichrostachys cinerea	84	-0.36162	0.361624	1.4356	0.0816
Sclerocarya birrea	33	-0.25297	0.252974	1.2878	0.0724
Senegalia caffra	16	-0.16432	0.164318	1.1785	0.0593
Combretum collinum	12	-0.13566	0.135657	1.1452	0.0546
Vachellia karroo	10	-0.11961	0.119606	1.1270	0.0519
Dombeya rotundifolia	9	-0.11106	0.111056	1.1174	0.0505
Lannea edulis	9	-0.11106	0.111056	1.1174	0.0505
Euclea crispa	7	-0.0927	0.092705	1.0971	0.0476
Faurea galpinii	7	-0.0927	0.092705	1.0971	0.0476
Grewia caffra	7	-0.0927	0.092705	1.0971	0.0476
Ozoroa paniculosa vs. *paniculosa*	7	-0.0927	0.092705	1.0971	0.0476
Vachellia tortilis	7	-0.0927	0.092705	1.0971	0.0476
Commiphora edulis	5	-0.07227	0.072269	1.0749	0.0449
Ziziphus mucronata	5	-0.07227	0.072269	1.0749	0.0449
Lannea discolor	4	-0.06103	0.061026	1.0629	0.044
Ozoroa laecans	4	-0.06103	0.061026	1.0629	0.044
Pappea capensis	4	-0.06103	0.061026	1.0629	0.044
Searsia leptodictya	4	-0.06103	0.061026	1.0629	0.044
Searsia zeyheri	4	-0.06103	0.061026	1.0629	0.044
Annona senegalensis	3	-0.04887	0.048874	1.0500	0.0445
Berchemia zeyheri	3	-0.04887	0.048874	1.0500	0.0445
Flemingo grahamiana	3	-0.04887	0.048874	1.0500	0.0445
Grewia bicolor	3	-0.04887	0.048874	1.0500	0.0445
Gymnosporia buxifolia	3	-0.04887	0.048874	1.0500	0.0445
Ozoroa sphaerocarpa	3	-0.04887	0.048874	1.0500	0.0445
Searsia pyroides	3	-0.04887	0.048874	1.0500	0.0445
Bridelia mollis	2	-0.0355	0.0355	1.0361	0.0512
Crotalaria monteiroi var *galpinii*	2	-0.0355	0.0355	1.0361	0.0512
Grewia occidentalis	2	-0.0355	0.0355	1.0361	0.0512
Hippocratea parvifolia	2	-0.0355	0.0355	1.0361	0.0512
Mundulea sericea	2	-0.0355	0.0355	1.0361	0.0512
Osyris lanceolata	2	-0.0355	0.0355	1.0361	0.0512
Pyrostria hystrix	2	-0.0355	0.0355	1.0361	0.0512
Strychnos henningsii	2	-0.0355	0.0355	1.0361	0.0512
Strychnos madagascariensis	2	-0.0355	0.0355	1.0361	0.0512
Searsia keetii	1	-0.02024	0.020243	1.0204	N/A

H’-Diversity, EN – Effective number, J’ – Evenness