

COMPOSITION, SPATIAL ABUNDANCE, CO-OCCURRENCE AND HOST
PREFERENCE OF MISTLETOES IN THE CENTRAL HIGHLAND SAVANNA
OF NAMIBIA

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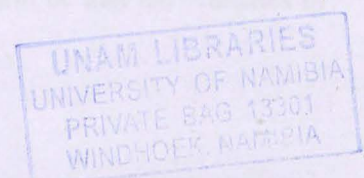
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ABSTRACT

Aerial parasitic plants, commonly called mistletoes, are a polyphyletic group of organisms with a common evolutionary ancestor. This study was aimed at determining composition, spatial abundance within hosts, co-occurrence and host preference of mistletoes in the central highland savannas. The study site was divided into four sampling areas based on the presence of the distribution records of the species. Forty circular plots were demarcated and for every infested host plant species within these plots, canopy height, two diameter measurements at approximately 90°, number of mistletoes, mistletoe species were recorded. All non-infested plant species within the plot were also identified and their abundances were recorded. Based on field records and herbarium records, four mistletoe species were identified and mapped namely; *Oncocalyx welwitschii*, *Plicosepalus kalachariensis*, and *Tapinanthus oleifolius*, belonging to the Family Loranthaceae and, *Viscum rotundifolium* which belongs to Family Viscaceae. A simple linear regression model established that canopy volume accounted for 12% of the variation in mistletoe abundance ($R^2 = 0.12$, $p < 0.001$). However, canopy diameter was a better predictor of mistletoe abundance than canopy volume and accounted 20% of the variation in mistletoe abundance within the host canopy ($R^2 = 0.20$, $p = 0.0003$). Canopy volume was a poor predictor because it might have included branches of various sizes even those that do not support mistletoe establishment. Also gaps within the host canopy as well as the extent and positioning of branches might have led to an overestimation of the actual volume of the host canopy that can potentially be infested by parasites. The results further revealed a statistically significant relationship between mistletoe abundance and vertical canopy position ($\chi^2 = 67.089$, $df = 6$, $p < 0.001$) with most mistletoes occurring in the lower and middle third of the canopy of the host plant. The presence of *V. rotundifolium* and *P. kalachariensis* on the lower third of the canopy of the host plant could be explained by habitat preference and deposition behaviour of the Redfaced mousebird (*Urocolius indicus*). This means that the selection of this bird species for lower third of canopy for nesting and roosting, results in defecating of seeds more frequently on this part. On the contrary, the distribution of *T. oleifolius* and *O. welwitschii* in the middle third of the canopy could have been due to perch preference of the Yellow-fronted Tinker Barbets (*Pogoniulus chrysoconus*). It is possible they perch in the middle third of the canopy because there is a low risk of predation. Also, it could be that the branches in

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LIST OF ABBREVIATIONS AND/OR ACRONYMS

CV	Canopy volume
df	Degree of Freedom
WIND	National Herbarium of Namibia

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DEDICATION

I dedicate this research to all environmentalists, researchers, students, and anyone passionate about nature. May this research improve the understanding of mistletoes ecology in the central highland savanna.

for my purpose

I declare that this thesis is based on original and original work carried out by me. Any reference to work done by any other person or any material derived from other sources has been properly cited and referenced.

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

1.1.1 Parasitic plants

Nutritional adaptation is one of the features several taxa have gradually developed that involve using other organisms to obtain food (Starr *et al.*, 2012). Starr *et al.* (2012) defined parasitic plants as organisms that benefit by living in or on other plants at the expense of the host by absorbing sugars, water, and minerals. Parasitic plants are a diverse functional group of approximately 20 Families with over 4500 species, each representing an independent evolutionary origin of parasitism of short-lived annual herbs to long-lived shrubs or trees (Der & Nickrent, 2008). Parasitic plants are components of all types of terrestrial biomes from the rainforest, savanna, desert, and tundra and are integral in structuring and functioning of their ecosystems (Heide-Jørgensen, 2008; Press & Phoenix, 2005). Savanna, as the focus of this study, is defined as a distinctive vegetation type found within the tropical climate belt and is characterized by a continuous cover of mainly C4 perennial grasses with or without scattered trees, or these forming a semi-closed canopy with grasses underneath (Huntley & Walker, 2012).

According to Silva (1996), the stability of savanna plant communities depends on the type, intensity, and extent of perturbation. Perturbation refers to abrupt and relatively short changes in particular environmental conditions (Silva, 1996). Some perturbations in the savanna are changes in the prevailing climate, and these affect the savanna community directly by modifying the community structure or indirectly by affecting soil nutrients and moisture (Silva, 1996). As a result, biodiversity is affected (Butin, 1995) and the community structure is altered (Büssing, 2000; Calladine & Pate, 2000) and parasitic plant invasions are also likely to be facilitated (Press & Phoenix, 2005).

Thus, parasitic plants can be used as a measure of habitat health, or when in superabundance as an indicator of landscape perturbation (Norton & Reid, 1997).

Walter *et al.* (2007) referred to community structure as a term used to indicate organisms that are present in a given environment, their abundance, and how they relate to each other. To understand the extent of impacts on the ecosystem it is crucial to study the number of individuals per species (abundance), the number of different species represented in an ecological community, landscape or region (species richness) and diversity index, which is a measure of biodiversity which quantifies how equal the community is numerically (species evenness).

According to Aukema (2003), parasitic plants alter host physiology, morphology, productivity, and behaviour. Furthermore, parasitic plants may show a preference for certain host plants over others. This disproportionate infestation is likely to alter the geographical distribution of host plants (Runyon *et al.*, 2006). Therefore, parasitic plants influence the functional diversity of a community by magnifying differences between host and non-host species, as well as generating differences between infested and non-infested individuals within a host species.

Parasitic plants are often viewed negatively due to the devastations that some of them may pose to important crops and thereby negatively impacting the livelihoods of people that depend on such crops (Kokla & Melnyk, 2018; Runyon *et al.*, 2009). In sub-Saharan Africa, parasitic plants such as *Striga* species (Witchweed) can lead to millions of dollars of losses in crop yields, devastating livelihoods (Tjiurutue *et al.*, 2019). Parasitic plants often act as keystone species that have a disproportionately large effect on the natural environment relative to their abundance (Press & Phoenix, 2005). According to previous studies parasitic plants offer several benefits such as the

maintenance of a healthy ecosystem by suppressing dominant species, facilitating the coexistence and diversity of sub-ordinate plant species (Pennings & Callaway, 1996; Press & Phoenix, 2005), nutrient cycling (Press & Phoenix, 2005), medicinal benefits (Tjiurutue *et al.*, 2019) and provision of shelter and food to other species (Pennings & Callaway, 2002).

Parasitism is the most common dietary mode in natural communities. As a result, revised food webs have shown that parasitic plants behave differently from other plants, hence they are now regarded as key regulators of energy flow and trophic dynamics (Press & Phoenix, 2005). Depending on the extent to which parasites are autotrophic, parasitic plants are generally divided into holoparasites and hemiparasites (Visser, 1981). Holoparasites depend entirely on the host for the completion of their life cycle because they do not contain appreciable amounts of chlorophyll and therefore, cannot photosynthesize, hence depend heavily on the host plant for survival (Johnson & Chionski, 1993; Veste, 2007). Hemiparasites contain chlorophyll and therefore have some photosynthetic capacity but depend on the host for the supply of water and nutrients (Veste, 2007).

Hemiparasites can further be classified as obligate or facultative hemiparasites. Hemiparasites attached to the aerial parts of host plants (usually trunk or branches) are all obligate parasites that obtain all water and inorganic nutrients from the host (Johnson & Chionski, 1993; Okubamichael *et al.*, 2011). While, facultative hemiparasites are often opportunistic parasites that may require host only at certain life cycle stages or may complete their life cycles without the host (Kaiser, 2015). The location of attachment to the host plant and the degree of host dependency are the major features that define parasitic growth form. On the basis of haustorial connection to the host, parasites can be divided into stem or root parasites. Stem parasites

variously called shoot or aerial parasites such as *Cucusta* spp. form haustorial connections on the aerial part of the host and roots parasites such as *Hydnora* spp. form connections with host roots (Kuijt, 1969; Visser, 1981). Hence, due to their degree of host dependency, obligate parasites cannot survive without a host.

1.1.2 Aerial parasitic plants

Aerial hemiparasitic plants, commonly called mistletoes, are a polyphyletic group of organisms with a common evolutionary ancestor (Mathiasen *et al.*, 2008; Vidal-Russell & Nickrent, 2008). According to Okubamichael *et al.* (2011), mistletoes are evergreen, perennial, flowering, and parasitic plants that are adapted to live on aerial parts of their hosts. Thus, the term mistletoe is a description of parasitic plant habit referring specifically to aerial obligate parasites that occurs in the Order of Santalales. Previous studies on mistletoes have been mainly based on parasitic interactions and the direct effects on the host plants (Mathiasen *et al.*, 2008; Fadini & Lima, 2012). However, there is still a gap in knowledge on mistletoe ecology in the Namibian savanna ecosystems particularly in the central highland savanna.

1.1.3 Life history

Mistletoes contain members of five Families within the Santalales (Kuijt 1968, 1969; Nickrent & Soltis, 1995), and the aerial parasitic life-form is thought to have evolved independently five times (Nickrent & Franchina, 1990; Nickrent *et al.*, 1998; Nickrent, 2002) namely: Misodendraceae, Loranthaceae, Amphorogynaceae, Santalaceae and Viscaceae. All Viscaceae, Misodendraceae, and most Loranthaceae are aerial parasites. The Loranthaceae and Viscaceae are the well-studied mistletoes, comprising the majority (> 98%) of mistletoe species which make up approximately 940 and 350 species, respectively (Watson, 2001). They are found ranging from boreal climates to temperate, tropical, and arid zones, and absent only from extremely dry or cold

regions. In Africa, approximately 70% of Loranthaceae species occur in Guineo-Congolian forests, the Afromontane forests, Somalia-Masai bushland, and the Zambezian woodlands whereas, 45 of the estimated 100 *Viscum* species occur in eastern and southern Africa (Polhill & Wiens, 1998).

1.1.4 Biology and Phenology

Mistletoes are known to be dioecious, with male plants producing pollen and female plants producing berries (Aukema, 2003). According to Maloney and Rizzo (2002) mistletoes can be either broad or dwarf leafed. Broad-leafed mistletoes are green, large with thick leaves, often woody with shrubby brittle stems Aukema (2003), and the seeds are dispersed by birds (Maloney & Rizzo, 2002). Dwarf mistletoes are distinguished by the small size and leafless morphology Aukema (2003), typically non-woody, the seeds often dispersed mainly by the forcible discharge of seeds from the fruit (Maloney & Rizzo, 2002).

The study of hemiparasitic growth form of mistletoes is critical to the understanding of their biology and resource availability that constrains the distribution and growth of host plants (Fineran & Hocking, 1983). Due to the hemiparasitic growth habit, mistletoes are less affected by nutritional, edaphic and hydrological factors that otherwise limit the distribution, growth, and phenology of most plants. This is because the host plant buffers the mistletoe against large-scale fluctuations in resource availability (Ehleringer & Marshall, 1995). The infestation process is considered to be similar for all mistletoes (Kolb, 2002). With optimum temperature, moisture, and light, the seeds of mistletoes germinate and a hypocotyl is formed that elongates and is attached firmly to the host (Lamont, 1983). Eventually, a penetration peg develops on the area of infestation that mechanically penetrates the host bark to the host's phloem and or xylem. Eventually, a haustorium develops followed by aerial shoots.

In southern Africa mistletoes are reported to have prolonged fruiting seasons, ranging from three months to year-round (Godschalk, 1983; Polhill & Wiens, 1998), whereas, in the Neotropics, flowering and fruiting seasons range from 10 to 12 months with a pronounced wet-season peak (Sargent, 1994; Skutch, 1980; Stiles, 1985). Research in the Colombian cloud forests have reported continuous fruiting seasons with a generalized peak during the wet season, flowering seasons are also continuous, with nectar and fruit resources available year-round (Restrepo, 1987). A study by Reid (1986) of the Australian Loranthaceae reported that the flowering season for several species extended throughout the year, with different patterns associated with regional climates and fruiting occurring throughout the year.

1.1.5 Pollination and seed dispersal strategies

Pollination in mistletoes is carried out by insects, birds, and rarely by wind (Watson, 2001). However, some mistletoe species also use some form of explosive pollination such as *Erianthemum dregei* and *Agelanthus transvaalensis* (Polhill & Wiens, 1998). Explosion pollination occurs when flowers open in response to birds that are foraging near it thereby reducing the waste of pollen (Feehan, 1985). Bird pollinated flowers are usually large and conspicuous in colour, producing large amounts of sugar-rich nectar (Kirkup, 1998). However, a variety of insects are known to be key pollinators of mistletoes in the Viscaceae and Loranthaceae Families (Kuijt, 1969). In Mexico, Central America, and in South America, hummingbirds are the key pollinators (Azpeitia and Lara, 2006) and in Africa, two genera of Sunbird (*Nectarinia* and *Arachnothera*) have been reported as key pollinators of mistletoes (Polhill & Wiens, 1998).

Mistletoe species often rely on birds for direct seed dispersal (Aukema, 2003). However, some mistletoe species such as *Misodendrum* disperse their seeds by wind

and *Tristerix* by marsupials (Amico & Aizen, 2000). Mistletoes are generally regarded as bird-dispersed and mistletoe fruits show a range of attributes consistent with ornithochory (e.g. large, sweet, and bright in colour when ripe). Therefore, birds play a significant role in long-distance dispersal. Within sub-Saharan Africa, the Yellow-fronted Tinker Barbets (*Pogoniulus chrysoconus*) are known to disperse many species of mistletoe (Dowsett-Lemaire, 1988; Godschalk, 1985; Yan, 1993). However, a recent evaluation of New World mistletoes has reported vertebrate dispersers to have played a key role in the diversification of mistletoes (Restrepo *et al.*, 2002).

The successful seed dispersal mechanism of mistletoes is due to a sticky viscin that coats the seed, enabling it to attach to the bird's bill or abdomen and subsequently to host branches following defecation or regurgitation by the avian disperser (Okubamichael *et al.*, 2011). Thus, the sticky viscin of mistletoe seeds explains the origin of the word 'mistletoe' which means 'dung-stick' - a name based on the early observations that mistletoes appear where bird droppings are deposited on trees (Aukema, 2003). The birds also engage in bill or abdomen wiping to remove the seed resulting in sticking the seed to the potential host plant (Aukema, 2003; Green *et al.*, 2009; Roxburgh, 2007).

1.1.6 Mechanisms of establishment and survival

Mistletoes are reported to withdraw resources from the vascular system of their hosts through a specialized transfer organ called haustorium (Aukema, 2003). Haustorium is a specialized structure that enable parasitic plants to attach and penetrate the tissues of the host plant's aerial parts and this creates a direct connection between the vascular systems of the two plants (Malcom & Jonathan, 1995). This structure allows parasitic plants to penetrate the tissues of the host plant's root or stem, creating a direct

connection between the vascular systems of the parasite and host plant (Starr *et al.*, 2012).

There are two types of haustoria namely; the primary and secondary haustoria. The primary haustorium develops directly from the primary root apex, and it is the only haustorium that functions throughout the lifetime of the parasite (Kuijt, 1969). The secondary haustoria develop from lateral and adventitious roots and are often short-lived, sometimes only for a few months. The haustorium usually grows through the bark and into the tree's water-conducting tissues thus, allowing the transportation of water, organic and inorganic compounds into the parasite (Aukema & Martinez del Rio, 2002a; Okubamichael *et al.*, 2011; Polhill & Wiens, 1998; Veste, 2007).

Mistletoe seed establishment and survival are highly dependent on host suitability (Norton & Ladley, 1998). Generally, the majority of parasitic plants have a wide host range however, they can show a preference (the disproportional infestation in relation to the availability of hosts in the environment) for some hosts species; this may result from environmental factors such as the preferential attraction of pollinators or dispersers (Troncoso *et al.*, 2010), from an active selection of the host by the parasite (Runyon *et al.*, 2006), or host-parasite compatibility mechanisms (Press & Phoenix, 2005).

According to previous studies, host selection can be influenced by factors such as the composition (the different types of plants in the community) and abundance (number of individuals per species) of host species, host structure and host characteristics such as height, branch size and bark type (Arruda *et al.*, 2006; Medel *et al.*, 2004; Sales-Teodoro *et al.*, 2010; Sargent, 1995). Besides, the mistletoe-host relationship is also likely to be influenced by community dynamics. This occurs by having high mistletoe

infestation on susceptible host individuals, which in turn increases mistletoe abundance. As a result, this increases mistletoe fruit production and reinforces mistletoe distribution (Aukema & Martínez del Río, 2002b; Dean *et al.*, 1994; Overton, 1994).

Mistletoe infestations affect trees differently, normally if the infestation is severe, trees can be weakened, have stunted growth or dead branches, or die completely however, healthy trees can tolerate a few mistletoe branches infestations, (Glatzel & Geils, 2009). In cases where more than two mistletoe species co-occur on the same host plant, the impact is likely to be more detrimental as there is a competition for resources, sometimes even causing the death of the parasitized individual host plants.

1.1.7 Mistletoe occurrence in the habitat

Mistletoes occupy a habitat with a distinct spatial structure. As a result, mistletoe populations are a collection of local plant populations occupying a subdivided habitat (Kareiva, 1990) and that is viewed as metapopulations. A metapopulation refers to a collection of local populations coupled with dispersal or other processes (Hanski & Gilpin, 1991). Consistent patterns of mistletoe dispersal or spread and host invasion have been reported for distinct species across ecosystems worldwide (Botto-Mahan *et al.*, 2000; Hist *et al.*, 2011; Lopez de Buen & Ornelas, 2002; Watson & Rawsthorne, 2013). As such, mistletoe distribution is influenced by their interactions with their host plants, as well as their dispersal agents and environmental conditions.

1.2 Statement of the Problem

Although some studies to date show that mistletoes often prefer hosts that most greatly enhance the growth, reproduction, and fitness of the parasite population (Press & Phoenix, 2005), what makes some hosts to be particularly preferred over others is not

always clear. With the changing climatic conditions, ecosystem dynamics are likely to be disrupted and this is likely to have a significant influence on the savanna ecosystems. Although mistletoes are drivers of tree mortality, they also play important roles in maintaining ecosystem biodiversity despite their management being a challenge (Norton & Reid, 1997). Therefore, the scientific understanding of mistletoe ecology in the context of the ecosystem dynamics is important (Ramón, *et al.*, 2016). Although mistletoe species occurring in Namibia have been reported, limited studies on mistletoe ecology have been conducted in Namibia. The idea that certain host species characteristics can be used as surrogates to measure mistletoe abundance has been investigated (Aukema & Martinez del Rio 2002a; Okubamichael *et al.*, 2011). However, few indicators have proven reliable, especially across different ecosystems. Furthermore, although the vertical distribution of mistletoes within the canopy of the host trees has been studied (Ward, 2005; Sangüesa-Barreda *et al.*, 2012), little is known about the extent to which mistletoe position within the canopy is influenced by host characteristics. Thus, a further sound investigation is needed to understand the mechanisms underlying the mistletoe distribution in the central highland savanna.

Aspects of mistletoe ecology have also been reported in the central highland of Namibia (Amutenya, 2017). However, less is known about other aspects, especially their co-occurrence dynamics. It has been observed that host plants with more than two mistletoe species have low production and reduced fitness. Thus, the need for such information is urgent given the current concerns about the simultaneous occurrence of two or more mistletoe species can be detrimental to the host plants and on overall savanna biodiversity.

1.3 Aim of the study

This study aimed at determining composition, spatial abundance within hosts, co-occurrence, and host preference of mistletoes in the central highland savanna of Namibia.

1.4 Objectives

The specific objectives of this study were:

- (a) To determine the species composition of mistletoes in selected sites of the central highland savanna of Khomas Region, Namibia.
- (b) To determine the relationship between host size (canopy volume and canopy diameter) and mistletoe abundance within the canopy.
- (c) To determine the relationship between vertical host canopy position and spatial mistletoe abundance.
- (d) To determine the co-occurrence of different mistletoe species on host plants.
- (e) To determine mistletoe host preference in the highland savannas of Khomas Region, Namibia.

1.5 Null Hypotheses

- (a) H_0 : There is no relationship between host size (canopy volume and canopy diameter) and mistletoe abundance.
- (b) H_0 : There is no relationship between vertical host canopy position and spatial mistletoe abundance.
- (c) H_0 : Different species of mistletoes do not co-occur on host plants.
- (d) H_0 : Mistletoe species do not show any host preference in the highland savanna of Khomas Region, Namibia.

1.6 Significance of the study

The study also provides reliable host features that can be used as surrogates to estimate mistletoe abundance. Knowledge of the vertical organization of mistletoe production will improve our understanding of mistletoe infestation and distribution. Additionally, the mechanism of mistletoe co-occurrence on hosts enhances our understanding of the plant population dynamics, as this may set the conditions for species coexistence. Determining host preference helps in identifying plant species that are at a higher risk of excessive mistletoe infestations. Moreover, since the climate change-related environmental perturbations are likely to affect mistletoes, studying mistletoe ecology may give a good indicator of environmental conditions and ecosystem health. The present research information can also be applied not only to the control of mistletoe infestation (if necessary) but also to the management and conservation of the Namibian savanna ecosystems.

1.7 Limitation of the study

Due to limited selected area, the findings will be limited to the four selected sites. As a result, the limited spatial scope of investigation will constrain the extrapolation of findings to other ecosystems or regions.

CHAPTER 2: LITERATURE REVIEW

2.1 Functional ecology of mistletoes in natural ecosystems

Mistletoes are regarded as keystone species that promote biodiversity by providing high-quality fruit and nectar, secure nesting and roosting sites for birds, and provide abundant nutrient-rich litter (Cooney & Watson, 2005; Cooney *et al.*, 2006; Watson, 2001). A study by Watson and Herring (2006) undertaken in remnant woodland in Australia revealed that mistletoes provided a critical nutritional and nesting resources for many animals, and determined the distributions of many species.

Mistletoes can also be regarded as ecosystem engineers, as a natural enemy of the host and as a keystone resource (Press & Phoenix, 2005). A study by Godfree *et al.* (2003) examined the relationship between the mistletoe *Arceuthobium americanum* and the structure of *Pinus conorta* var. *murrayan* stands in central Oregon. The results showed that the death of mature trees created a growing space for younger host cohorts as well as for other plants. This serves as a good example on how mistletoes can act as a natural enemy of the host and as a keystone resource which appear to be crucial to ecosystem function and structure. Mistletoes can be used as indicators of change in ecosystem structure and function. For instance, Barbu (2007) found that in areas where negative abiotic factors were concentrated, such as greater erosion, higher pollution levels, and frequent drought, the hosts become more sensitive to mistletoe infestation. Thus, mistletoes may provide information on environmental stressors, and climatic conditions.

Mistletoes may also provide information on biodiversity and trophic interactions. Studies by March and Watson (2007; 2010) evaluated the litter contribution from hemiparasitic mistletoes *Amyema miqueli*, in an open eucalypt forest (*Eucalyptus blakelyi*, *E. dwyeri* and *E. dealbata*) at three scales; the forest stand, single trees, and

individual mistletoes. The study found that aerial hemiparasites that occur in tree canopies can alter litter-fall, decomposition rates and soil microbial communities beneath the canopies of their hosts which results in greater nutrient returns beneath mistletoe infected trees than beneath uninfected trees. This means that increase in below canopy soil fertility with mistletoe infestation leads to an increase in the spatial heterogeneity of nutrient availability with potential to alter ecological factors such as species diversity and plant productivity. Similarly, various studies on the enhanced soil nutrient concentrations beneath-canopy of savanna trees infested by mistletoes in a southern African supports the above mentioned findings (Ndagurwa 2015; Ndagurwa *et al.*, 2014; Muvengwi *et al.*, 2015).

Community change may be explained by the mechanism of suppression of dominant species. For instance, Pennings and Callaway (1996) investigated the effects of the native parasitic plant *Cuscuta salina* on the structure and dynamics of the plant community in a California salt marsh. The study showed that *Cuscuta salina* preferred *Salicornia virginica* as a host. Because this host was the community dominant, its suppression in areas where *Cuscuta* was abundant facilitated the expansion of the competitively subordinate species *Limonium californicum* and *Frankenia salina*, this in turn increased community diversity. In addition to the effects of parasitism, parasitic plants may further increase diversity through the facilitation of invasion (Joshi *et al.*, 2000). According to Joshi *et al.* (2000) an increase in the bare ground following die-back of the parasite *Rhinanthus alectorolophus* at the end of the season was reported to facilitate weed invasion that led to an increase in community diversity. Thus, it can be suggested that parasitic plants can contribute to the community diversity by suppressing the community dominantes or following die-back of the parasite itself.

2.2 Economic impact of mistletoes

Mistletoes are commonly known as bird lime, all heal, devil's fuge (English) and in Namibia they are locally referred as voëlent (Afrikaans). In general, these aerial parasites are from several plant families, especially Loranthaceae and Viscaceae (Polhill & Wiens, 1998). According to Begho *et al.* (2007) mistletoes can grow on many tree crops of economic importance including the shea butter tree, the neem tree, citrus species, especially sweet orange and grape. In spite of the important economic roles that parasitic plants play in both natural and agricultural systems, mistletoes are viewed as notorious and devastating parasites which pose serious losses to these economically-valuable fruit trees and medicinal plants growing in wild forests, gardens or orchards (Jiofack *et al.*, 2010).

Mistletoe infestations are likely to affect host growth and reproduction, which may cause changes in competitive interactions between host and non-host species (Press & Phoenix, 2005). Regardless of the negative impacts of mistletoes, mistletoes are recognized as culturally significant plants of which many species are used in pharmaceuticals, and as ornamentals which contribute significantly to the world's economy. In many north European countries, mistletoes are semi-domesticated and have a strong symbolic cultural association with both Christian and Pagan winter festivities (Mabey, 1996; Zuber, 2004). Mistletoes are also commercially valuable non-food crops that are harvested and traded for their seasonal ornamental value.

According to Jadhav *et al.* (2010), mistletoes of the Loranthaceae and Viscaceae are widely used in almost every continent to treat various ailments including hypertension, cancer, and diabetes, or used as a diuretic agent. It has been reported that mistletoes are now known as "cure-all" and have been found beneficial as a drug/remedy for more than twenty health problems (Adodo, 2004). For instance, the tea made from

Loranthus spp. is believed to cure bone fractures and body pain (Ken'ichi, *et al.*, 2006). In South-western Ethiopia remedies for tumour are prepared by crushing fresh leaves of *Tapinanthus globiferus* and mixed with cold water to be administered orally (Yineger & Yewhalaw, 2007). In Saudi Arabia, fresh stems of *Tapinanthus globiferus* commonly known as Hadhal are given orally to all types of livestock for the treatment of fever and removal of the placenta after parturition (Sher & Alyemeni, 2011), while in the Ebolowa region of Cameroon, one handful of the fresh leaves of *Tapinanthus globiferus* is usually mixed with one handful of the root bark of *Boswellia odorata*, the ingredients are macerated in 5L of local beer, and one glassful is taken twice a day for two weeks to cure syphilis (Noumi & Eloumou, 2011). In Namibia a study on ethnobotanical uses of parasitic plants indicated that of the 52 species of parasitic plants found in Namibia, only 14 have documented uses of which, *Viscum rotundifolium* plant is used to removal of warts and as astringent and *Oncocalyx welwitschii* leaves are used as expulsion of afterbirth in cattle (Tjiurutue *et al.*, 2019). In spite of the important economic roles that parasitic plants play in both natural and agricultural systems, this information is lacking, especially in the African context including Namibia. This could be because not much information is readily available on the chemical ecology of many African mistletoes. Locally, it can be suggested that the economic and cultural significance of mistletoes in Namibia can be considered low due to a lack of knowledge about these valuable plants.

2.3 Host-parasite compatibility mechanism

Diverse factors such as host characteristics have been reported to influence the establishment, survival, and the distribution of mistletoes among host plants (Aukema & Martinez del Rio, 2002a; Okubamichael *et al.*, 2011). The absorptive organs named haustoria play a crucial role in enabling mistletoes to be physically as well as

physiologically connected to their hosts. Therefore, the ability of mistletoes to establish on a potential host relies primarily on the ability of its haustorium to penetrate the host bark and establish a functional connection with the host. Various studies on mistletoe-host specificity have only used artificial transplanting of mistletoe seeds onto different potential host species and monitoring seedling development (Clay *et al.*, 1985; Yan, 1993). The success of the establishment and survival of mistletoe seedlings on each particular host species can be used as a measure of mistletoe-host compatibility.

Mistletoe-host compatibility is a function of host susceptibility to infestation and of mistletoe infectivity (Yan, 1993). This means that if mistletoes are compatible by chemical, physiological and physical processes at the mistletoe-host interface with the potential host plant, they are likely to establish on the potential host plant, germinate, and survive. Its likely compatibility is met because mistletoes contain the specific chemicals that allow recognition of the host and hence initiate haustoria penetration into the host's xylem (Fadini, 2011). However, if mistletoes are incompatible with the host plant the bark of many non-host plant species is resistant to haustorial penetration by mistletoes (Yan, 1993). Hence, mistletoe infestation may be blocked before establishment can occur. This blockage occurs as a result of chemicals that are released by the host that prevents the haustoria from developing and hence penetrating the host's tissues; in some cases, some haustoria manage to develop but they fail to penetrate the host. Thus, the mistletoes may not be able to establish or may establish but not survive. For example, non-host species sometimes develop a wound periderm that blocks access to the xylem, thereby curtailing further establishment of mistletoes (Yan, 1993).

It has been reported that mistletoe infestation occurs on closely related hosts (Norton & Carpenter, 1998). This means that plant species that are related to the most abundant host plant species are likely to act as hosts than non-related plant species. The pattern of infestation prevalence may be influenced by processes such as deposition of seeds on host trees by dispersers, germination of mistletoe seeds, and the establishment of seedlings and survival of mistletoe plants on different hosts (Aukema & Martinez del Rio, 2002a; Hoffmann *et al.*, 1986; Rödland & Ward, 2002; Yan, 1993). Based on these studies, mistletoe-host compatibility mechanisms are the primary factors that enable mistletoe establishment and survival and may be used to explain mistletoe co-occurrence and preference.

2.4 Determinants of mistletoe abundance

2.4.1 Height

According to various studies, mistletoe abundance is likely to be influenced by host structure and characteristics (e.g. host height, canopy diameter, branch size, and canopy shape) (Aukema & Martinez del Rio 2002a; Okubamichael *et al.*, 2011). Therefore, to determine which host characteristic is reliable to measure mistletoe abundance, it is crucial to understand how these characteristics can affect mistletoe abundance (Soares & Tomé, 2001). Height is one of the most researched host characteristics and has a significant effect on the mistletoes establishment on potential host plants (Aukema & Martinez del Rio, 2002a). Okubamichael *et al.* (2011) found that mistletoe parasitism is likely to increase with the height of the host plant where taller host plants were shown to have high mistletoe abundance than shorter host plants (Aukema & Martinez del Rio, 2002a).

The increase of mistletoe infestation with host plant height has been reported to occur partly because older plants (which are generally taller) have had more time to

accumulate mistletoes and that previously infested plants are more likely to receive more seeds and become infested (Okubamichael *et al.*, 2011). In line with this finding, Glatzel and Geils (2009) reported that mistletoe seeds may fall from the mistletoes in the upper part of the host plant creating new infestations on the lower branches of the host leading to more infectivity on that particular host plant.

Literature has also shown that preference for taller plants by bird dispersers is the suggested reason for higher mistletoe abundance in tall trees. Seed-dispersing birds are known to have preferences for perching and feeding in taller rather than shorter infested individuals (Donohue, 1995; Martinez del Rio *et al.*, 1996; Reid *et al.*, 2000; Aukema & Martinez del Rio, 2002a). Aukema and Martinez del Rio (2002a) suggested that it could be possible that birds have learned to associate tall plants with mistletoes and specifically target tall plants when foraging. They also noted a clear preference of birds perching on tall plants, regardless of whether the plants were parasitized or not. It could also be that many birds forage and perch in sites that are regarded to be safe from predators and select different parts of the canopy in response to the presence of predators (Suhonen, 1993; Krams, 2001). Therefore, the disproportional perching and deposition behaviour may affect mistletoe distribution patterns.

On the contrary, several other studies (e.g. Amutenya, 2017; Aukema & Martinez del Rio, 2002b; Donohue, 1995; Overton, 1994; Reid, *et al.*, 2000) reported a weak relationship between host plant size and mistletoe abundance. Firstly, this is because already parasitized hosts of a specific height are more likely to receive seeds than unparasitized hosts of the same height. This increases the variation in the infestation intensity of trees, and of tall trees in particular, and reduces the fit of a regression model. Secondly, dispersers are also likely to be attracted to trees for reasons other

than size. Other factors such as branch size and canopy shape may also be important in determining mistletoe abundance in given environments. Thus, host characteristics may not be equally important (Medel *et al.*, 2004).

2.4.2 Canopy diameter

Another host feature that is likely to affect mistletoe abundance is the canopy diameter. A study by Rahmad *et al.* (2014) reported a positive relationship between mistletoe abundance and plant canopy diameter. The positive relationship between mistletoe abundance and tree diameter in this study could be due to the fact that larger trees received more mistletoe seeds as they served as better perches for birds (Overton 1994). On the contrary Lopez de Buen *et al.* (2002) found that there was no significant influence of host diameter on mistletoe abundance.

2.4.3 Branch size

The survival and establishment of mistletoe seedlings on the host are strongly influenced by the host branch size on which seeds are placed (Sargent, 1995). This suggests that the characteristics of the branch selected by birds within host plants may influence mistletoe recruitment patterns.

A study by Reid (1991) proposed that mistletoes' requirement for small branches/stems may have promoted coevolution between small-bodied birds and mistletoes throughout the world. In line with this argument, studies conducted in Australia suggested that smaller host branches or stems are more susceptible to mistletoe infestation than larger ones (Reid, 1987; 1989). This is because smaller branches are easy to penetrate and permit seedling establishment while larger branches are too thick to permit mistletoe establishment. Earlier studies by Paine (1950), using artificial inoculation of orchard-grown plants also suggested that new host growth was more

susceptible to mistletoe infestation however, these studies used a limited range of stem sizes. It was found that new growth (shoots/branches) were more susceptible to mistletoe infestation because they had a lower mechanical resistance compared to the relatively thick, rough bark of older branches.

Sargent (1995) investigated the fate of the seeds of *Phoradendron robustissimum* (Viscaceae) planted on *Sapium oligoneuron* (Euphorbiaceae). After 2 and 3 years the rate of survival and establishment were reported greatest on branches in the 10-14 mm diameter size class. It was found that in *Phoradendron robustissimum* greatest mistletoe mortality occurred on both small and large branches, but that the causes of each were different. On the smallest branches, mortality occurred because the host branch died, while on the largest branches mortality occurred because the mistletoe appeared unable to develop a haustorial connection with the host.

2.4.4 Canopy shape

Canopy shape is also a major factor that is likely to influence the abundance of mistletoes. Aukema and Martinez del Rio (2002a) reported that plants with flat-topped canopies are likely to host more *Phoradendron* individuals because the exposed canopies receive high light intensity and more moisture. They found that light intensity affects *Phoradendron* abundance in that exposed plant canopies provide better habitats for mistletoes.

Rahmad *et al.* (2014) reported that plants with conical crown shape tend to host more mistletoe individuals than plants with non-conical canopy shape. This is because the conical canopies are reported to create large gaps at the top of the canopy, thereby allowing greater sunlight penetration that favoured the growth and development of mistletoe species (Smith & Brewer, 1994).

2.5 Spatial distribution patterns of mistletoes in host canopies

Understanding the patterns of mistletoe distribution in the host tree canopy is the first step toward the formulation of hypotheses regarding underlying mechanisms that shape the growth of mistletoe plants and understanding of the factors regulating their abundance and distribution (Norton & Reid, 1997).

Rizzini (1980) studied the woody mistletoe *Psittacanthus robustus* (Loranthaceae) in savannas of central and south-eastern Brazil. This species parasitized 12 species of Vochysiaceae and two species of Melastomataceae, indicating a clumped distribution and infestations on the uppermost portions of taller host trees. Distribution patterns of *Psittacanthus robustus* in south-eastern Brazil showed highly aggregated distribution within hosts (Guerra *et al.*, 2018; Sales-Teodoro *et al.*, 2010).

Hist *et al.* (2011) reported that the main biological mechanism explaining the patterns of distribution is related to the behaviour of seed dispersal birds and territoriality. Frugivorous birds perch more often on hosts with fruiting mistletoes, generating clumped seed deposition on already parasitized plants (Aukema & Martinez del Rio, 2002b; Medel *et al.*, 2004). Besides, foraging dispersers can also track fruiting plants on habitat patches, leading to an increased infestation in areas with higher mistletoe prevalence (Garcia *et al.*, 2009; Martinez del Rio *et al.*, 1996). Therefore, foraging decisions made by avian dispersers are likely to create a positive feedback process leading to a clumped distribution pattern of mistletoes (Sales-Teodoro *et al.*, 2010).

Dawson *et al.* (1990) and Lamont and Southall (1982) reported that mistletoe position within the forest is likely to be dependent on the opportunities available for seed-dispersing birds to defecate or regurgitate seed with the maximum mistletoe densities at mid-height in the host. This was also supported by Hollinger (1989) who found most

mistletoe (*Alepis flavida* and *Peraxilla tetrapetala*) foliage in the middle portion of a *Nothofagus solandri* canopy. Thus, mistletoe distribution is primarily influenced by dispersers.

A study in *Nothofagus* forests in New Zealand showed a non-random distribution of three mistletoes with respect to height on the host plant (Norton *et al.* 1997). *Alepis flavida* and *Peraxilla tetrapetala* were most common in the lower and middle parts of the host tree, while *Peraxilla colensoi* was most common in the middle and upper parts of the host tree. The findings indicate that it may be that the different forest structures at the two sites present different opportunities for birds and hence for mistletoe establishment, with mistletoes most common in those parts of the forest canopy most frequented by birds. Similarly, Dawson *et al.* (1990) reported that mistletoe position within the forest is likely to be dependent on the opportunities available for seed dispersing birds to defecate or regurgitate seed. Thus, reviews on the distribution of mistletoes within-host canopy report different results depending on the mistletoe species studied. Therefore, these results cannot be used to extrapolate distribution patterns of mistletoes observed in semi-arid environments.

2.6 Dispersal agents of mistletoes

2.6.1 Bird dispersers

Bird dispersers and mistletoes have a mutualistic relationship. For instance, mistletoes act as a foraging substrate for frugivorous birds and provide nesting and roosting sites for birds while, frugivorous birds are dispersers of these plants (Press & Phoenix, 2005; Watson, 2001). Mistletoe fruits are usually large, conspicuously coloured, and often high in soluble carbohydrates, minerals, lipids, and fats, and can have an abundance of amino acids (Lamont, 1982).

Reid (1991) reported that some mistletoe species have developed contrasting colours of red, black, purple, and dark blue that target specific frugivorous birds. In turn, the bird dispersers such as the genus *Dicaeum* (mistletoe birds) have modified tongues and crops that allow them to efficiently process mistletoe fruits. The study also found that they frequently dispersed the seeds to suitable host branches where the mistletoes could establish. Similarly, members of the bird genus *Phainopepla* have been reported to have a specialized digestive system and they breed during the fruiting season of the desert mistletoe *Phoradendron californicum* (Walsberg, 1975).

Bird dispersers are reported to play a crucial role in creating and sustaining diversity in plant communities (Schupp *et al.*, 2002). Interactions between mistletoes and birds have been studied in many countries, especially in forested regions of Australia, North America, and Europe. The majority of these studies reported a positive relationship between mistletoe abundance and bird species richness was established (Bennetts *et al.*, 1996; Ikin *et al.*, 2014; Mathiasen *et al.*, 2008; Watson, 2002). However, it is still not clear which particular resources of the host plant contribute to this response.

Similarly, Zuria *et al.* (2014) found that bird species richness and abundance were positively related to the abundance of mistletoe plants in the surveyed hedgerows in tropical agricultural landscapes of central Mexico. This pattern was due to the following explanations: firstly, mistletoes directly increased food availability for birds in both the rainy and dry seasons; Secondly, mistletoes increased foraging opportunities for insectivorous and generalist birds who are attracted to invertebrates that are also using mistletoe plants as food. Lastly, mistletoes increased structural complexity that provided cover against predators while roosting, as well as safer nesting sites. Thus, it was concluded that mistletoes are important for promoting a

higher bird species richness and abundance in human-modified landscapes, such as agricultural systems in the tropics.

Studies have indicated that mistletoe-dispersing birds visited certain tree species significantly more often than others (Aukema & del Rio, 2002a; López de Buen & Ornelas, 1999). For example, Carlo *et al.* (2004) a study on avian foraging at two shaded coffee plantations in Ciales, Puerto Rico, reported that foraging activity and abundance of fruits were positively correlated across the study sites. Dispersing birds mostly preferred host plant species that fruited over prolonged periods or that provide birds with a fairly constant fruit supply. This shows that bird dispersers may learn through time to differentially visit certain host species based on the reward of mistletoe fruits found only on infected trees (Godschalk 1983, 1985). The reward being offered increases the chance of efficient dispersal of mistletoe seeds to the appropriate host thereby facilitating host specificity (Aukema & del Rio, 2002a).

Roxburgh and Nicolson's (2005) study in *Acacia*-dominated savanna, showed that disperser preferences were related to the prevalence of mistletoe infestation among different host tree species. Yellow-fronted Tinker Barbets (*Pogoniulus chrysoconus* Temminck); Black-collared Barbets (*Lybius torquatus* Dumont) (Capitonidae); and Plum-coloured Starlings (*Cinnyricinclus leucogaster* Boddaert, Sturnidae) were the main dispersers of the two mistletoe species studied. All three bird dispersal species fed on *Phragmanthera dschallensis* while only Tinker Barbets fed on *Plicosepalus kalachariensis* (Loranthaceae). These basic findings are consistent with research showing that bird dispersers have a mutualistic association with mistletoes, and are responsible for the kinds of trees the mistletoe seeds encounter and the frequency of encounter.

2.6.2 Herbivorous small mammals

According to Okubamichael *et al.* (2011), small mammals serve as secondary dispersers of mistletoe seeds. Small mammals usually swallow the whole berry, and as they move from one area to another they disperse the seeds by excreting a mass of semi-digested berry pulp and seeds. Ingestion of mistletoe seeds through the mammal's gut plays a role in promoting germination and development of a 'holdfast' (Amico & Aizen, 2000).

Okubamichael *et al.* (2011) stated that mistletoes are unique in retaining their evergreen fleshy leaves, stems, and bear fruits even during the dry winter months. Thus, mistletoes are valuable as they remain available when there are few alternative sources of dietary protein for small mammals. Hence, mistletoes may act as a keystone food source for small mammals especially during the winter season when other sources of food in the ecosystem are scarce. Herbivorous small mammals such as the Bushveld Elephant-shrew (*Elephantulus intufi*), Mutimammate Mouse (*Mastomys coucha*), Mutimammate Mouse (*Mastomys natalensis*), and Namaqua Rock Mouse (*Aethomys namaquensis*) are examples of mistletoe seed dispersers in savanna ecosystems (Amutenya, 2017). Amico and Aizen, (2000) studied *Dromiciops australis*, a nocturnal marsupial endemic to the northern portion of the temperate forests of southern South America, and reported that *D. australis* is a highly efficient disperser of loranthaceous mistletoe *Tristerix corymbosus* seeds.

2.7 Host preference of mistletoes

The impact of parasitic plants on community structure depends on which species are parasitized (Press & Phoenix, 2005). Often, this is related to host diversity, preference for particular host species, and the degree to which the preferred species can be selected. Most parasitic can parasitize more than one species. Host plants that are

disproportional host infestation was due to the differential establishment of mistletoe seeds, the behaviour of dispersing birds, and morphological characteristics of the hosts. In terms of morphological characteristics, *Schinus montana* lacked spines and was predominantly found along the Yerba Loca creek, which made it preferable because its ability to avoid water stress to the mistletoe, whilst attracting the avian vector of the mistletoe, therefore enhancing the probability of the vector spreading. A study by Mourão *et al.* (2016) evaluated the host preference of *Struthanthus flexicaulis* among species of the plant community in ironstone outcrops in Southeast Brazil. *Struthanthus flexicaulis* preferred *Mimosa calodendron* (Fabaceae) and the interaction was maintained and intensified not only by birds but also very likely by the ability of *M. calodendron* to fix nitrogen, thereby enhancing the mistletoe development.

Similarly, a study by Cranegie *et al.* (2009) reported that the host preference of *Dendrophthoe vitellina* and *Amyema bifurcate* on eucalypt trees in Australia indicated that mistletoe host preference was positively correlated to host tree species. A study on host-preference and density of woodrose-forming mistletoes (Loranthaceae) on savanna vegetation, South Africa Zerefos *et al.* (2003) found that mistletoe host preference was negatively correlated with host wood density. By reviewing the studies by Cranegie *et al.* (2009) and Zerefos *et al.* (2003) it can be suggested that although some factors such as host abundance play a role in determining host preference, other factors such as the preferential attraction of bird dispersers Troncoso *et al.* (2010), host-parasite compatibility mechanisms Press and Phoenix (2005) and geographical host range (Griffiths *et al.*, 2016) are equally important. Host preference may also depend on the diversity of potential hosts available and niche suitability Lira-Noriega *et al.* (2015) may also be equally important.

A study by Roxburgh and Nicolson (2005) reported that the differential use of hosts by mistletoes may also depend on a bird's perching preference. It has been shown that in Africa 70% of mistletoes are generalist species that parasitize hosts from several families whereby, 12% are specific on hosts from one family but occasionally parasitize a few genera of other families and 18% are specific to one or a few host species of a single genus (Polhill & Wiens, 1998). This indicates that the generalist mistletoes may encounter incompatible host species at a different locality, and thus may parasitize a subset of available host species at a given locality.

The reason why parasites may have a different host preference in different locations is not yet known. However, in mistletoes, changes in host susceptibility to infestation between different regions has been suggested (Snyder *et al.*, 1996). Changes in host susceptibility to mistletoe infestation in different locations might be due to the effects mediated by physical and biological gradients across the landscape (Pennings & Callaway, 1996). For instance, Pennings and Callaway (1996) investigated the effect of a native parasitic plant, *Cuscuta salina*, on the structure and dynamics of the plant community in a California salt marsh. The study indicated that the effect of *Cuscuta* on the plant community differed across elevation. *Cuscuta* depressed *Salicornia* biomass in both the high- and low-*Salicornia* zones; however, recent heavy *Cuscuta* infections led to an increase in *Limonium* and *Frankenia* only in the high *Salicornia* zone. This could have been because *Cuscuta* infections in the low-*Salicornia* zone were less virulent or more transient. On the other hand, it may have been that *Limonium* and *Frankenia* were less able to invade infected patches in the low-*Salicornia* zone.

2.8 Mistletoe co-occurrence on host plants

Mistletoe infestations have a major impact on the growth and reproduction of the host plants. It has been reported that infestations can trigger a cascade of harmful effects

for the host species, such as reduced reproductive fitness and increased mortality (Aukema, 2003; Press & Phoenix, 2005). However, a higher density of a given species of mistletoe, or even increased density due to the occurrence of more than one mistletoe species, can be expected to diminish the fitness of the host individual.

If one host species is compatible (structural and physiological) with more than one mistletoe species, mistletoe co-occurrence is likely to be observed. In line with the above, Arruda *et al.* (2012) reported six occurrences of multiple mistletoe species on the same host in the Federal District of Brasília. According to their findings, the occurrence of mistletoe species was determined by mistletoe compatibility with their hosts.

The simultaneous occurrence of two species of mistletoes can have harmful effects on the host, including changes to the physiology, anatomy, and behavior of the host (Arruda *et al.*, 2009; Arruda *et al.*, 2012; Press & Phoenix, 2005). Mourão *et al.* (2009) reported that mistletoes affect the reproductive success of its host by reducing the plant production. Consequently, the physiological effects of mistletoe can lead to host mortality (Mourão *et al.*, 2009; Sales-Teodoro, 2010). At higher mistletoe density due to the occurrence of more than one mistletoe species on the same host, mistletoes can diminish the fitness of the host plant, which may be reflected in diminished competitive and reproductive ability of the hosts.

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the study site

3.1.1 Location and extent

The study was conducted in the central highland savanna of Namibia (Figure 1), which occurs on the central plateau at the altitude of 1350 m to 2200m and lies east of the Namib Desert. The area falls within the geographic coordinates of 21 ° to 24 ° South and 16 ° to 18 ° East. The present study had four localities in Khomas Region, spread over a distance of approximately 9.6 - 100 km apart.

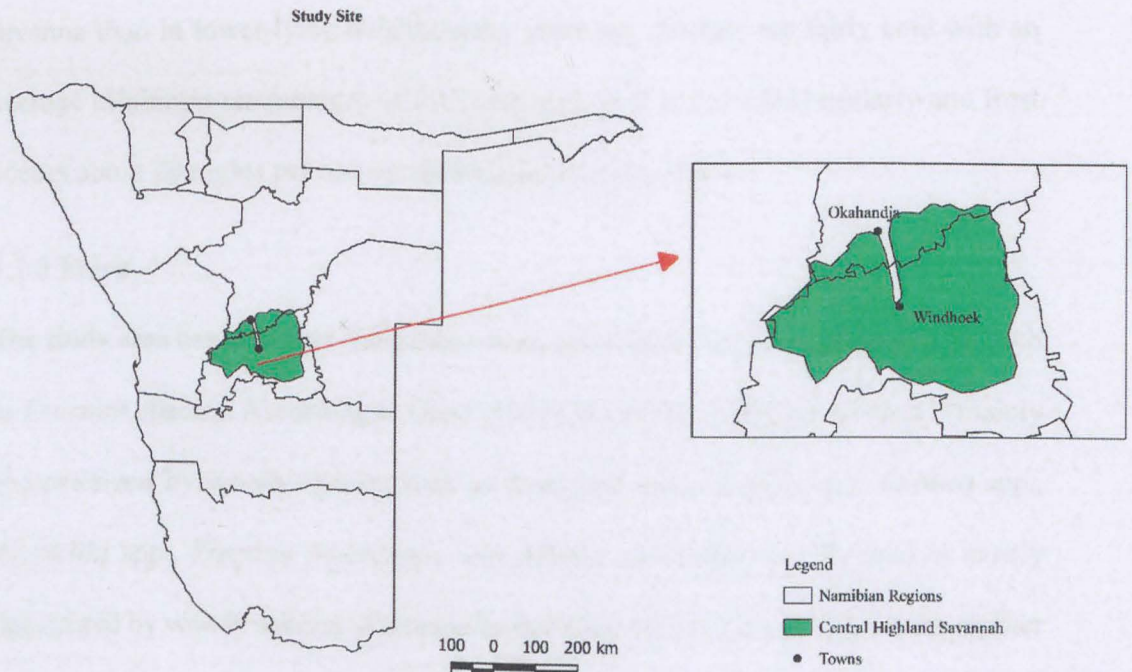


Figure 3. 1 Location of the study area indicating the area covered by the central highland savanna.

3.1.2 Climate

The central highland savanna consists of a semi-arid climate (Mendelsohn *et al.*, 2002). Usually, the wet season occurs from November to April while, the dry season is mainly from May to October, with annual rainfall range from 350 - 400 mm, most of which occurs between January and March (Mendelsohn *et al.*, 2002).

The minimum temperatures range from 5 °C to 18° C and the maximum temperatures range from 30 °C to 32 °C (Mendelsohn *et al.*, 2002). There is a high evaporation rate leading to an annual water deficit exceeding 2000 mm (Mendelsohn *et al.*, 2009). The average maximum temperature of about 29°C in summer is cooler in the highland savanna than in lower-lying neighbouring savannas. Winters are fairly cold with an average minimum temperature of 3°C, although -9°C is recorded regularly and frost occurs about 20 nights per annum (Mendelsohn *et al.*, 2009).

3.1.3 Flora

The study area has abundant indigenous trees and shrubs with some alien species such as *Prosopis* species. According to Giess (1971), the central highland savanna is mainly characterized by woody species such as *Senegalia* spp., *Searsia* spp., *Grewia* spp., *Vachellia* spp., *Ziziphus mucronata*, and *Albizia anthelmintica*. The area is mostly dominated by woody species of *Senegalia mellifera* which is a well-known encroacher species (Bester *et al.*, 2002). Grass species include the common species such as *Stipagrostis* spp., *Enneapogon* spp., *Aristida* spp., *Sporobolus* spp., and *Eragrostis* spp.

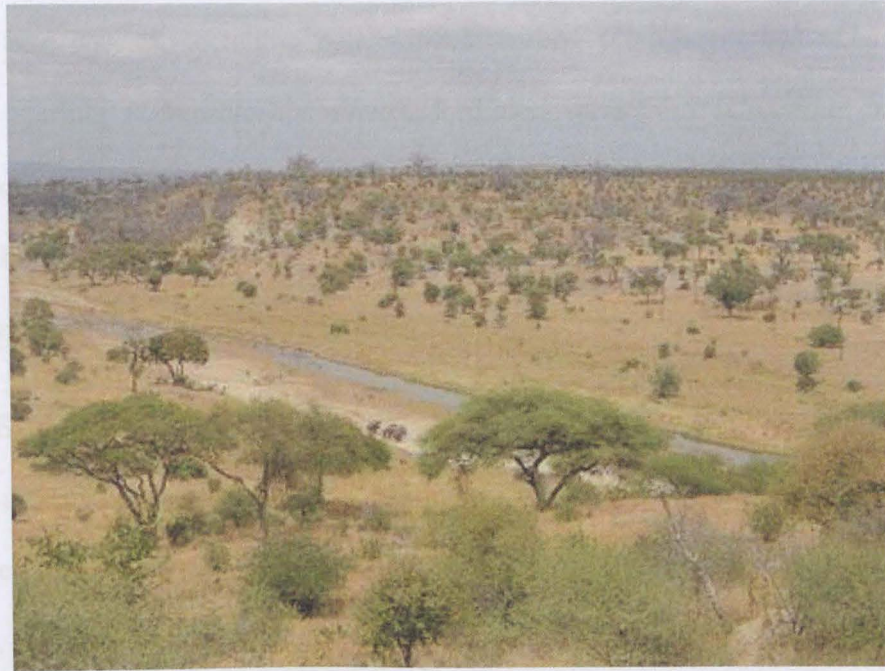


Figure 3. 2 A typical highland savanna landscape, near Farm Kiamsab West 364.

Photo: L. Ondigo (2019)

3.1.4 Fauna

The central highland savanna of Namibia has a high degree of animal endemism and biodiversity in comparison to other regions of Namibia (Barnard, 1998). The high altitude biomes such as the Aus Mountains support several reptile and insect species with a severely restricted range. Only 0.2% of the central highland savanna is managed as government-protected conservation areas. The central highland savanna is also known to support some herbivorous small mammals such as the Bushveld Elephant-shrew (*Elephantulus intufi*), Mutimammate Mouse (*Mastomys coucha*), Natal Mutimammate Mouse (*Mastomys natalensis*), and Namaqua Rock Mouse (*Aethomys namaquensis*). Furthermore, the area contains ungulates such as warthog, hartebeest, kudu, and gemsbok as well as large mammalian predators (e.g. cheetah, leopard, jackal, and caracal), insects, and reptiles.

Many bird species, including pale winged starling (*Onychognathus nabouroup*), glossy starling (*Lamprotornis nitens*), Redfaced mousebird (*Urocolius indicus*), masked weaver (*Ploceus velatus*), lesser masked weaver (*Ploceus intermedius*), monteiro's hornbill (*Tockus monteiri*), and Yellow-fronted Tinker Barbets (*Pogoniulus chrysoconus*) have also been observed.

3.1.5 Geology, soils and the physical environment

The study area is described as a mountainous central plateau that rises 1000-2000 m between the escarpment in the west and the Kalahari sand field in the east (Joubert, 1997). It is characterized by high undulating landforms, a thin soil layer, and a stratum of exposed bedrock. The landforms are typically made of actively eroding landscapes, especially in the hilly or undulating areas that cover much of the central plateau. The ground surface tends to be hard due to the presence of rocks or stones (Joubert, 1997).

The Khomas Highlands was created around 650 million years ago. The Khomas subgroup is known to be the youngest of the Damara Sequence and consists of metamorphic rocks such as mica schist, traversed by micaceous quartzite, subordinate calcareous schist, and impure marble and amphibole schist (SACS, 1980; Miller & Schalk, 1980). The soils of this region have been classified as leptosols, which are coarse shallow soils, containing a high gravel content and low water holding capacity and are relatively nutrient-poor and can lead to high rates of water run-off and erosion during heavy rainfall. Major rivers in western-central Namibia are the Swakop and Kuiseb Rivers of which the Khomas Highland is a source which runs east to west from Windhoek toward the sea. All these rivers are ephemeral and are dry for most parts of the year.

3.2 Study species

A desktop study based on herbarium data and literature sources (Mannheimer, 2012) was used to check the distribution and number of mistletoes in the study area. Mistletoe species and their distribution data were obtained from the National Botanical Research database and Herbarium Management System (BRAHMS). Herbarium data on the distribution of mistletoe were used to locate the mistletoes for field assessments.

3.3 Field data collection

The study area was divided into four selected sampling sites (Goreangab dam 22.5286° S, 17.0087° E; National Botanical Garden of Namibia 22.61255° S, 17.05614° E; University of Namibia Main campus grounds 22.6122° S, 17.0584° E; and Farm Kiamsab West 364 22.9948° S, 16.2871° E) based on the herbarium locality data. In each of the sampling areas, focal plants with mistletoe infestation were purposively chosen. Focal plant was referred as to an individual plant infested by the mistletoe species under study.

For each of the four sampling sites, circular plots (10 m diameter) were demarcated around the focal plants. A total of forty circular plots were established with the focal plants at the centre of each plot. All trees within the plot were inspected for the presence of mistletoes (Appendix 1). Care was taken to identify all mistletoes. Mistletoes can be difficult to see from ground level because of obscuring foliage and small size therefore, a systematic method was used for each plant to ensure that errors were reduced. While it was easy to estimate mistletoe abundance for shorter host plants it was more difficult for taller host plants with high canopies. The present study considered only live mistletoe individuals.

Within each plot, geographical coordinates were taken for each focal plant using a Global Positioning System (GPS). For each of the infested host plants identified, mistletoe species growing on them were identified to determine species composition. Host canopy height was measured using a 2 m range pole and two canopy diameter measurements were taken at right angles to each other using a tape measure. The canopy diameter readings were taken from the widest extent of foliage, and the total number of mistletoes occurring in the host canopy were counted and recorded.

To determine the spatial distribution of mistletoes within the host canopy in terms of vertical positioning, mistletoes were recorded as occurring on the lower, middle, or upper third of the canopy, and mistletoe abundance was recorded in each category (Ward, 2005). To determine mistletoe co-occurrence, observations were made where two or more species of mistletoe occurred on the same host individual. To determine host preference, infested host species and individual plants of the identified host species not infested within these plots were identified, and their abundance was recorded (Appendix 1). Finally, pictures of all mistletoe species encountered during the survey were taken for visual and morphological identification.

3.4 Data analyses

3.4.1 Species composition of mistletoes in the highland savanna

Species composition of mistletoes in the central highland savanna was determined based on the herbarium records of the National Herbarium of Namibia (WIND) and from the field observations. Mistletoes recorded were then described and mapped using the QGIS (Quantum Geographic Information System).

3.4.2 Relationship between host size (canopy volume and canopy diameter) and mistletoe abundance

Because the central highland savanna of Namibia consists of various host species with different canopy structures it was problematic to use different formulas according to the canopy shape. Thus to reduce errors Canopy volume (CV) was calculated using a standard formula of an ellipsoid $CV = \frac{2}{3}\pi H (A/2 \times B/2)$ (Thorne *et al.*, 2002) because it is flexible and accommodates all canopy shapes.

H= height

A= east - west canopy diameter

B= south - north canopy diameter

A Shapiro - Wilk test (Zar, 1999) was used to determine whether the data for the canopy size (canopy volume and canopy diameter) and mistletoe abundance were normally distributed. A Simple Linear Regression Analysis was used to determine whether canopy volume or canopy diameter can be used as estimates of mistletoe abundance.

3.4.3 Comparison of mistletoe abundance among vertical positions in host canopy

The observed distribution of mistletoes within the host canopy was determined to establish whether the distribution was random. Thus, a Chi-square test (χ^2) of Association was used to determine if there was a significant association between vertical host canopy position and mistletoe abundance.

3.3.4 Determination of co-occurrence of mistletoe species on hosts

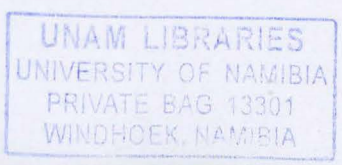
To determine the association (co-occurrence) between different mistletoe species, a Chi-square test (χ^2) was used to test if the distributions of the mistletoe species were independent of each other with respect to the host trees occupied.

3.4.5 Host preference of mistletoes in the highland savannas

To determine the host preference of mistletoes (whether there was a significant disproportional infestation in relation to the availability of hosts in the environment), a Chi-square test (χ^2) of association was used.

Table 4.1 Mistletoe species recorded in highland savannas

Mistletoe species	Host tree	Number of trees	Number of mistletoes
<i>Phoradendron villosum</i>	<i>Acacia drepanolobium</i>	1	1
<i>Phoradendron villosum</i>	<i>Acacia drepanolobium</i>	1	1
<i>Phoradendron villosum</i>	<i>Acacia drepanolobium</i>	1	1
<i>Phoradendron villosum</i>	<i>Acacia drepanolobium</i>	1	1
<i>Phoradendron villosum</i>	<i>Acacia drepanolobium</i>	1	1



CHAPTER 4: RESULTS

4.1 Species composition and descriptions of mistletoes in the highland savanna of Namibia

Based on field records and herbarium records, only four mistletoes belonging to two families were identified, recorded, and mapped for the present study (Table 4.1). When examining the difference in the distribution patterns of mistletoe species between those previously reported by the herbarium records of the National Herbarium of Namibia (WIND) and those from the present study, a new locality was reported for *Oncocalyx welwitschii*. The four mistletoe species are described below in detail with their distribution information also mapped based on herbarium data and field records from the present study.

Table 4. 1 Mistletoe species recorded in the present study area

Mistletoe species	Family	Primary host species	Secondary host species
<i>Oncocalyx welwitschii</i>	Loranthaceae	<i>Vachellia reficiens</i>	No record
<i>Plicosepalus kalachariensis</i>	Loranthaceae	<i>Albizia anthelmintica</i>	<i>Vachellia reficiens</i> , <i>V. karroo</i> , and <i>V. hebeclada</i> ,
<i>Tapinanthus oleifolius</i>	Loranthaceae	<i>Senegalia mellifera</i> , and <i>Dichrostachys cinerea</i>	<i>V. karroo</i> , and <i>V. hebeclada</i>
<i>Viscum rotundifolium</i>	Viscaceae	<i>Ziziphus mucronata</i> , and <i>Boscia albitrunca</i> ,	<i>V. hebeclada</i> , and <i>Ehretia alba</i>

4.1.1 *Oncocalyx welwitschii* (Engl.) Polhill & Wiens.

Oncocalyx welwitschii is a parasitic plant species in the Family Loranthaceae. The branches are usually chunky, brittle, and beige to brownish coloured originating from swollen bases. Leaves are opposite to alternate, with a leaf blade that is usually less than 30 mm long. Flowers are bright yellow occasionally orange and hairless with a

prominent threadlike style with a globose stigma. Fruits are ovoid, smooth, and red when ripe (Figure 4.1) (Mannheimer, 2012). *Oncocalyx welwitschii* has been reported to parasitize *Senegalia* and *Vachellia* species, (Kyalangalilwa *et al.*, 2013) and *Boscia* species. *Oncocalyx welwitschii* flowers from November to January, coinciding with the summer rains.

According to the herbarium data, *O. welwitschii* is distributed in central and north-western Namibia (Figure 4.2) and an altitude of approximately 1278 m. The present study extended the distribution of this species to the south-eastern end of its previous distribution.



Figure 4. 1 *Oncocalyx welwitschii* (with bright yellow flowers)

Photo: L. Ondigo (2019)

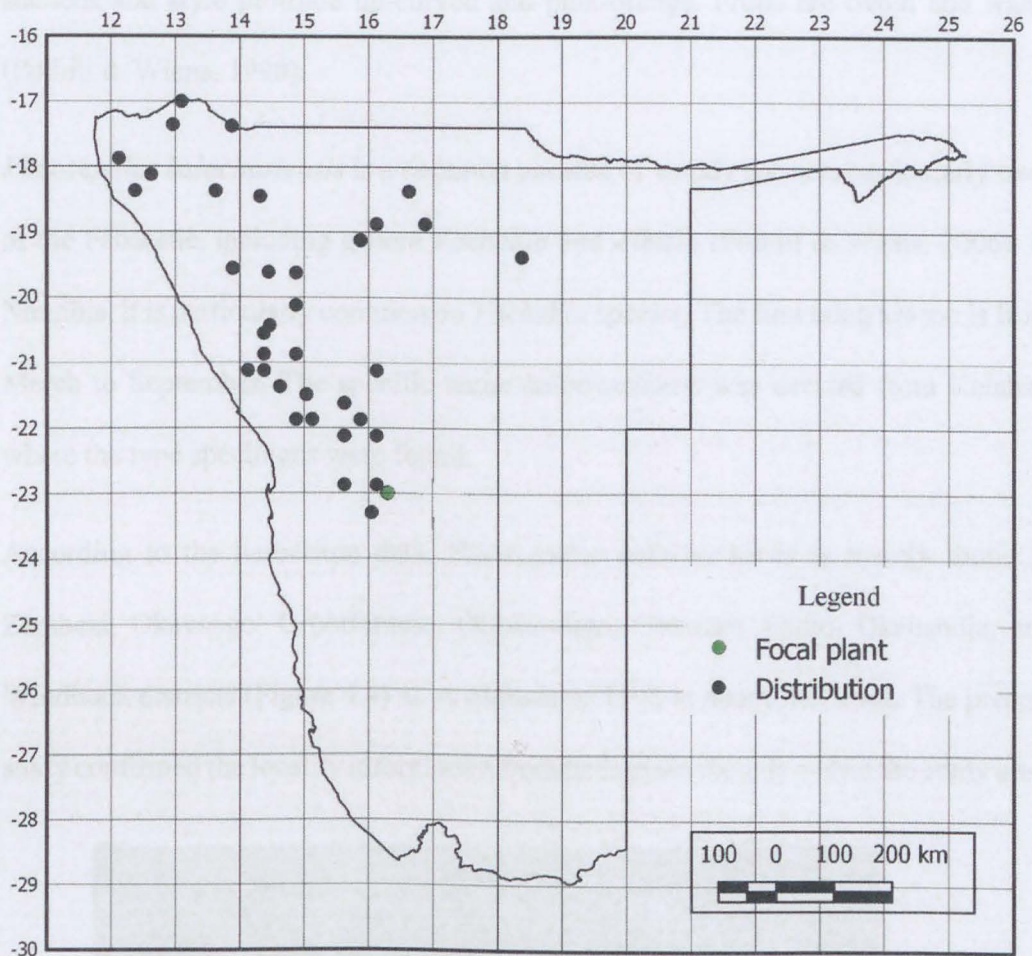


Figure 4. 2 Distribution map of *Oncoclyx welwitschii* in Namibia also indicating focal plants/points in green.

4.1.2 *Plicosepalus kalachariensis* (Schinz) Danser

Plicosepalus kalachariensis is a shrubby, hemiparasitic perennial woody species in the Family of Loranthaceae. The branches are brittle and greyish that originates from swollen bases. Leaves are light green to glaucous, simple, opposite to sub-opposite. Dull yellow flowers clustered in leaf axils, with flushed pink to a reddish-orange tube, usually darker towards the base, but sometimes banded or mottled (Figure 4.3);

stamens and style protrude up-curved and pink-orange. Fruits are ovoid and warty (Polhill & Wiens, 1998).

Plicosepalus kalachariensis is a common parasite of woody species, particularly trees of the Fabaceae, including genera *Vachellia* and *Albizia* (Polhill & Wiens, 2006). In Namibia, it is particularly common on *Vachellia* species. The flowering season is from March to September. The specific name *kalachariensis* was derived from Kalahari where the type specimens were found.

According to the herbarium data, *Plicosepalus kalachariensis* is mainly found in Zambezi, Okavango, Grootfontein, Otjiwarongo, Omaruru, Outjo, Okahandja, and Windhoek districts (Figure 4.4) at an altitude of 1595 m above sea level. The present study confirmed the locality information from herbarium records within the study area.



Figure 4. 3 *Plicosepalus kalachariensis* (flowers with dull yellow flushed pink-orange tube).

Photo: S. Rügheimer (2019)

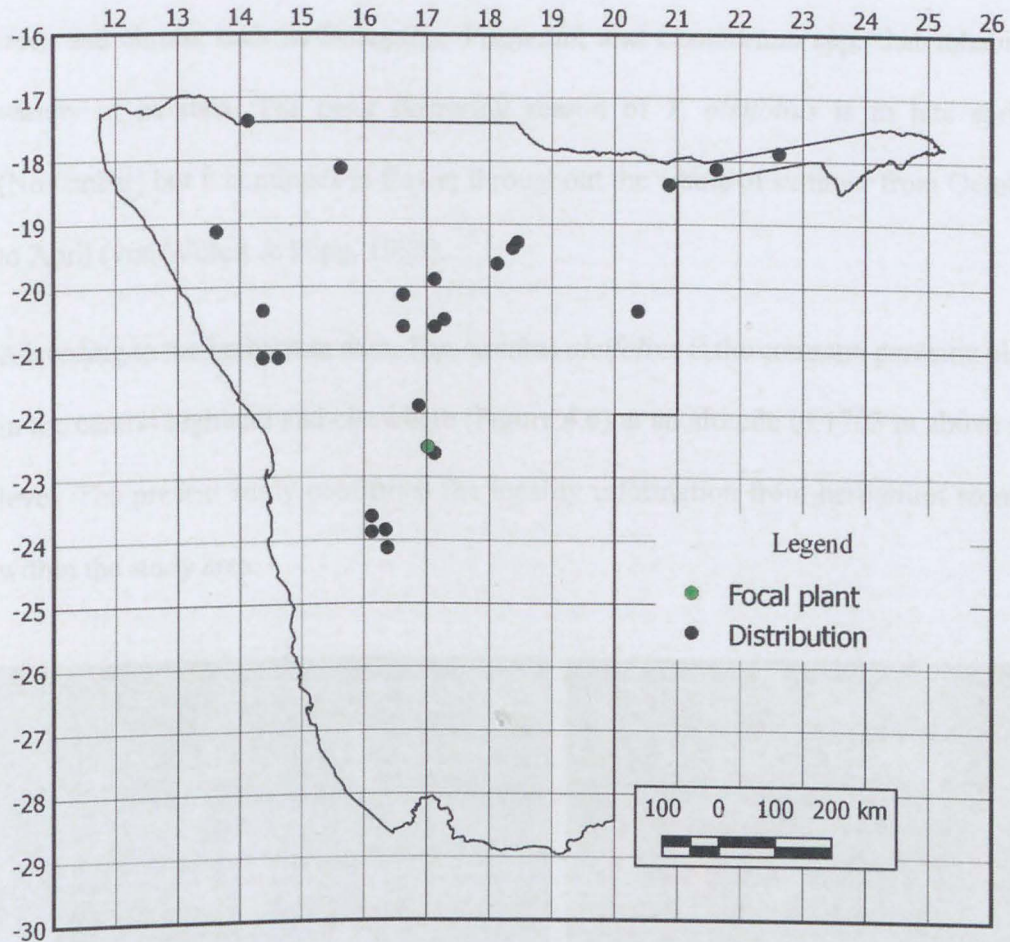


Figure 4. 4 Distribution map for *Plicosepalus kalachariensis* in Namibia also indicating focal plants /points in green.

4.1.3 *Tapinanthus oleifolius* (Wendl.) Danser

Tapinanthus oleifolius is a common shrubby parasitic perennial plant from the Family Loranthaceae. The branches are often finely hairy, brittle, and greyish, originating from swollen base. The leaves are dull green, simple, opposite to sub-opposite. Flowers are red with whitish spots, head of buds yellowish or greenish-white. Red-orange, ovoid, smooth, berries when ripening (Mannheimer, 2012).

Tapinanthus oleifolius is a common and widespread species growing on a variety of trees and shrubs such as *Senegalia*, *Vachellia*, and *Combretum* spp. that inhabit a variety of habitats. The peak flowering season of *T. oleifolius* is in late spring (November) but it continues to flower throughout the whole of summer from October to April (von Willert & Popp, 1995).

According to the herbarium data, *Tapinanthus oleifolius* is the common parasitic plant in the central highland and elsewhere (Figure 4.6) at an altitude of 1703 m above sea level. The present study confirmed the locality information from herbarium records within the study area.

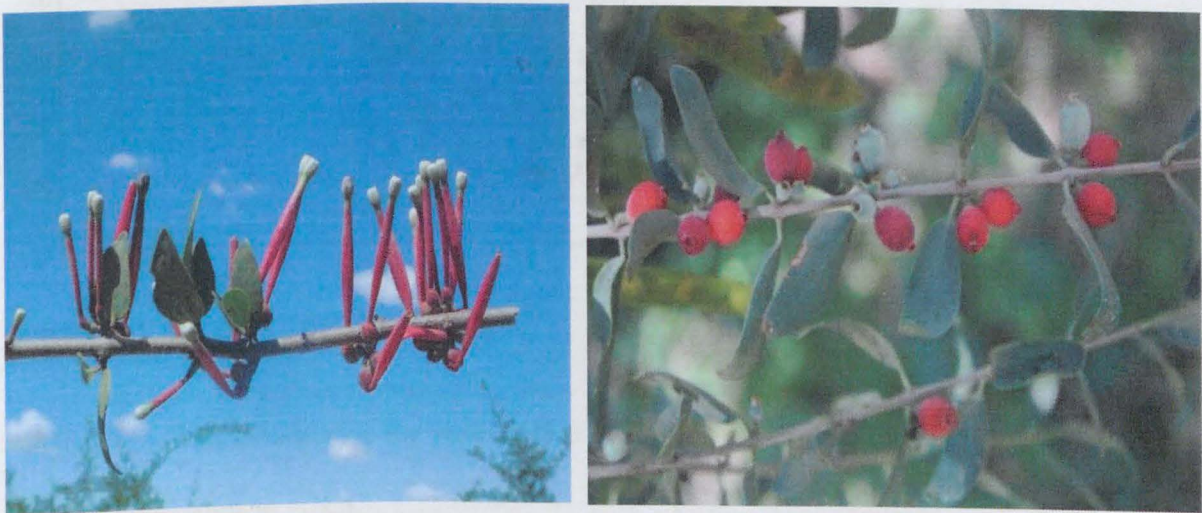


Figure 4. 5 *Tapinanthus oleifolius* with (a) red flowers and (b) red ripen berries.

Photo: L. Ondigo (2019)

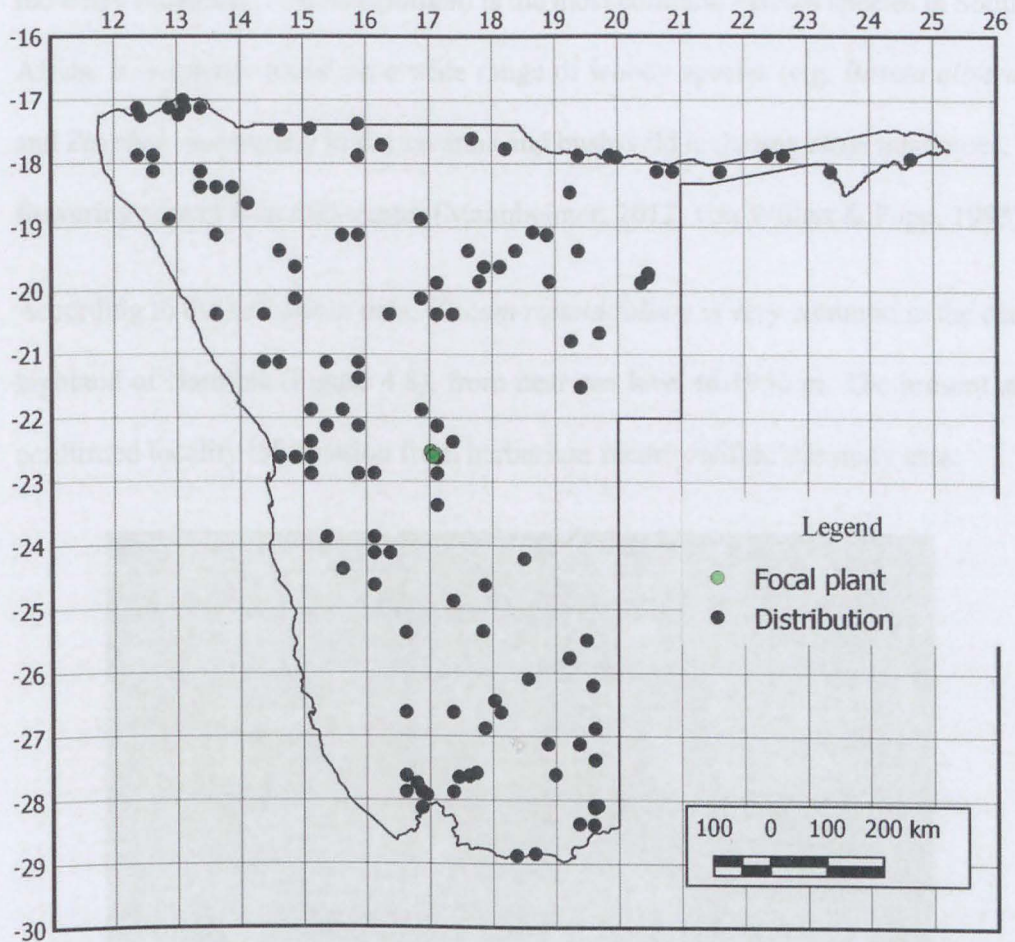


Figure 4. 6 Distribution map for *Tapinanthus oleifolius* in Namibia also indicating focal plants/points in green.

4.1.4 *Viscum rotundifolium* L. f.

Viscum rotundifolium is a small shrubby, often rounded and multi-branched mistletoe from the Viscaceae family (Mannheimer, 2012). The branches are mostly light green, glaucous, and distinctly ribbed near tips. The leaves are opposite and highly variable in shape, ovate-subcircular to elliptic-oblong. The flowers are cream-green that are small and inconspicuous forming clusters in axils. The fruit are on short stalks, globose, smooth, red to dark orange when ripe (Figure 4.7) (Mannheimer, 2012). The

red-berry mistletoe (*V. rotundifolium*) is the most common *Viscum* species in Southern Africa. It is usually found on a wide range of woody species (e.g. *Boscia albitrunca* and *Ziziphus mucronata*) in the savanna and bush-veld including other mistletoes. The flowering season is in mid-winter (Mannheimer, 2012; von Willert & Popp, 1995).

According to the herbarium data, *Viscum rotundifolium* is very common in the central highland of Namibia (Figure 4.8), from near sea level to 1950 m. The present study confirmed locality information from herbarium records within the study area.



Figure 4. 7 *Viscum rotundifolium* (with red to dark orange fruits when ripening).

Photo: L. Ondigo (2019)

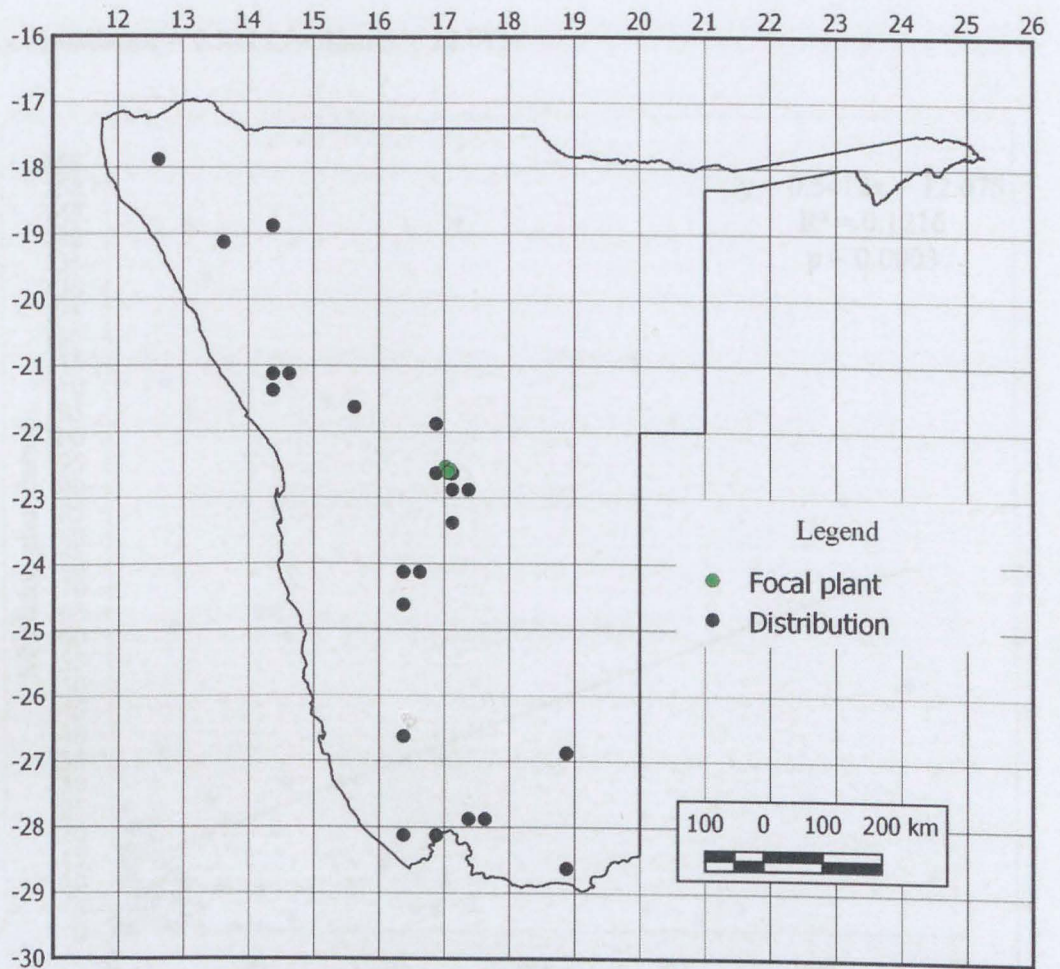


Figure 4. 8 Distribution map for *Viscum rotundifolium* in Namibia also indicating focal plants/points in green.

4.2 Relationship between host size (canopy volume and canopy diameter) and mistletoe abundance

There was a significant positive linear relationship between canopy volume and mistletoe abundance, ($R^2 = 0.1216$, $p = 0.0003$). However, canopy volume accounted for only 12% of the variability in mistletoe abundance. The slope of the regression is 0.5412. This represents the mean increase of mistletoe abundance for every additional

one cubic meter in plant canopy volume. From the regression equation, predicted mistletoe abundance = $0.5412 (\text{volume}) + 12.075$.

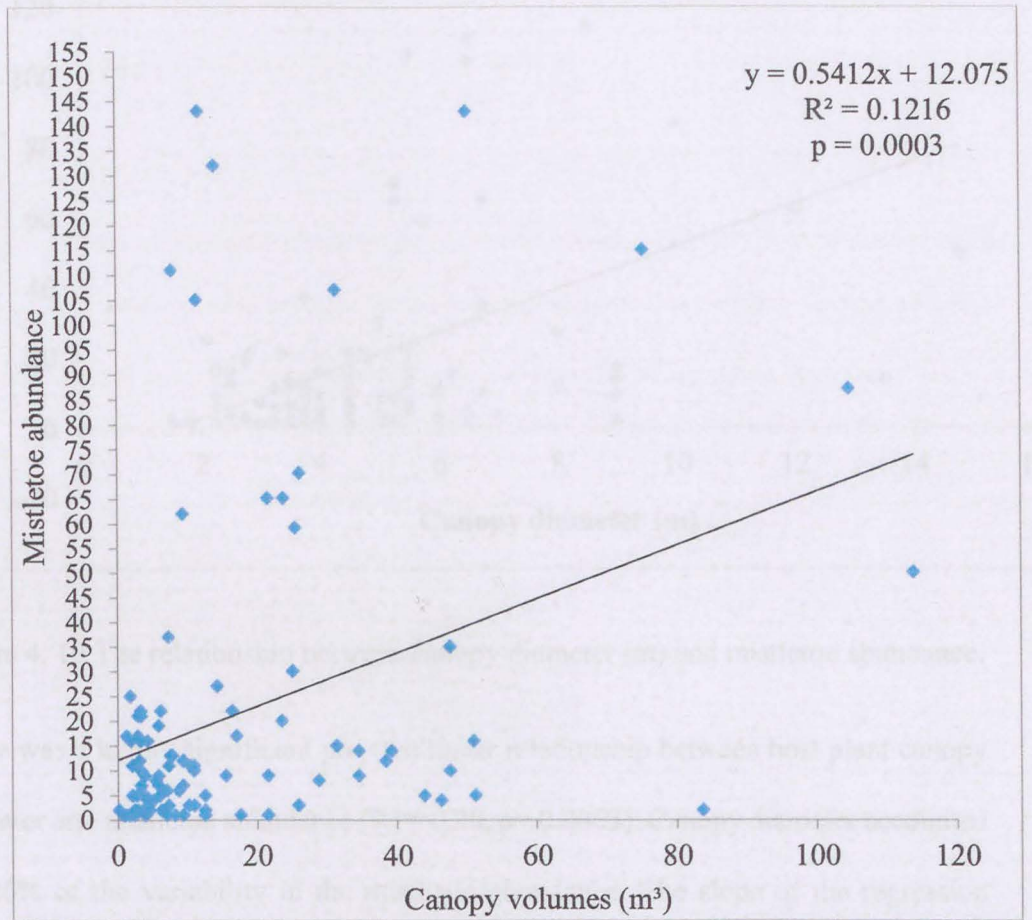


Figure 4. 9 The relationship between canopy volume (m³) and mistletoe abundance.

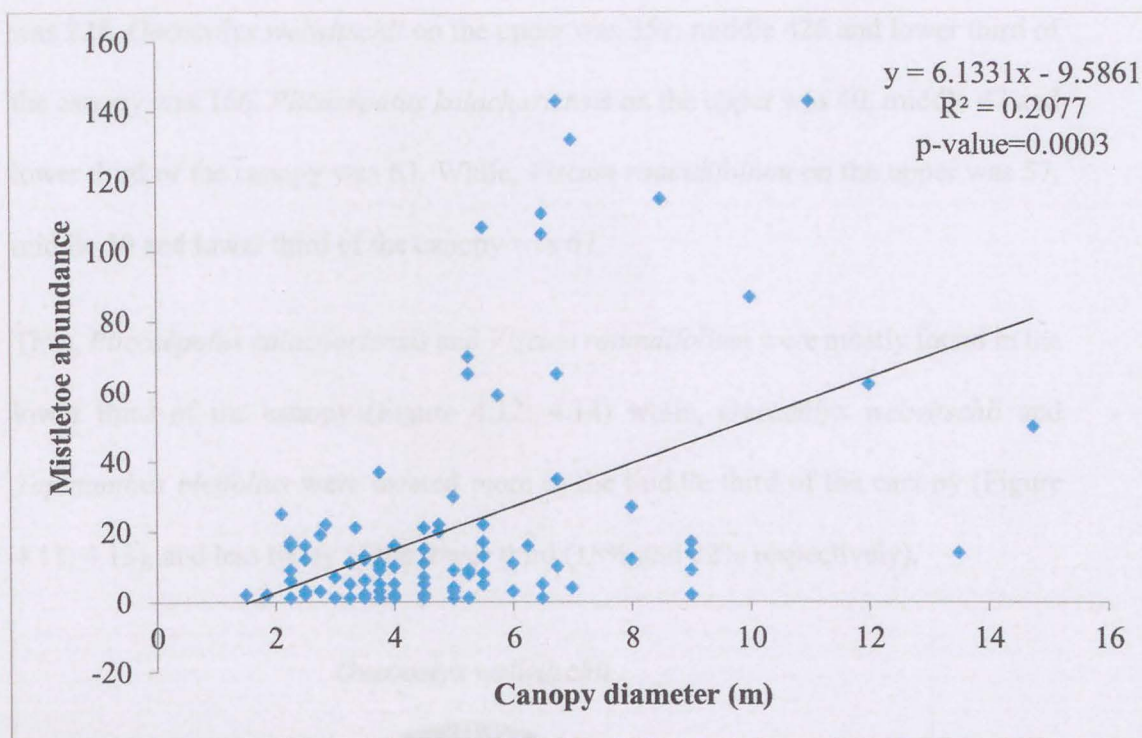


Figure 4. 10 The relationship between canopy diameter (m) and mistletoe abundance.

There was a highly significant positive linear relationship between host plant canopy diameter and mistletoe abundance ($R^2 = 0.20$, $p = 0.0003$). Canopy diameter accounted for 20% of the variability in the mistletoe abundance. The slope of the regression equation is 6.1331. This coefficient represents the mean increase of mistletoe abundance for every additional one meter in plant canopy diameter. From the regression equation, predicted mistletoe abundance = $6.1331 (\text{diameter}) - 9.5861$.

4.3 Mistletoe abundance in relation to vertical canopy position

There was a significant association between vertical host canopy position and mistletoe abundance ($\chi^2 = 67.089$, $df = 6$, $p < 0.001$). All four mistletoe species showed non-random distribution with respect to their position in the canopy of the host plants. The number of observation made for the vertical position per specie were as follows; *Tapinanthus oleifolius* on the upper was 344, middle 446 and lower third of the canopy

was 228. *Oncocalyx welwitschii* on the upper was 351, middle 426 and lower third of the canopy was 166. *Plicosepalus kalachariensis* on the upper was 40, middle 47 and lower third of the canopy was 63. While, *Viscum rotundifolium* on the upper was 57, middle 50 and lower third of the canopy was 67.

Thus, *Plicosepalus kalachariensis* and *Viscum rotundifolium* were mostly found in the lower third of the canopy (Figure 4.12; 4.14) while, *Oncocalyx welwitschii* and *Tapinanthus oleifolius* were located more in the middle third of the canopy (Figure 4.11; 4.13), and less likely in the lower third (18% and 22% respectively).

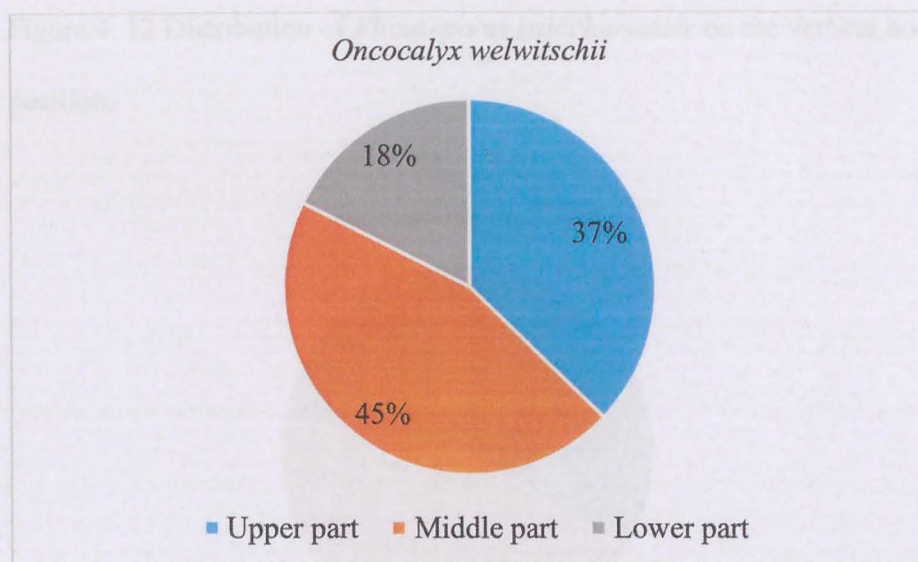


Figure 4. 11 Distribution of *Oncocalyx welwitschii* on the vertical host canopy position.

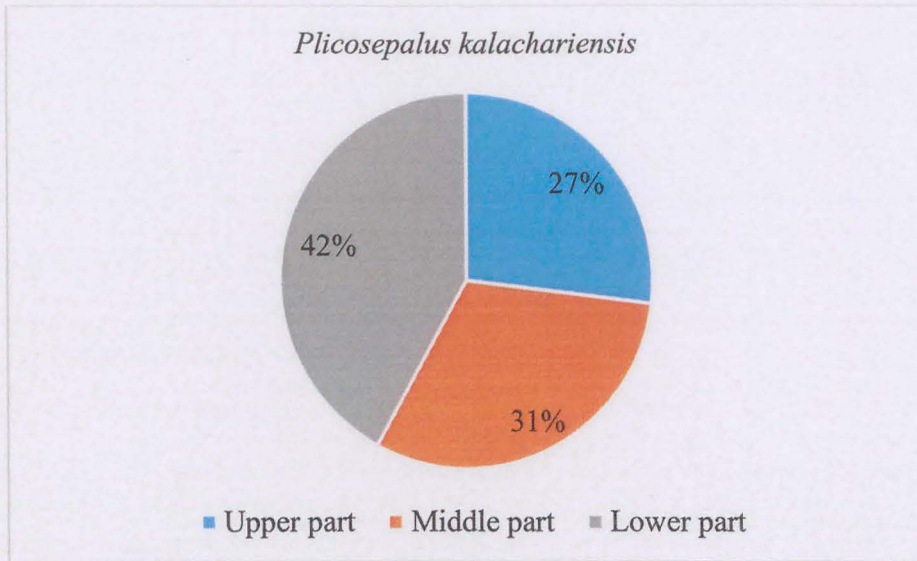


Figure 4. 12 Distribution of *Plicosepalus kalachariensis* on the vertical host canopy position.

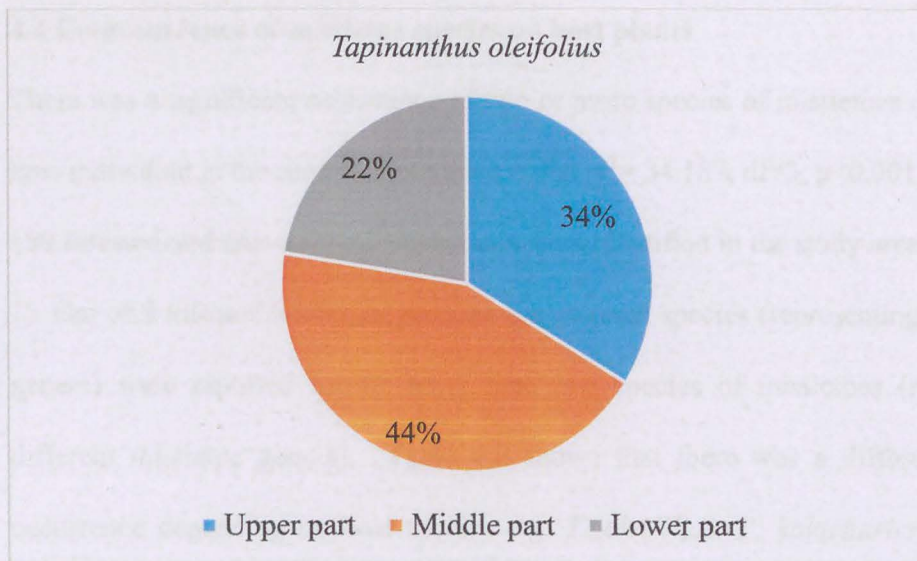


Figure 4. 13 Distribution of *Tapinanthus oleifolius* on the vertical host canopy position.

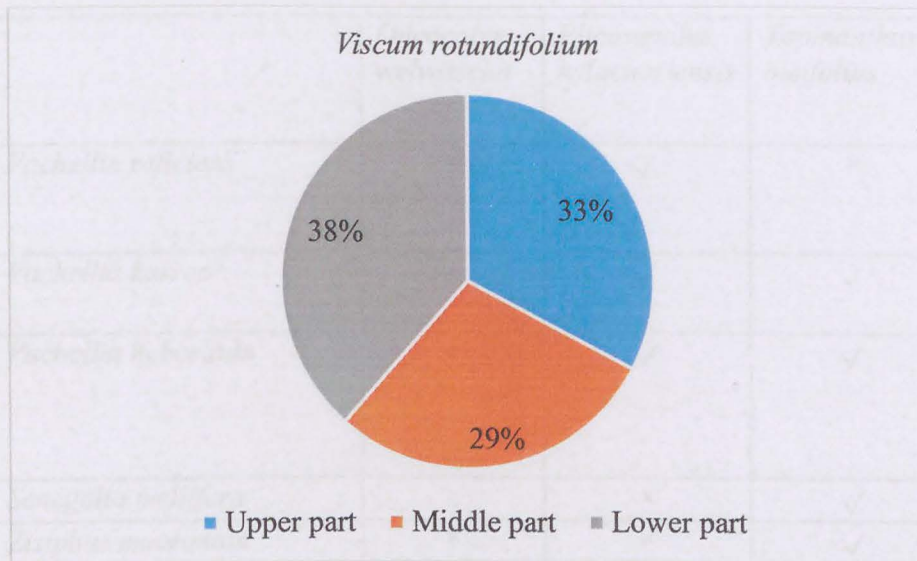


Figure 4. 14 Distribution of *Viscum rotundifolium* on the vertical host canopy position.

4.4 Co-occurrence of mistletoe species on host plants

There was a significant occurrence of two or more species of mistletoes on the same host individual in the central highland savanna ($\chi^2 = 34.187$, $df=3$, $p < 0.001$). A total of 199 infested and non-infested individuals were identified in the study area (Appendix 1). Out of 9 infested host plant species, 6 host plant species (representing 4 different genera) were reported having more than one species of mistletoes (representing different mistletoe genera). Table 4.2 shows that there was a difference in co-occurrence depending on host species e.g. *T. oleifolius*, *P. kalachariensis*, and *V. rotundifolium* were often found co-occurring on host species of the genus *Vachellia*.

Table 4. 2 Host species found to harbour more than one species of mistletoes. A tick (✓) represents the presence of more than one mistletoe species on the same host plant while a cross (×) represents an absence of co-occurrence.

	<i>Oncocalyx welwitschii</i>	<i>Plicosepalus kalachariensis</i>	<i>Tapinanthus oleifolius</i>	<i>Viscum rotundifolium</i>
<i>Vachellia reficiens</i>	×	✓	×	✓
<i>Vachellia karroo</i>	×	✓	✓	×
<i>Vachellia hebeclada</i>	×	✓	✓	✓
<i>Senegalia mellifera</i>	×	×	✓	✓
<i>Ziziphus mucronata</i>	×	×	✓	✓
<i>Boscia albitrunca</i>	×	×	✓	✓

According to table 4.3, *Tapinanthus oleifolius*, *P. kalachariensis*, and *V. rotundifolium* co-occurred with other mistletoes. Although *O. welwitschii* shares a similar host species with *P. kalachariensis* and *V. rotundifolium*, there was no co-occurrence of *O. welwitschii* with other mistletoe species on the same host individual at Farm Kiamsab West 364.

Table 4. 3 Co-occurrence of mistletoe species in the study area. A tick (✓) represents the presence of more than one mistletoe species on the same plant, a cross (×) represents an absence of co-occurrence, and a dash (-) indicates where mistletoe species co-occurred with itself.

	<i>Tapinanthus oleifolius</i>	<i>Viscum rotundifolium</i>	<i>Plicosepalus kalachariensis</i>	<i>Oncocalyx welwitschii</i>
<i>Oncocalyx welwitschii</i>	×	×	×	-
<i>Plicosepalus kalachariensis</i>	✓	×	-	×
<i>Tapinanthus oleifolius</i>	-	✓	✓	×
<i>Viscum rotundifolium</i>	✓	-	×	×

4.5 Mistletoe species host preference in the Central Highland savannas of Namibia

As can be seen from figure 4.15, all the mistletoe species showed strong associations with one or more primary hosts. *Oncocalyx welwitschii* primarily preferred *V. reficiens* from Farm Kiamsab West 364 (Table 4.4), *P. kalachariensis* parasitized four host species but primarily preferred *A. anthelmintica*. In addition, *T. oleifolius* parasitized four host species but primarily preferred *S. mellifera* and *D. cinerea*. *Viscum rotundifolium* primarily preferred *Z. mucronata* and *B. albitrunca*, even though it also parasitized *V. hebeclada* and *V. karroo*. Statistical analysis shows significant mistletoe host preference ($\chi^2= 372.510$, $df= 24$, $p< 0.001$) within the sampled plant communities.

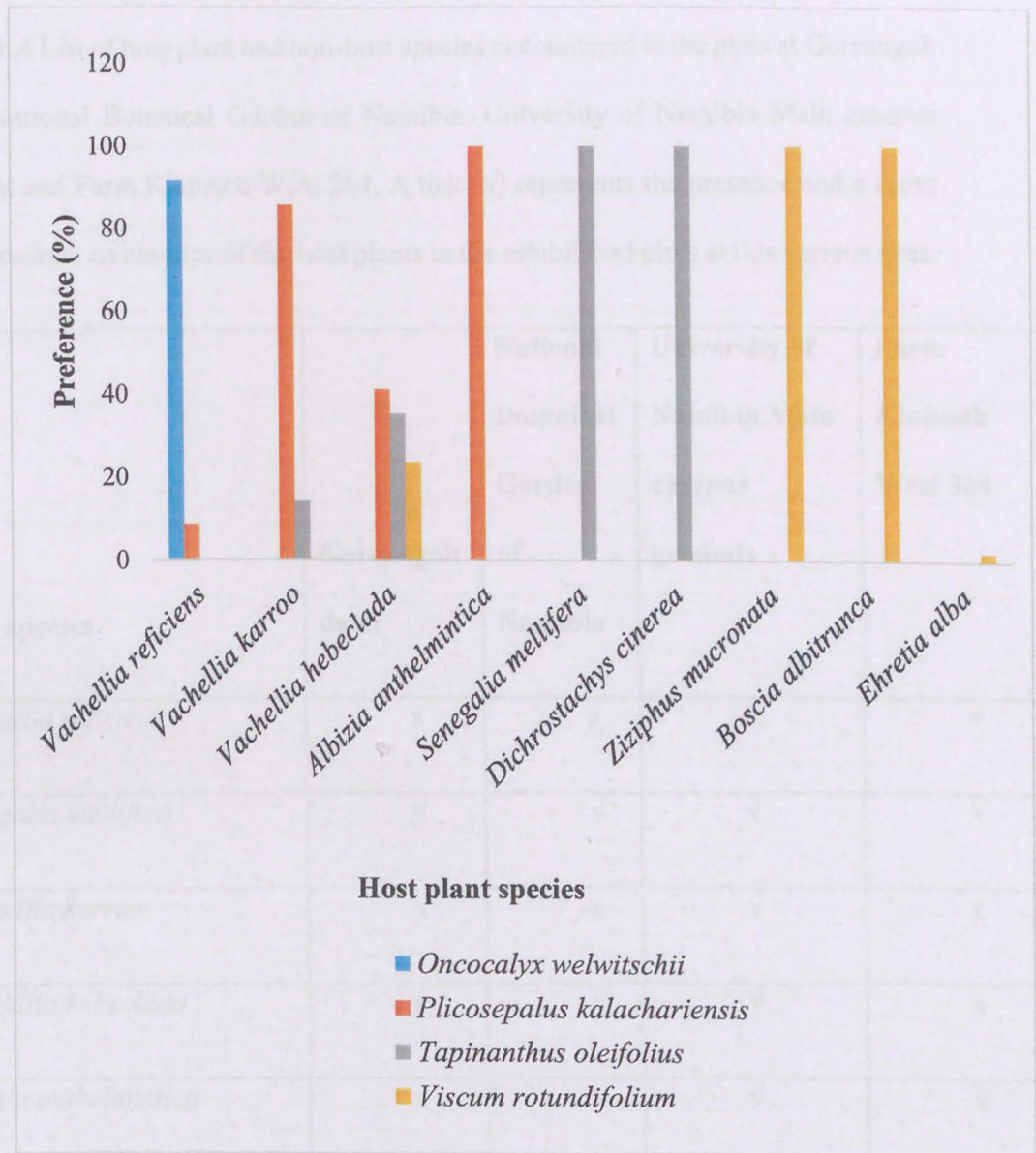


Figure 4. 15 Host preference of mistletoes in the central highland savanna.

According to table 4.4, a total of 17 plant species were recorded at the four surveyed sites. *Vachellia* spp. were the most dominant with 4 species namely; *Vachellia reficiens*, *Vachellia hebeclada*, *Vachellia karroo*, and *Vachellia erubescens*.

Table 4. 4 List of host plant and non-host species encountered in the plots at Goreangab dam, National Botanical Garden of Namibia, University of Namibia Main campus grounds and Farm Kiamsab West 364. A tick (√) represents the presence and a cross (x) represents an absence of the host plants in the established plots at this various sites.

Host species	Goreangab dam,	National Botanical Garden of Namibia	University of Namibia Main campus grounds	Farm Kiamsab West 364
<i>Vachellia reficiens</i>	x	x	√	√
<i>Senegalia mellifera</i>	√	√	√	√
<i>Vachellia karroo</i>	√	x	√	x
<i>Vachellia hebeclada</i>	x	√	√	x
<i>Albizia anthelmintica</i>	x	√	√	√
<i>Dichrostachys cinerea</i>	√	x	x	√
<i>Ziziphus mucronata</i>	√	√	√	x
<i>Boscia albitrunca</i>	√	√	√	x
<i>Vachellia erubescens</i>	x	x	x	√
<i>Prosopis sp.</i>	x	x	x	√
<i>Catophractes alexandri</i>	x	x	x	√

<i>Tarchonanthus camphoratus</i>	x	x	x	√
<i>Montinia caryophyllacea</i>	x	x	x	√
<i>Lycium bosciifolium</i>	x	x	x	√
<i>Grewia flava</i>	√	√	x	x
<i>Ehretia alba</i>	√	√	x	x
<i>Combretum apiculatum</i>	x	√	x	x

CHAPTER 5: DISCUSSION

5.1 Species composition of mistletoes in the highland savanna of Namibia

According to Table 4.1, only four mistletoe species were identified, recorded, and mapped in the present study, namely: *Oncocalyx welwitschii*, *Plicosepalus kalachariensis*, and *Tapinanthus oleifolius*, belonging to the Family Loranthaceae and, *Viscum rotundifolium* which belongs to Family Viscaceae. All four mistletoe species reported were found at their previously reported localities in the existing herbarium database, except for *Oncocalyx welwitschii* which was recorded beyond its current known location to the south-eastern end of its distribution, making this a new locality to be captured on the Herbarium database.

Species composition (and richness) of mistletoes reported in the present study was expected. This is because there are only four mistletoes species that have been reported in the central highland savanna by the National Herbarium of Namibia and in literature (Mannheimer, 2012). Thus, due to the limited study size, the reported findings might not be a reflection of mistletoe or host species in the central highland savanna.

5.2 Relationship between host size (canopy volume and canopy diameter) and mistletoe abundance

There was a positive linear relationship between canopy volume and mistletoe abundance (Figure 4.9). Although, the relationship was highly significant, canopy volume accounted for a low variation in mistletoe abundance (only 12%).

Branch size could have accounted for a low coefficient of determination between canopy volume and mistletoe abundance. Canopy volume includes branches of various sizes, including those that may not support mistletoe establishment (e.g. small and too thick branches). For instance, at small branch sizes mistletoe death may result and

thick bark may lead to the inability to penetrate, hence limit establishment for many mistletoes (Sargent, 1995). This could have been the case for the present study.

Another possible reason why canopy volume accounted for a low variation in mistletoe abundance is possible potential gaps within the host canopy as well as the extent and positioning of branches. These variables might have led to an overestimation of the actual volume of the host canopy that can potentially be infested by parasites.

Pratt and Stiles (1983) reported that the behaviour of birds greatly affects mistletoe abundance. This could be because birds prefer individual plants for shelter, food, and perch sites (Aukema & Martinez del Río, 2002a). The establishment of mistletoes is likely to be greater on such preferred individuals (Reid *et al.*, 2000). Low variation could thus also be explained by the perching behaviour of birds that could have disproportionately dispersed more mistletoe on certain individual plants than on others, irrespective of the canopy volume.

Canopy diameter could be a better surrogate to measure mistletoe abundance than canopy volume, close to 20% of it can be used to explain mistletoe abundance, unlike 12% reported for canopy volume (Figure 4.10). This could be because the canopy diameter influence the establishment and survival of mistletoes and further affect the distribution of mistletoes among host trees.

5.3 Mistletoe abundance in relation to vertical canopy position

According to Figure 4.11 - 4.14 thirty-eight percent (38%) of *V. rotundifolium* (Figure 4.14) and 42% of *P. kalachariensis* (Figure 4.12) were found in the lower third of the canopy while 44% of *T. oleifolius* (Figure 4.13) and 45% of *O. welwitschii* (Figure 4.11) were found in the middle third of the canopy.

The presence of *V. rotundifolium* and *P. kalachariensis* on the lower third of the canopy of the host plant could be explained by habitat preference and deposition behaviour of the dispersal birds due to habitat characteristic. It could be that the Redfaced mousebird (*Urocolius indicus*) that disperse *V. rotundifolium* and *P. kalachariensis* select the lower third of the canopy in response to the presence of secure nesting and roosting sites. This means that the selection of this bird species for the lower third of canopy for nesting and roosting, results in defecating of seeds more frequently on this part. Therefore, the more they visit the lower third of the canopy the more seeds they deposit leading to more infestations (Roxburgh & Nicolson 2005). Thus, mistletoe dispersers are important in determining the specific location of where seeds are placed on plants, which is important for mistletoe survival and it needs to be tested.

On the contrary, the distribution of *T. oleifolius* and *O. welwitschii* in the middle third of the canopy could be due to perch preference of the Yellow-fronted Tinker Barbets (*Pogoniulus chrysoconus*). Unlike their large relatives, Yellow-fronted Tinker Barbets are usually small in body size hence, they may perch in the middle third of the canopy because there is a low risk of predation. Previous studies reported that predation risk varies within the tree canopy, is higher for the birds that use the outer parts of branches in the lower canopy (Ekman, 1986; Suhonen, 1993), and the uppermost parts of young trees (Krams, 1996). Thus, birds forage and perch in sites that are regarded to be safe from predators and select different parts of the canopy in response to their presence (Suhonen (1993); Krams (2001) which could be the case in the present study.

For the establishment and survival of mistletoe seedlings, branch size plays a crucial role (Sargent, 1995). Also, it could be that the branches in the middle part are more abundant than those found in the upper and lower part of the canopies, resulting in

branch sizes in the middle part of the host canopy to be more likely susceptible to mistletoe infestation because there is a high probability they provide better mistletoe establishment and survival. For instance, studies conducted in Australia suggested that smaller host branches or stems are most likely to be more susceptible to mistletoe infestation than larger or small ones (Reid, 1987; 1989).

5.4 Co-occurrence of mistletoe species on host plants

The present study found a significant co-occurrence of mistletoe species on host plants where *T. oleifolius*, *P. kalachariensis*, and *V. rotundifolium* generally co-occurred on *Vachellia* spp. The co-occurrence could be due to compatibility, local host abundance, the behaviour of bird dispersers, and overlap in fruiting seasons, as discussed below.

The co-occurrence between *T. oleifolius*, *P. kalachariensis*, and *V. rotundifolium* on *Vachellia* spp. could be due to compatibility and local abundance of *Vachellia* hosts (Roxburgh & Nicolson, 2005). Out of 199 individual host plants reported in the present study, 124 individuals belonging to the *Vachellia* spp. (Table 4.4). Mistletoes have been found to infect closely related hosts and to infect the most abundant host species hence tree species that are related to the most abundant host species may be more likely to act as hosts than non - related trees (Roxburgh & Nicolson 2005). In support of the above, Norton and Carpenter (1998) pointed out that in general, the pattern of mistletoe infestation within a given area depend primarily on the spatial distribution of hosts, which affects the likelihood of encounter with mistletoe dispersers.

A study by Aukema and Martinez del Rio (2002b) reported that bird dispersers influence aggregation of mistletoes that leads to co-occurrence. Generally, birds are attracted to infested plants with mistletoes. Therefore, when bird dispersers feed on

and regurgitate mistletoe seeds, they increase the chances of various mistletoe species to be deposited on the same plant.

Another factor that could have caused the co-occurrence is the overlap in the fruiting season of these mistletoe species. This might be because the peak fruiting times of *P. kalachariensis*, *T. oleifolius*, and *V. rotundifolium* occur between April and September (von Willert & Popp, 1995). Therefore, an overlap in fruiting times among these mistletoes species might have also increased the chances of dispersal birds to feed on these mistletoe species and deposit on the same host individuals. As a result, there is a high probability of different mistletoe fruits to be dispersed to a host plant containing other species (Norton *et al.*, 1997).

In comparison, there was no co-occurrence of *O. welwitschii* with other mistletoe species (Table 4.3 & Appendix 1). This could be due to competitive exclusion and non-overlap in mistletoe primary hosts. It has been reported that the presence of one mistletoe species on a host can exclude the establishment of a second mistletoe species (Hawksworth & Weins, 1996). It is therefore possible that *T. oleifolius* observed parasitizing plant species on the same site with *O. welwitschii* could not co-exist on the same host individual. Hence, *O. welwitschii* could be a host-specific species that allows it to have a competitive edge over other non-specific mistletoes. For instance, Jerome and Ford (2002) suggested that host specificity in *Arceuthobium americanum* reduces potential competition with other mistletoe species that may utilize the same host species at a given site. Also, similar studies on competitive exclusion mechanisms have been reported in North America, New Zealand, and Australia (Hawksworth & Wiens, 1972; Blick & Burns, 2009; Blick *et al.*, 2012) for other mistletoe species.

Lack of co-occurrence between *O. welwitschii* and *T. oleifolius* on the same host individual in the study site could also be because of non-overlap in mistletoe primary host. As observed in the present study (Figure 4.15), the primary host plants for *O. welwitschii* is *Vachellia reficiens* while, for *T. oleifolius* is *Senegalia mellifera* and *Dichrostachys cinerea*, (Table 4.1) it is evident that these two mistletoe species do not share the same primary hosts. This could mean that a pattern of non-overlap in mistletoe primary host use may be indicative of competitive exclusion discussed above.

Although, *V. reficiens* was also found at the University of Namibia Main campus grounds (Table 4.4), it was only reported being parasitized by *O. welwitschii* at Farm Kiamsab West 364. Using the geographic mosaic approach by Okubamichael *et al.* (2016), it can be argued that the distribution of *O. welwitschii* at Farm Kiamsab West 364 was strongly affected by the evolutionary hot spots where the host, bird dispersal, and environmental conditions ideal for the establishment of this mistletoe overlap (Lira-Noriega *et al.*, 2015). Applying the findings of Pennings and Callaway (1996) in the present study, it can be argued that *O. welwitschii* preferred *V. reficiens* as a host because this host was the community dominant at Farm Kiamsab West 364, hence the suppression of *V. reficiens* in Farm Kiamsab West 364 will abundantly facilitate the expansion of the competitively subordinate species such as *Vachellia erubescens* and *Albizia anthelmintica*. As a result community diversity will increase.

5.5 Host preference of mistletoe species in the highland savannas of Namibia

The present study found a significant mistletoe host preference in the central highland savanna (Figure 4.15). The mistletoe host preference recorded in this study might have been influenced by local host abundance, and host susceptibility to infestation

(Aukema & Martinez del Rio, 2002a; Roxburgh & Nicolson, 2005; Troncoso *et al.*, 2010), as discussed below.

Interestingly, *O. welwitschii* preferred only *V. reficiens* from Farm Kiamsab West 364. It might be the degree of host preference is related to the local host abundance (Fadini, 2011). This could be the case in the present study because *V. reficiens* was the most abundant plant species with 86 individuals (Appendix 1) and frequently encountered within the surveyed part of Farm Kiamsab West 364. Studies by Norton and Carpenter (1998) and Okubamichael *et al.* (2011) found that in less diverse semiarid savannas where the dominance of one or a few plant species are typical, mistletoes are more likely to be specific to one genus or even to a single host species.

Although *V. reficiens* was recorded at University of Namibia Main campus grounds and Farm Kiamsab West 364 (Table 4.4), *O. welwitschii* infested only *V. reficiens* from Farm Kiamsab West 364. This indicates that host availability alone does not determine mistletoe establishment instead, suitable environmental conditions for the mistletoe are a prerequisite. This observation is supported by the works of Lira-Noriega *et al.* (2015) and Lira-Noriega and Peterson (2014) on the mistletoe *Phoradendron californicum* demonstrated that the distribution of this species is strongly affected by the evolutionary hot spots where the host, dispersal vectors and environmental condition of the mistletoes overlap which could be the case for this present study.

The present study also reported two mistletoe species that had more than one primary host species. *Tapinanthus oleifolius* preferred *S. mellifera* and *D. cinerea* while, *V. rotundifolium* preferred *Z. mucronata* and *B. albitrunca*. (Table 4.1). This could be due to host susceptibility to infestation. *Senegalia mellifera* and *D. cinerea* are susceptible to infestation by *T. oleifolius* because they are drought-resistant species

that are adapted to survive in dry conditions. It has been reported that mistletoe survival depends on the abilities of these host plants to withstand stressful conditions (Watson, 2001). Furthermore, since *S. mellifera* and *D. cinerea* are a well-known bush-encroachment species (Bester *et al.*, 2002), the preference for these problematic species by *T. oleifolius* in the present study could be used in controlling the proliferation of *S. mellifera* and *D. cinerea* in the central highland savanna.

Viscum rotundifolium was found parasitizing primarily *Z. mucronata* and *B. albitrunca*. (Table 4.1). The association between *V. rotundifolium* and these two species might be due to compatibility at the genetic, mechanical, physiological, and biochemical levels (Fadini, 2011). According to Okubamichael *et al.* (2011), *V. rotundifolium* is the least prevalent and very host-specific of all *Viscum* spp. in southern Africa. It was also found that the sharing of primary hosts is less likely where mistletoes are from different Families. This indicates that mistletoe species in Loranthaceae or Viscaceae parasitize mainly host genera that are not used by the other mistletoe species. For instance, *Boscia albitrunca* and *Ziziphus mucronata* are some of the most common host trees for mistletoes in Viscaceae but they are not common hosts for mistletoes in Loranthaceae.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- a) Four mistletoe species were identified, recorded and mapped in the present study, namely: *Oncocalyx welwitschii*, *Plicosepalus kalachariensis*, and *Tapinanthus oleifolius*, belonging to the Family Loranthaceae and, *Viscum rotundifolium* which belongs to Family Viscaceae.
- b) There was a significant relationship between host size (canopy volume and canopy diameter) and mistletoe abundance. Canopy diameter was a better predictor of mistletoe abundance than canopy volume.
- c) There was a significant relationship between vertical host canopy position and spatial mistletoe abundance due to habitat preference, deposition behaviour and perch preference. The general patterns of mistletoe abundance and distribution observed in this study could be useful in the management and conservation of mistletoes species in central highland savanna.
- d) Different species of mistletoes co-occurred on host plants due to compatibility, local host abundance, behaviour of bird dispersers, and overlap in fruiting seasons.
- e) There was a significant mistletoe host preference species in the central highland savanna due to local host abundance, and host susceptibility to infestation. The preference for *S. mellifera* and *D. cinerea* by *Tapinanthus oleifolius* can be used to control the distribution of these problematic bush-encroachment species.

6.2 Recommendations

The following are the recommendations for future research:

- a) Due to the limitation of the present study size, it is recommended that such a study be spatially expanded to collect data on the species composition of mistletoes and host plants from the other parts of the central highland savanna that were not covered by the present study.
- b) It is recommended to use other quadratic models to study the relationship between mistletoe abundance and canopy size and to correct for empty spaces in the canopy to improve the fit. Also, another parameter such as branch size should be investigated to determine if it's more reliable than canopy diameter to measure mistletoe abundance in the central highland savanna.
- c) A study should be carried out to determine the factors that affect the mistletoe position on the vertical host canopies. This can be done by finding out the autecological characteristics of these species that make them prefer certain canopy positions. This will contribute to a greater understanding of the spatial relationship between mistletoes and vertical canopy positions reported in the present study.
- d) Studies should be conducted to evaluate the behaviour of avian dispersers and to identify the specific bird dispersers in relation to mistletoe distribution. This will bring more insights why some mistletoes are not parasitizing host plants in other locations.
- e) An understanding of mistletoe-host compatibility and host resistance to mistletoe infestation mechanisms need to be explored in the semi-arid savanna ecosystems. This will shed light on why certain plant species are more susceptible to mistletoe infestation.

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APPENDICES

Appendix 1: Mistletoe species and their distribution in the selected sites of the central highland savanna of Khomas region Namibia

Site where <i>Oncocalyx welwitschii</i> were collected															
PLOT 1															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>O. welwitschii</i>	1	22.99	16.29	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	16	<i>Vachellia erubescens</i>	1	0	3.5	2	2.5	2	4	10
<i>O. welwitschii</i>	2			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	11	0	0	0	2	2.5	2	2	6	3
<i>O. welwitschii</i>	3			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	2	0	0	0	3	2	2.5	0	1	1

<i>O. welwitschii</i>	4			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	1	0	0	0	2.5	2	1	0	0	1
<i>O. welwitschii</i>	5			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	9	0	0	0	3	2.5	2.5	3	4	2
<i>O. welwitschii</i>	6			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	2	0	0	0	2.5	2	2	1	0	1
<i>O. welwitschii</i>	7			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	16	0	0	0	3	2	2	5	11	0
<i>O. welwitschii</i>	8			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	8	0	0	0	3	2.5	3	4	4	0
<i>O. welwitschii</i>	9			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	7	0	0	0	2.5	2	2.5	3	1	3
<i>O. welwitschii</i>	10			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	111	0	0	0	2.5	3.5	3	35	43	33

<i>O. welwitschii</i>	11			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	22	0	0	0	3	2.5	3	7	10	5
PLOT 2															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>O. welwitschii</i>	1	22.99	16.29	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	105	<i>Prosopis</i> sp.	1	0	3.5	3	3.5	43	60	2
<i>O. welwitschii</i>	2			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2.5	2	1.5	0	0	0
<i>O. welwitschii</i>	3			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2.5	2	1.5	0	0	0
<i>O. welwitschii</i>	4			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	5	0	0	0	2.5	2.5	2	1	3	1

<i>O. welwitschii</i>	5		Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2	1	1	0	0	0
<i>O. welwitschii</i>	6		Farm Kiamsab West 364	<i>Vachellia reficiens</i>	1	0	0	0	2.5	2	2	0	1	0
<i>O. welwitschii</i>	7		Farm Kiamsab West 364	<i>Vachellia reficiens</i>	5	0	0	0	2.5	2	2	0	3	2
<i>O. welwitschii</i>	8		Farm Kiamsab West 364	<i>Vachellia reficiens</i>	5	0	0	0	2.5	2	2	0	4	1
<i>O. welwitschii</i>	9		Farm Kiamsab West 364	<i>Vachellia reficiens</i>	2	0	0	0	3	2	2	0	1	1
<i>O. welwitschii</i>	10		Farm Kiamsab West 364	<i>Vachellia reficiens</i>	10	0	0	0	3	2	2	0	8	2
<i>O. welwitschii</i>	11		Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	1.5	1	1	0	0	0

<i>O. welwitschii</i>	12			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	1.5	1	2	0	0	0
<i>O. welwitschii</i>	13			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	5	0	0	0	3	2	2.5	1	4	0
PLOT 3															
Mistletoe species	Q N o.	GPS of focal plant(*)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>O. welwitschii</i>	1	23	16.29	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	17	<i>Vachellia erubescens</i>	2	0	3	5	4	3	12	2
<i>O. welwitschii</i>	2			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	<i>Albizia anthelmintica</i>	1	0	2.5	2	1	0	0	0
<i>O. welwitschii</i>	3			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0			0	1.5	2	1	0	0	0

<i>O. welwitschii</i>	4			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0				0	2.5	3	2.5	0	0	0
<i>O. welwitschii</i>	5			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0				0	2	1	1	0	0	0
<i>O. welwitschii</i>	6			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0				0	2	2.5	2.5	0	0	0
<i>O. welwitschii</i>	7			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	2				0	2.5	2	2.5	0	1	1
<i>O. welwitschii</i>	8			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	1				0	3	2	2.5	0	1	0
<i>O. welwitschii</i>	9			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0				0	3	2	1.5	0	0	0
<i>O. welwitschii</i>	10			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0				0	3	2	1.5	0	0	0
PLOT 4																

<i>O. welwitschii</i>	6			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	1.5	2	2.5	0	0	0
<i>O. welwitschii</i>	7			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2.5	2	2.5	0	0	0
<i>O. welwitschii</i>	8			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2	2	1	0	0	0
<i>O. welwitschii</i>	9			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2	2	1	0	0	0
<i>O. welwitschii</i>	10			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2	2	2	0	0	0
PLOT 5															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part

<i>O. welwitschii</i>	1	22.99	16.29	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	27	0	0	0	3	4	4	6	15	6
<i>O. welwitschii</i>	2			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	143	0	0	0	4.5	5	6	61	70	12
<i>O. welwitschii</i>	3			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	1	1.5	1	0	0	0
<i>O. welwitschii</i>	4			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	1.5	3	2.5	0	0	0
<i>O. welwitschii</i>	5			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	1	0	0	0	2	2	2.5	0	0	1
<i>O. welwitschii</i>	6			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	1.5	1	1	0	0	0
<i>O. welwitschii</i>	7			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	1.5	1	1	0	0	0

<i>O. welwitschii</i>	8			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2	2	2.5	0	0	0
<i>O. welwitschii</i>	9			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	17	0	0	0	3.5	1	2.5	3	11	3
PLOT 6															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>O. welwitschii</i>	1	22.99	16.29	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	132	0	0	0	3.5	4	3	62	57	13
<i>O. welwitschii</i>	2			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	1.5	1.5	1	0	0	0
<i>O. welwitschii</i>	3			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	3	3	4	0	0	0

<i>O. welwitschii</i>	4			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	142	0	0	0	4	6	6	58	44	40
PLOT 7															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>O. welwitschii</i>	1	22.99	16.28	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	62	<i>Catophractes alexandrii</i>	5	0	3	4	2.5	30	26	6
<i>O. welwitschii</i>	2			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0		0	0	2.5	2	2.5	0	0	0
<i>O. welwitschii</i>	3			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0		0	0	2.5	2	2	0	0	0
<i>O. welwitschii</i>	4			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0		0	0	2	2	1.5	0	0	0

<i>O. welwitschii</i>	5			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2.5	2.5	3	0	0	0
<i>O. welwitschii</i>	6			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2.5	1	1	0	0	0
<i>O. welwitschii</i>	7			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2.5	2	2	0	0	0
<i>O. welwitschii</i>	8			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	1	0	0	0	3	2.5	3	1	0	0
<i>O. welwitschii</i>	9			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	3	2.5	2	0	0	0
<i>O. welwitschii</i>	10			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	3	2	2	0	0	0
PLOT 8															
Mistletoe species	Q	GPS of focal plant(°)	Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)		Canopy division			
	N														
	o.														

		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>O. welwitschii</i>	1	23	16.29	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	12	<i>Dichrostachys cineria</i>	1	0	6	4	4	1	7	4
							<i>Senegalia mellifera</i>	20	0						
PLOT 9															
Mistletoe species	Q.N.o.	GPS of focal plant(°)	Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)	Canopy division				
		South	East							North-South	East-West	Upper part	Middle part	Lower part	
<i>O. welwitschii</i>	1	23	16.29	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	3	<i>Senegalia mellifera</i>	1	0	3	3.5	2.5	1	1	1
<i>O. welwitschii</i>	2			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	<i>Tarconanthus camphoratus</i>	1	0	2.5	2	2.5	0	0	0
<i>O. welwitschii</i>	3			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	2	0	0	0	1.5	1.5	1	0	2	0

<i>O.welwitschii</i>	4			Farm Kiamsab West 364	<i>Vachellia reficeins</i>	0	0	0	0	1	1	1	0	0	0
<i>O.welwitschii</i>	5			Farm Kiamsab West 364	<i>Vachellia reficeins</i>	0	0	0	0	1	1.5	1.5	0	0	0
<i>O.welwitschii</i>	6			Farm Kiamsab West 364	<i>Vachellia reficeins</i>	0	0	0	0	1.5	1	1	0	0	0
<i>O.welwitschii</i>	7			Farm Kiamsab West 364	<i>Vachellia reficeins</i>	0	0	0	0	1.5	1	1	0	0	0
<i>O.welwitschii</i>	8			Farm Kiamsab West 364	<i>Vachellia reficeins</i>	0	0	0	0	1.5	1	1	0	0	0
<i>O.welwitschii</i>	9			Farm Kiamsab West 364	<i>Vachellia reficeins</i>	0	0	0	0	1.5	1.5	1	0	0	0
<i>O.welwitschii</i>	10			Farm Kiamsab West 364	<i>Vachellia reficeins</i>	0	0	0	0	1.5	1.5	1	0	0	0
PLOT 10															

Mistletoe species	Q No.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>O.welwitschii</i>	1	23	16.98	Farm Kiamsab West 364	<i>Vachellia reficiens</i>	3	<i>Montinia caryocphyllum</i>	5	0	2.5	2.5	2.5	0	0	3
<i>O.welwitschii</i>	2			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	21	<i>Albizia anthelmintica</i>	1	0	2.5	2	2.5	12	7	2
<i>O.welwitschii</i>	3			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	<i>Lycium bosciifolium</i>	1	0	1.5	2	2	0	0	0
<i>O.welwitschii</i>	4			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	1		0	0	2	2.5	2.5	0	1	0
<i>O.welwitschii</i>	5			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0		0	0	2.5	3	3	0	0	0

<i>O.welwitschii</i>	6			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2	2	2.5	0	0	0
<i>O.welwitschii</i>	7			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	0	0	0	0	2	2	1.5	0	0	0
<i>O.welwitschii</i>	8			Farm Kiamsab West 364	<i>Vachellia reficiens</i>	4	0	0	0	3	2.5	2.5	0	3	1

Sites where *Plicosepalus kalachariensis* were collected

PLOT 1															
Mistletoe species	Q N o.	GPS of focal plant (°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)		Canopy division		
		Sout h	East							North-South	East-West	Upper part	Middle part	Lower part	
<i>P. kalachariensis</i>	1	22.53	17.02	Goreangab dam	<i>Vachellia karoo</i>	30	0	0	<i>Tapinanthus oleifolius</i>	2	6	4	15	8	7

<i>P. kalachariensis</i>	2			Goreangab dam	<i>Vachellia karoo</i>	20	0	0		2	5	4.5	0	5	15
<i>P. kalachariensis</i>	3			Goreangab dam	<i>Vachellia karoo</i>	5	0	0		7	4	3.5	0	2	3
<i>P. kalachariensis</i>	4			Goreangab dam	<i>Vachellia karoo</i>	6	0	0		1.4	3	4	1	2	3
PLOT 2															
Mistletoe species	Q No.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>P. kalachariensis</i>	1	22.53	17.02	Goreangab dam	<i>Vachellia karoo</i>	16	0	0	<i>Tapinanthus oleifolius</i>	2.5	6.5	6	3	3	10
PLOT 3															
Mistletoe species	Q No.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)		Canopy division		

					abundance on infested plant										
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>P. kalachariensis</i>	1	22.53	17.02	Goreangabdam	<i>Vachellia karoo</i>	7	<i>Senegalia mellifera</i>	8	<i>Tapinathus oleifolius</i>	2	3	3	4	0	3
PLOT 4															
Mistletoe species	Q.N.o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)		Canopy division		
		South	East	UNAM							North-South	East-West	Upper part	Middle part	Lower part
<i>P. kalachariensis</i>	1	22.53	17.02	UNAM	<i>Vachellia reficiens</i>	1	<i>Senegalia mellifera</i>	2	0	2.5	3	4.5	0	1	0
	2			UNAM	<i>Vachellia hebeclada</i>	2	<i>Boscia albitrunca</i>	1	0	1	4	3	0	0	2
PLOT 5															

Mistletoe species	Q No.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>P. kalachariensis</i>	1	22.53	17.02	UNAM	<i>Vachellia karoo</i>	3	<i>Vachellia karoo</i>	1	<i>Tapinanthus oleifolius</i>	1.5	4	3.5	0	3	0
							<i>Senegalia mellifera</i>	7							
PLOT 6															
Mistletoe species	Q No.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>P. kalachariensis</i>	1	22.53	17.02	UNAM	<i>Vachellia reficiens</i>	10	<i>Vachellia reficiens</i>	1	0	2	7	6.5	5	3	2

	2			UNAM	<i>Albizia anthelmintica</i>	1		0	0	1.5	4	4	1	0	0	
PLOT 7																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)			Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part	
<i>P. kalachariensis</i>	1	22.53	17.02	UNAM	<i>Vachellia karoo</i>	16	<i>Senegalia mellifera</i>	2	<i>Tapinanthus oleifolius</i>	2	7	6	4	7	5	
	2						<i>Vachellia refeciens</i>	1								
PLOT 8																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)			Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part	

<i>P. kalachariensis</i>	1	22.53	17.02	UNAM	<i>Vachellia hebeclada</i>	1	<i>Senegalia mellifera</i>	2	0	1.5	3	3	1	0	0	
							<i>Vachellia refeciens</i>	2								
PLOT 9																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)			Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part	
<i>P. kalachariensis</i>	1	22.53	17.02	UNAM	<i>Vachellia karoo</i>	12	<i>Senegalia mellifera</i>	4	<i>Tapinanthus oleifolius</i>	1.5	4	3	3	6	3	
							<i>Ziziphus mucronata</i>	1								
PLOT 10																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)			Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part	

		South	East								North-South	East-West	Upper part	Middle part	Lower part
<i>P. kalachariensis</i>	1	22.53	17.02	UNAM	<i>Vachellia karoo</i>	12	0	0	<i>Tapinanthus oleifolius</i>	1.5	4	3	2	4	6
<i>P. kalachariensis</i>	2			UNAM	<i>Vachellia karoo</i>	2	0	0		2	4	3	0	2	0
<i>P. kalachariensis</i>	3			UNAM	<i>Vachellia karoo</i>	5	0	0	<i>Tapinanthus oleifolius</i>	2	4	2.5	1	1	3
<i>P. kalachariensis</i>	4			UNAM	<i>Vachellia karoo</i>	1	0	0		1.5	3	3.5	0	0	1

Sites where *Tapinanthus oleifolius* were collected

PLOT 1															
Mistletoe species	Q	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)		Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part

<i>T. oleifolius</i>	1	22.53	17.02	Goreangab dam	<i>Senagalia mellifera</i>	22	0	0		0.8	2.5	3.2	10	9	3	
<i>T. oleifolius</i>	2			Goreangab dam	<i>Senagalia mellifera</i>	25	0	0		0.8	2	2.2	11	6	8	
<i>T. oleifolius</i>	3			Goreangab dam	<i>Vachellia karoo</i>	9	0	0	<i>Plicosepalus kalachariensis</i>	2.2	3	4.5	1	4	4	
<i>T. oleifolius</i>	4			Goreangab dam	<i>Senagalia mellifera</i>	59	0	0		1.5	5	6.5	40	15	4	
<i>T. oleifolius</i>	5			Goreangab dam	<i>Senagalia mellifera</i>	16	0	0		0.8	1.5	3	8	5	3	
PLOT 2																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Canopy height (m)	Diameter (m)			Canopy division		
		South	East								North-South	East-West	Upper part	Middle part	Lower part	
<i>T. oleifolius</i>	1	22.53	17.02	Goreangab dam	<i>Vachellia karoo</i>	2	0	0	<i>Plicosepalus kalachariensis</i>	1.5	1.5	2.2	0	1	1	
<i>T. oleifolius</i>	2			Goreangab dam	<i>Senegalia mellifera</i>	22	0	0	0	1.5	3.5	6	7	5	10	

<i>T. oleifolius</i>	3			Goreangab dam	<i>Senegalia mellifera</i>	13	0	0	0	1.2	3	4	4	5	4
PLOT 3															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)		Canopy division		
		Sout h	East							Canopy height (m)	North- South	East- West	Upper part	Middle part	Lower part
<i>T. oleifolius</i>		22.53	17.02	Goreangab dam	<i>Senegalia mellifera</i>	9	<i>Boscia albintrunca</i>	1	0	1.5	2	2.5	5	3	1
<i>T. oleifolius</i>				Goreangab dam	<i>Senegalia mellifera</i>	16	<i>Ziziphus micronata</i>	1	0	1.3	2.5	2.5	3	9	4
PLOT 4															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)		Canopy division		
		Sout h	East							Canopy height (m)	North- South	East- West	Upper part	Middle part	Lower part

<i>T. oleifolius</i>	1	22.53	17.72	Goreangab dam	<i>Senegalia mellifera</i>	17	<i>Senegalia mellifera</i>	1	0	0.5	2	2.5	10	5	2
							<i>Boscia albitrunca</i>	2	0						
PLOT 5															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)		Canopy division		
		South	East							Canopy height (m)	North- South	East- West	Upper part	Middle part	Lower part
<i>T. oleifolius</i>	1	22.53	17.02	Goreangab dam	<i>Senegalia mellifera</i>	21	0	<i>Vachellia hebeclada</i>	0	0.5	3.5	3.2	7	10	4
<i>T. oleifolius</i>	2			Goreangab dam	<i>Senegalia mellifera</i>	15	0		0	0.5	3.5	4	6	8	1
PLOT 6															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)		Canopy division		

		South	East							Canopy height (m)	North-South	East-West	Upper part	Middle part	Lower part
<i>T. oleifolius</i>	1	22.53	17.02	Goreangab dam	<i>Dichrostachys cinerea</i>	10	<i>Senegalia mellifera</i>	6	0	1.5	4	3.5	5	3	2
							<i>Grewia flava</i>	3	0						
							<i>Ehretia alba</i>	2	0						
							<i>Boscia albitrunca</i>	1	0						
PLOT 7															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)		Canopy division		
		South	East							Canopy height (m)	North-South	East-West	Upper part	Middle part	Lower part
<i>T. oleifolius</i>	1	22.57	17.09	Goreangab dam	<i>Senegalia mellifera</i>	3	<i>Boscia albitrunca</i>	2	0	1.5	6	5.5	2	1	0
							<i>Vachellia reficiens</i>	2							

						<i>Senegalia mellifera</i>	3									
PLOT 8																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)			Canopy division		
		South	East								Canopy height (m)	North-South	East-West	Upper part	Middle part	Lower part
<i>T. oleifolius</i>	1	22.57	17.10	Goreangab dam	<i>Senegalia mellifera</i>	115	0	0	0	2	9	8	40	60	15	
<i>T. oleifolius</i>	2			Goreangab dam	<i>Senegalia mellifera</i>	107	0	0	0	2	6	5	22	65	20	
<i>T. oleifolius</i>	3			Goreangab dam	<i>Senegalia mellifera</i>	35	0	0	0	2	7	6.5	10	20	5	
<i>T. oleifolius</i>	4			Goreangab dam	<i>Senegalia mellifera</i>	13	0	0	0	0.5	6	5	3	4	6	
<i>T. oleifolius</i>	5			Goreangab dam	<i>Senegalia mellifera</i>	65	0	0	0	1	7	6.5	20	30	15	
PLOT 9																

Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)			Canopy division		
		South	East								Canopy height (m)	North-South	East-West	Upper part	Middle part	Lower part
<i>T. oleifolius</i>	1	22.61	17.06	Goreangab dam	<i>Acacia hebeclada</i>	87	0	0	<i>Plicosepalus kalachariensis</i>	2	10	10	25	40	22	
<i>T. oleifolius</i>	2			Goreangab dam	<i>Acacia hebeclada</i>	50	0	0	<i>Plicosepalus kalachariensis</i>	1	15	14.5	10	30	10	
<i>T. oleifolius</i>	3			Goreangab dam	<i>Acacia hebeclada</i>	70	0	0	<i>Viscum rotundifolium</i> and <i>Plicosepalus kalachariensis</i>	2	5	5.5	10	20	40	
PLOT 10																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)			Canopy division		

		South	East							Canopy height (m)	North-South	East-West	Upper part	Middle part	Lower part
<i>T. oleifolius</i>	1	22.61	17.06	Goreangab dam	<i>Senegalia mellifera</i>	11	0	0	<i>Viscum rotundifolium</i>	1	5	4	2	8	1
<i>T. oleifolius</i>	2			Goreangab dam	<i>Senegalia mellifera</i>	63	0	0	0	1.5	5.5	5	30	20	13
<i>T. oleifolius</i>	3			Goreangab dam	<i>Senegalia mellifera</i>	143	0	0	0	0.5	7	6.5	53	60	30

Sites where *Viscum rotundifolium* were collected

PLOT 1															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)		Canopy division		
		South	East							Canopy height(m)	North-South	East-West	Upper part	Middle part	Lower part
<i>V. rotundifolium</i>	1	22.53	17.02	National Botanical Garden of Namibia	<i>Ziziphus mucronata</i>	6	<i>Senegalia mellifera</i>	4	0	1.5	3	3	2	2	2

<i>V. rotundifolium</i>	2			National Botanical Garden of Namibia	<i>Ziziphus mucronata</i>	2			0	1.2	3	2	0	2	0
<i>V. rotundifolium</i>	3			National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	12			0	1	3	2	4	3	5
PLOT 2															
Mistletoe species	Q	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Diameter (m)			Canopy division		
	N	South	East							Canopy height(m)	North-South	East-West	Upper part	Middle part	Lower part
<i>V. rotundifolium</i>	1	22.53	17.02	National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	1	<i>Grewia flava</i>	2	0	1.5	4	3	0	1	0
							<i>Boscia albitrunca</i>	3							
							<i>Ehretia alba</i>	1							

							<i>Albizia anthelmintica</i>	2							
							<i>Senegalia mellifera</i>	3							
							<i>Combretum alpiculatum</i>	1							
PLOT 3															
Mistletoe species	Q No.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Diameter (m)			Canopy division		
		South	East							Canopy height(m)	North-South	East-West	Upper part	Middle part	Lower part
<i>V. rotundifolium</i>	1	22.57	17.09	National Botanical Garden of Namibia	<i>Ehretia alba</i>	2	<i>Ehretia alba</i>	3		1.5	2.5	2	0	1	1
<i>V. rotundifolium</i>	2			National Botanical Garden of Namibia	<i>Ehretia alba</i>	1	<i>Senegalia mellifera</i>	2	0	1.5	2	2.5	1	0	0
							<i>Vachellia reficiens</i>	4	0						

PLOT 4																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)			Canopy division		
		South	East								Canopy height(m)	North-South	East-West	Upper part	Middle part	Lower part
<i>V. rotundifolium</i>	1	22.57	17.10	National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	1	<i>Senegalia mellifera</i>	4	0	1.5	5.5	5	1	0	0	
							<i>Vachellia reficiens</i>	1	0							
							<i>Ehretia alba</i>	3	0							
PLOT 5																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)			Canopy division		
		South	East								Canopy height(m)	North-South	East-West	Upper part	Middle part	Lower part

<i>V. rotundifolium</i>	1	22.57	17.09	National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	15	<i>Senegalia mellifera</i>	3	0	3	5	4	12	3	0
<i>V. rotundifolium</i>	2			National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	11	<i>Vachellia reficiens</i>	2	0	2	3	3.5	10	1	0
							<i>Ehretia alba</i>	3	0						
							<i>Grewia flava</i>	4	0						
PLOT 6															
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes	Diameter (m)			Canopy division		
		South	East							Canopy height(m)	North-South	East-West	Upper part	Middle part	Lower part
<i>V. rotundifolium</i>	1	22.61	17.06	National Botanical Garden of Namibia	<i>Vachellia hebeclada</i>	8	<i>Vachellia hebeclada</i>	2	<i>Plicosepalus kalachariensis</i> and <i>Tapinanthus oleifolius</i>	2	5	5.5	0	2	6
PLOT 7															

Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)			Canopy division		
		South	East								Canopy height(m)	North-South	East-West	Upper part	Middle part	Lower part
<i>V. rotundifolium</i>	1	22.61	17.06	National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	9	<i>Vachellia reficiens</i>	1	0	1.5	5	5.5	1	3	5	
<i>V. rotundifolium</i>	2			National Botanical Garden of Namibia	<i>Ziziphus mucronata</i>	9			<i>Tapinanthus oleifolius</i>	2	6	5.5	2	4	3	
<i>V. rotundifolium</i>	3			National Botanical Garden of Namibia	<i>Ziziphus mucronata</i>	14			<i>Tapinanthus oleifolius</i>	2	6	5.5	3	8	3	
PLOT 8																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)			Canopy division		

		Sout h	East						Canopy height(m)	North- South	East- West	Upper part	Middle part	Lower part	
<i>V. rotundifolium</i>	1	22.61	17.06	National Botanical Garden of Namibia	<i>Vachellia hebeclada</i>	2	<i>Senegalia mellifera</i>	2	<i>Tapinanthus oleifolius</i> and <i>Plicosepalus kalachariensis</i>	2	10	8	0	1	1
<i>V. rotundifolium</i>	2			National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	14	<i>Vachellia hebeclada</i>	2	0	1.5	2	25	4	7	3
PLOT 9															
Mistletoe species	Q N o.	GPS of plant(°)	focal	Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infested plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)	Canopy division			
		Sout h	East							Canopy height(m)	North- South	East- West	Upper part	Middle part	Lower part
<i>V. rotundifolium</i>	1	22.61	17.06	National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	11	<i>Senegalia mellifera</i>	1	0	1	3.5	4	3	3	5
							<i>Vachellia hebeclada</i>	2							

PLOT 10																
Mistletoe species	Q N o.	GPS of focal plant(°)		Location	Focal plant	Total mistletoe abundance on infested plant	Name of none infected plants	Abundance of none infested plants	Co-occurring mistletoes		Diameter (m)			Canopy division		
		South	East								Canopy height(m)	North-South	East-West	Upper part	Middle part	Lower part
<i>V. rotundifolium</i>	1	22.61	17.06	National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	19	0	0	<i>Tapinanthus oleifolius</i>	1.5	2.5	3	4	2	13	
<i>V. rotundifolium</i>	2			National Botanical Garden of Namibia	<i>Boscia albitrunca</i>	37	0	0	<i>Tapinanthus oleifolius</i>	1	4	3.5	10	7	20	