THE POPULATION DYNAMICS OF *ACACIA NILOTICA* SUBSP. *KRAUSSIANA* IN NORTHERN KWAZULU-NATAL

By

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Submitted in fulfilment of the requirements for the degree

MAGISTER SCIENTIAE

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January 2014

DECLARATION

I declare that the thesis hereby handed in for the qualification, Master of Science, Grassland Science, at the University of the Free State, is my own independent work and that I have not previously submitted the same work for a qualification at/in another University/faculty.

Signed:…………………………..

Date:…………………...........

Acacia nilotica, the plant of study, within uMkhuze Game Reserve.

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to all whose guidance and assistance was sought during the course of this study.

♦ I am very grateful to my supervisor, Prof. Nico Smit for his knowledge shared, encouragement, support and guidance throughout my study. Your patience with me while I was undertaking this study as well as attending to my full-time work commitments is greatly appreciated.

♦ This study was undertaken while employed by the Department of Agriculture and Environmental Affairs (DAEA). The Department is thanked for allowing me to undertake this work as part of my official duties, and allowing me to use the Departmental equipment and resources. The Department is also thanked for assisting me financially by providing me with a bursary to study over a period of two years. I would like to express my gratitude to Felicity Mitchell (Scientific Manager, Natural Resources Section), as my work place supervisor, for being so supportive, understanding and facilitative towards me and this study. A huge thank you too, to Cobus Botha, Michelle Keith and Clement Adjorlolo (DAEA-Natural Resource Section field scientists) for their integral in-field support during this project as well as for their tolerance towards me during the writing up stage of this study.

♦ Thank you to Jeremiah Gumbi (Ezemvelo KZN Wildlife) for being a meticulous scribe, sharing his valuable knowledge of the history of the reserve, assisting with site location and having a wonderful sense of humour while being so patient with me during my many tree measurements.

♦A huge thank you to my Mom, Dad and brother, Robert for being so supportive to me throughout my study, for their unfailing patience, encouragement and guidance and for their motivation during this study.

♦ Finally, a big thank you to the following that provided valuable assistance to me during the study:

- Dave Robertson, Park manager - uMkhuze Game reserve - and his staff for being so supportive of the project and for facilitation and help during the study period.
- Debbie Jewitt (Ezemvelo KZN Wildlife) for her patience and assistance in guiding me through the Maxent modelling program.
- Craig Morris (Agricultural Research Council - University of KwaZulu-Natal) for his time spent assisting me with statistical advice.
- Beanelri Janecke (University of the Free State) for advice on analysis of phenology data.

- All the staff of the Natural Resources Section, Department of Agriculture and Environmental Affairs (DAEA) for all their support, patience and encouragement throughout the study.
- Thandakwazi Nkhosi and the uMhkuze Field Rangers (Ezemvelo KZN Wildlife) who assisted with scribing and for providing a second pair of eyes and ears in the bush!
- Caroline Fox, S’bu Mfeka, Thandakwazi Nkhosi and Jeremiah Gumbi (KZN Wildlife St Lucia Research staff) for assisting me with BECVOL tree transect measurements.
- Craig Mulqueeny and Tarik Bodasing- (Ezemvelo KZN Wildlife) giving me assistance and useful knowledge of the reserve.
- Rikki Abbott for her assistance with the editing of this document.
- The Botanical education trust for their financial support during the study period.
- Ezemvelo KZN Wildlife and iSimangaliso Authority for permission to work in the reserve and Ezemvelo KZN Wildlife for access to uMkhuze Game Reserve records and data to assist me with my research as well as providing me with the ability to build on the research done by Pete Goodman.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A general increase in woody plants has been recognised in savannas and grasslands globally, especially over the last century (Fuhlendorf 1999, Buitenwerf *et al.* 2012). This process can be defined as either bush encroachment or woody plant thickening. In areas where woody plant species have encroached into open savannas and grasslands, but where these species had not occurred previously, the term 'bush encroachment' is used. The process defined as 'bush thickening' is used in areas where these species had occurred previously and an increase in tree density and cover has been observed. Since, in many situations, both these circumstances can occur, these words are often used in conjunction with one another. In this study, the process of increases in tree density (whether it is in an area where the woody species previously existed or not) is referred to as 'thickening', although both woody plant encroachment and thickening have been observed throughout the area under study.

The encroachment or thickening of woody plants is defined by Wiegand *et al.* (2006) as 'an increase in woody plant density'. This proliferation is slow and generally results in thickets that are so dense that other savanna and grassland plants are unable to survive in these areas (Archer 1995). The vegetation type at greatest risk to the increase of woody plants is the savanna biome, which covers a sixth of the world's land surface (Skarpe 1992). Savannas are of great importance to the growing human population as they have a high socio-economic value, as well as supporting a large proportion of the livestock population which is used for human consumption (Scholes & Archer 1997). The composition of a savanna is influenced by many factors. Tedder *et al.* (2012) identify these factors that influence the composition of trees seedlings to grass composition and, thus, productivity as fire, herbivory and soil fertility. Approximately 32.8% (or 399 600 km^2) of South Africa can be classified as savanna (Rutherford *et al.* 2006), making it the largest biome in South Africa. Of this, approximately 20 million hectares have currently been subjected to an increase in woody plant density (bush encroachment) ((Smit 2003), cited by Pienaar (2006)). The interaction of a variety of factors determine the abundance and ratio of trees, shrubs and grasses, these include climate, soils and disturbance (Scholes & Archer 1997). There have been many studies indicating that there has been a significant increase in bush encroachment in South Africa over the last 50 years (Wigley *et al.* 2009). Generally, the thickening of bush and trees in savannas is a principle that is not fully understood. Its dynamics and causes are not always known and therefore finding answers to this problem is particularly difficult (Smit 2004, Ward 2005b).

The encroachment or thickening of woody plants has many ecological effects, two of which are pertinent for the study area, uMkhuze Game Reserve. Firstly, the loss of biodiversity (Parr *et al.* 2012) is caused by an increase in woody cover: the increase in woody cover tends to lead to a change of habitat structure where plant and animal species that prefer an open habitat decline/ migrate away from the area due to a lack of habitat (Steenkamp & Chown 1996). It also impacts stocking density in an area by reducing forage for grazers and limit accessibility. Secondly woody plant encroachment is also known to alter ecosystem goods and services. Water supply may be affected by an increase in trees which have higher transpiration rates than grass, and their deeper roots are able to tap into the groundwater (Gray & Bond 2013). The denser the stand of woody plants, the greater the demand is on water and hence a high density of woody plants has a greater water demand than that of an open savanna. Trees also have much higher interception rates than grasslands thereby reducing the recharge of groundwater. The sequestration of carbon is also affected (Coetsee *et al.* 2013). Although above-ground carbon found in savanna systems is said to increase with the increase of woody plants, the loss of grass leads to a reduction in the below-ground biomass and hence the carbon storage. The extent of below-ground carbon lost outweighs the above-ground carbon formation and hence creates a net carbon loss in the system (Coetsee *et al.* 2013).

1.2 CAUSES OF WOODY PLANT THICKENING

The direct causes of bush thickening are heavily debated. Fire and heavy grazing are often believed to be two of the main causes, although Ward (2005b) states that this is incorrect. The two-layer soil-water hypothesis is another accepted theory on the thickening of woody plants (Wiegand *et al.* 2005). There are several drivers that contribute to this process. These drivers can be divided into two groups; local and global. Local drivers are often associated with the change in land use such as a change in fire regimes or grazing. A change in fire regimes where burning is done less frequently or overstocking an area and promoting heavy grazing is also known to encourage the increase in woody plants (Wigley *et al.* 2010). Global drivers that promote this shift to woody plants include a change in climate which possibly leads to rainfall and temperature changes. An increase in atmospheric carbon dioxide concentrations is another driver that has been shown to assist in the woody plant change (Bond & Midgley 2000).

The main drivers of woody plant encroachment are described by many and are mainly associated with:

- **An increase in Carbon Dioxide (CO_2) in the atmosphere:** Plants require CO_2 for photosynthesis to convert light energy from the sun into chemical energy that is used to fuel the growth of the plant. Thus, an increase of CO_2 makes photosynthesis more efficient, increasing growth rate as well as carbohydrate reserves that are stored in the roots (Bond *et al.* 2008, Kgope *et al*. 2010). This increase in carbohydrates allows young plants to re-sprout and recover more rapidly after a fire event, giving them an extra chance to escape out of the fire trap and grow to maturity (Bond *et al.* 2008, Kgope *et al.* 2010). Over the last century, there has been a well-documented increase in CO_2 and this has encouraged an increase in the density of woody plants.

- **Land management**

1. Stocking densities and ratios

It is believed that an increase in overgrazing leads to a loss of grass biomass, which then lowers fire frequency, as well as the fire intensity thereby giving the woody plants an opportunity to establish (Midgley & Bond 2001, Britz & Ward 2007). The denser a thicket becomes, the less likely it is that a hot tree-killing fire will be able to move through this area. The increase of this problem has a negative effect on savannas worldwide. With this increase in trees, the sustainability of grazing in most areas has decreased (Rappole *et al.* 1986), thereby reducing stocking densities of grazers. This has also been a serious concern to conservation managers as an increase in thickets, decreases biodiversity (Wigley *et al.* 2009). Grasses, being an important component in a savanna ecosystem play a significant role in the competition with tree seedlings. They shade small plants, compete for nutrients in the soil and provide a fuel biomass for fire that can kill many small seedlings (Tedder *et al.* 2012). An area of low grass biomass, created by incorrect stocking provides favourable conditions for seedling growth. Thus, the competition between tree seedlings and grasses is another major driver of bush thickening. Many growth models that explain tree-grass co-existence tend to assume that growth of trees is not limited by grass (Riginos 2009). This is only partially correct because grasses are shown to have negligible effect on the growth of adult trees (Scholes & Archer 1997), although tree saplings (especially those that are shorter than 1 m in height) are found to be limited by grass much more than larger trees (Jeltsch *et al.* 1997, Riginos 2009). In their research on tree-grass interaction, Scholes and Archer (1997) indicate that grasses can act as a limiting factor for woody plant survival – this can be either directly (competition for resources) or indirectly (fuel load) and hence a low grass biomass created by overstocking of grazing herbivores can contribute to an increase in woody plants.

2. Fire mismanagement

Both the lack of fire or burning an area with the incorrect fire practices can encourage the growth and establishment of woody plants within an area. The season, type of fire, the frequency and the intensity (as determined by fuel load) of a fire are all important factors to take into consideration when managing an area for woody plant control (Trollope *et al.* 2004). Incorrect fire regime can lead to trees escaping the zone where top kill would occur, and maturing into adulthood.

- **The use of insecticides**

The use of insecticides to control insect pests is not one of the main drivers for the increase of woody plants but can play a significant role in the recruitment of woody plants. In the context of this study, it is important to mention the use of insecticides (such as DDT) that were used to control Nagana (trypanosomiasis), by killing its host, the tsetse fly, in the Northern Zululand area during the 1940-1950s had a very detrimental effect on the indigenous bruchid beetles. Bruchid beetles lay their eggs in the seeds of *Acacia* species, and their larvae eat the flesh of the seed, killing it in the process. From the DDT spray bruchid beetles, along with other insects were killed thereby decreasing the number of seeds predated on. This led to an increase of viable seeds within the seed bank and hence a greater *Acacia* recruitment (Goodman 1990).

1.3 *ACACIA NILOTICA* ENCROACHMENT/ THICKENING

Acacia nilotica has the ability to encroach unwantedly into areas and present farmers, foresters and other land users with serious management problems. An encroachment of plants like these can create difficulties when burning, a loss of grazing area due to an increase in tree density and create difficult access into areas for both animals and land users. In Australia, where this species is recognised as one of Australia's worst rangeland weeds (Kriticos *et al.* 1999) land managers are working hard to control and maintain this plant through various techniques. Biocontrol, in the form of bruchid beetles and a geometrid moth, has been introduced in some parts of the country (Dhileepan *et al.* 2006), while in other areas, quarantine camps have been suggested for the placement of livestock before they are moved onto the next grazing camp, for animals to deposit their seed-contaminated faeces and prevent further contamination of rangelands (Kriticos *et al.* 2003)

A. nilotica is subdivided into seven different subspecies, of which only subspecies, *kraussiana,* occurs south of the Zambezi River. Within the Southern African subregion, this plant is found to occur in the northern parts of Namibia, parts of Botswana, much of Zimbabwe and down into the eastern areas of South Africa (Coates Palgrave 2002). *A. nilotica* is dispersed prolifically within South Africa where the plant is found under a variety of climatic, topographic and soil conditions. This plant is common in the Limpopo, Mpumalanga, KwaZulu-Natal and parts of the Gauteng and North West provinces (Smit 2008). The map below (Figure 1.1), taken from Smit (2008) illustrates the distribution of *A. nilotica* within southern Africa.

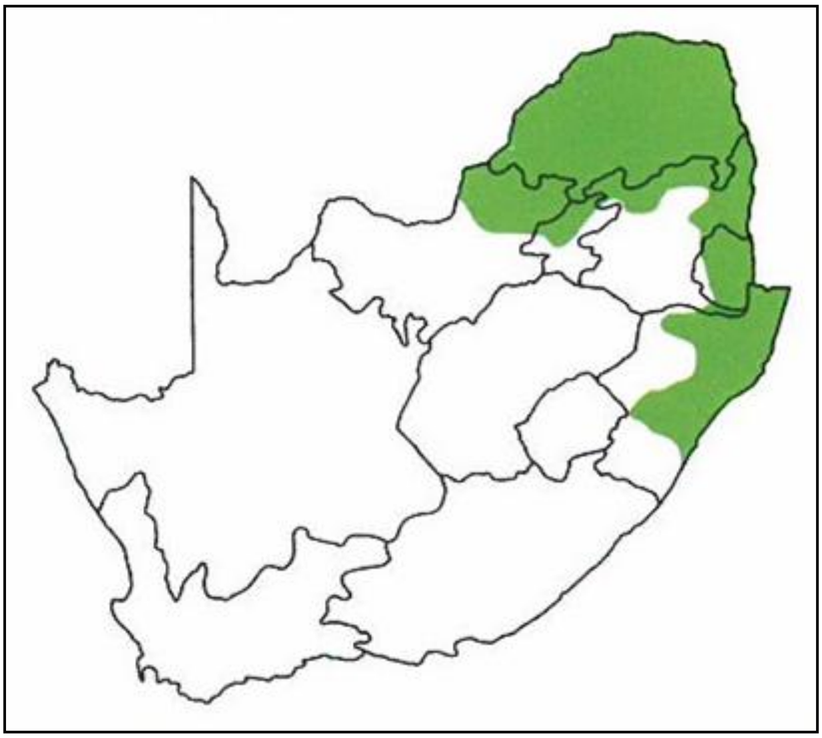


Figure 1.1 Distribution map of *Acacia nilotica* subsp. *kraussiana* in South Africa (Smit 2008).

Thickening of *Acacia nilotica* is an increasing problem acknowledged by many landowners (communal, commercial and conservation) in KwaZulu-Natal. The increase in density of this species is decreasing the area and quality of grazing land in the province, thereby reducing grazing capacity and biodiversity. This thickening is aggravated by any interference (natural or man-made) which causes an imbalance in the ecosystem. It is therefore important to understand the natural population dynamics in order to find a solution to this tree thickening problem. It is thus imperative to research the population dynamics of this species in order to manage this plant species effectively.

When the correct resources are available in abundance, *A. nilotica* can be controlled through different forms of control programmes, of which mechanical and chemical control measures are two options. These are often used in combination, but this method is time consuming and costly. Furthermore, it has to be done correctly or else the problem may intensify. Common procedures include selective cutting of plants and treating the stumps with an appropriate herbicide. Plants can also be ring-barked and the wounds painted with a weed killer (van Rooyen 2002).

Fire is another form of control for *A. nilotica*. Fire is an important tool used in controlling the encroachment of several woody species. Fire is known to limit the recruitment of *Acacia* species and also to weaken individual trees (Trollope 1984). *A. nilotica* trees are fairly intolerant to frequent hot fires. In Hluhluwe Game Reserve, 65.6% of juvenile trees burnt frequently showed a regression back to a seedling size tree, whereas those at a lower burn frequency only had a 7.8% resprout rate, the remaining being those to survive the top kill (Bond *et al.* 2001). Fire kills the shoots of young savanna trees thereby preventing growth from juvenile to adult. Any mortality of ‘aerial biomass’ is referred to as “top kill” (Hoffman *et al.* 2009). A fundamental management tool is to prevent trees from escaping this fire trap (greater than 2 m in height) and for it to kill the new shoots. Trees use energy to coppice and this prevents trees from flowering and seeding. A fire used to control bush encroachment, in creating a topkill to tress lower than 2 m in height, requires a fuel load of greater than 4000 kg/ha, an ambient temperature of above 25°C, a relative humidity of less than 30% and a wind speed of approximately 20 km/h (van Rooyen 2002).

Browsers, both wild and domestic, utilize the coppice of recently felled or burnt trees, which may keep trees small and under control (van Rooyen 2002). Ungulates can also play both an advantageous and disadvantageous role in seed survival. Seeds that pass through the gut of an animal get scarified, thereby accelerating the germination process of the seed. This also assists with the dispersal of the seeds to other areas, in this way expanding their area of dispersal (Miller 1994a). Seeds passing through an animal also have the chance of being killed through damage during the chewing process. In Australia where *A. nilotica* is recognised as one of Australia’s worst rangeland weeds (Kriticos *et al.* 1999), Miller (1996) found that only 5 to 25% of the seeds that passed through the digestive tract of a large herbivore went through fully intact. Interestingly, only 7 to 10% survived the passage through an African ungulate’s gut (Kriticos *et al*. 1999).

Rodents are also important in the control of seed germination by feeding regularly on *Acacia* seeds (Kerley & Erasmus 1991). They are also known to remove and eat seeds, that would have otherwise survived, from the dung of large herbivores such as elephants (Miller 1996). Insects, such as bruchid beetles have been shown to be particularly effective in controlling seeds. In research done at Nylsvlei in the Limpopo province of South Africa, (Miller 1994b) determined that 31 to 58% of the fallen *A. nilotica* seeds were infected by bruchid beetles. Bruchid beetles can infest the pods and seeds while they are still attached to the tree and are still developing. A re-infestation can occur once they have dried and have fallen on the ground (Miller & Coe 1993). In other case studies, *Bruchidius uberatus* have been known to kill 60% of all seeds produced from an *A. nilotica* tree (Ernst *et al.* 1989). In Australia, these bruchid beetles have been proven to be a highly successful biocontrol agent (Kriticos *et al.* 1999). Wilson (1985) mentions a shoot boring moth (*Cuphodes profluens*) that had been introduced as a biocontrol agent but which had not proven to be of any success. Since then, no further research seems to have been done on this moth (Kriticos *et al.* 1999, Dhileepan *et al.* 2006). In the natural environment, termites and ants are also known to play a role in seed predation. In research work done at Nylsvlei, 97.5% of the sample of *A. nilotica* seeds were destroyed through being buried (Miller 1994b).

uMkhuze Game Reserve within KwaZulu-Natal, as well as its neighbouring areas, is currently experiencing an increase of *A. nilotica* densities within the area. This influx of woody plants has caused some concern to the land managers as it is drastically decreasing the densities at which the properties can be stocked with game species and domestic livestock. In conservation areas, such as uMkhuze, biodiversity protection is a primary concern and therefore the rapid shading from an increase in tree density and competition of resources by woody plants is of great concern to the conservation managers. Ecotourism within the park is also at risk. The denser an area becomes, the more difficult it is for tourists to see into the thickets and spot animals. With these factors taken into consideration, the need arose to research aspects of the dynamics of *A. nilotica* within uMkhuze Game Reserve to try and understand this plant better.

The broad objectives of this study are:

1. To assess the potential distribution of *Acacia nilotica* within KwaZulu-Natal by using a predictive habitat modelling programme,
2. To evaluate the role of past management practices on the density, phytomass and population structure of established populations of *A. nilotica,*
3. To investigate the seasonal changes in *A. nilotica* phenology within uMkhuze Game Reserve, and
4. To develop a conceptual model to aid in the management of this species.

CHAPTER 2

STUDY AREA

2.1 SELECTION OF STUDY AREA

The uMkhuze Game Reserve was chosen as the area of study because it is currently experiencing the thickening/encroachment of *A. nilotica* throughout the park. This increase in *A. nilotica* density is becoming a management issue for the park and surrounding properties because it limits grazing, impacts negatively on biodiversity, reduces accessibility and hence decreases stocking densities of herbivores. The management records of this reserve have been well documented and historic information on fire, stocking densities and ratios, fixed point photographs and aerial photographs were available for this reserve. This system is managed and therefore has a few less unknown variables than an unmanaged system. These past management records provide valuable information to allow for a greater understanding of the ecological system under study.

Game farms, commercial beef farms or communal grazing properties within the region, with similar *A. nilotica* density issues may have provided an alternative study area for this research project. Many of these areas, however, are lacking the historical management records, or are not managed at all, and therefore it would have been difficult to have gained an idea of what activities or management had happened on these properties in the past.

2.2 GEOGRAPHICAL LOCATION

uMkhuze Game Reserve (27°30´ to 27°45´S, 32°05´ to 32°25´E) is situated on the coastal plain, approximately 18 km east of Mkuze town in Northern KwaZulu-Natal. The reserve forms part of the iSimangaliso World Heritage Site, proclaimed in 1999. The total area of the reserve is approximately 37 000 ha, this includes Nxwala Estate (state land), the Controlled Hunting Area (CHA) and Lower uMkhuze properties, which were added to the reserve in 1984, 1990 and 1990 to 1992, respectively. The reserve is situated at the base of the eastern slopes of the Lebombo Mountains, approximately 40 km from the coast. Altitude of the reserve varies from 30 metres above sea level (masl), where the topography is gently undulating in the south east of the reserve to 480 masl in the north west where the Lebombo Mountains meet the reserve (Smith & Goodman 1986). The Mkuze River borders the reserve on the north and the Msunduzi River on the east (Goodman 1990, Mulqueeny 2005). The location of the reserve within the province of KwaZulu- Natal is illustrated in Figure 2.1.

2.3 HISTORY OF UMKHUZE GAME RESERVE

The 25 000 ha Mkuze Game Reserve was initially proclaimed as a reserve in 1912 by the magistrate stationed at Ubombo. During this period, game was abundant in the area, although domestic livestock were still allowed to graze in the reserve. uMkhuze Game Reserve and surrounds experienced continual outbreaks of trypanosomiasis (Nagana) in 1917, where large numbers (approximately 25 000) of wildebeest were shot during the game eradication programme. During the period of 1942 to 1950, a further eradication programme took place in an attempt to control the disease. DDT spraying campaigns and tsetse fly trapping also took place. In 1954, what was then the Natal Parks Board, took control of the reserve, and by 1956, all people and their livestock were removed from the reserve. In 1984, 5 500 ha (Nxwala Estate) was added in the south of the reserve. This was followed by the incorporation of several other properties, of about 4 000 ha in total, into the reserve, in 1990. This portion of the reserve is now known as the Controlled Hunting Area (CHA). Between 1990 and 1992, six further properties in the Lower Mkuze area were purchased and added to the reserve (Mulqueeny 2005). Today, the reserve covers approximately 37 000 ha. Large herbivores are controlled through a regular culling and translocation programme. The outbreaks of trypanosomiasis are thought to be under control.

2.4 TOPOGRAPHY AND GEOLOGY

Goodman (1990) categorises the topography of uMkhuze Game Reserve into 5 different land type units. These correspond closely to the underlying parent material (geology) of the park where 16 different geological types have been identified and described within the park and its surrounds (Goodman 1990, Mulqueeny 2005). A large portion of these originate from the Jurassic and Cretaceous period and correlate strongly with the topography of uMkhuze Game Reserve. These 5 units are defined by Goodman (1990) as:

1. The **Lebombo mountains** in the west of the reserve, consisting mainly of dolerite,
2. **Early Cretaceous sediments** are seen as a gently undulating topography and are found underlying most of the park area,
3. A **Quaternary dune complex** that is slightly elevated and also undulating. These dunes comprise mainly red or yellow-brown sands,

4. **Late Cretaceous sediments** that are found in the lower lying areas, and
5. The **Alluvial floodplains** of the uMkhuze and Msunduzi Rivers.

A simplified illustration of the five land units is provided in Figure 2.2.

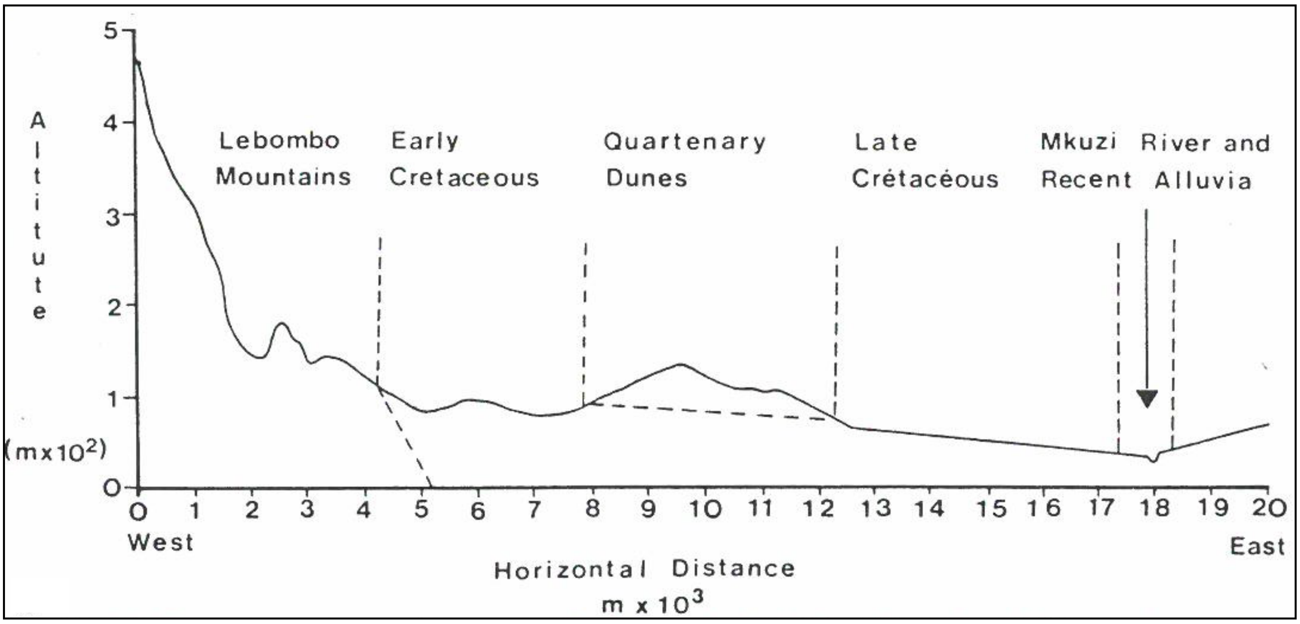


Figure 2.2 Topographical cross-section through uMkhuze Game Reserve illustrating the five apparent land units (Goodman 1990).

A more detailed explanation of the underlying geology and geomorphology of the reserve is provided by Goodman (1990). The land type unit in which the plant of study, *A. nilotica*, is assumed to be most prominent would be that of the Late Cretaceous zone.

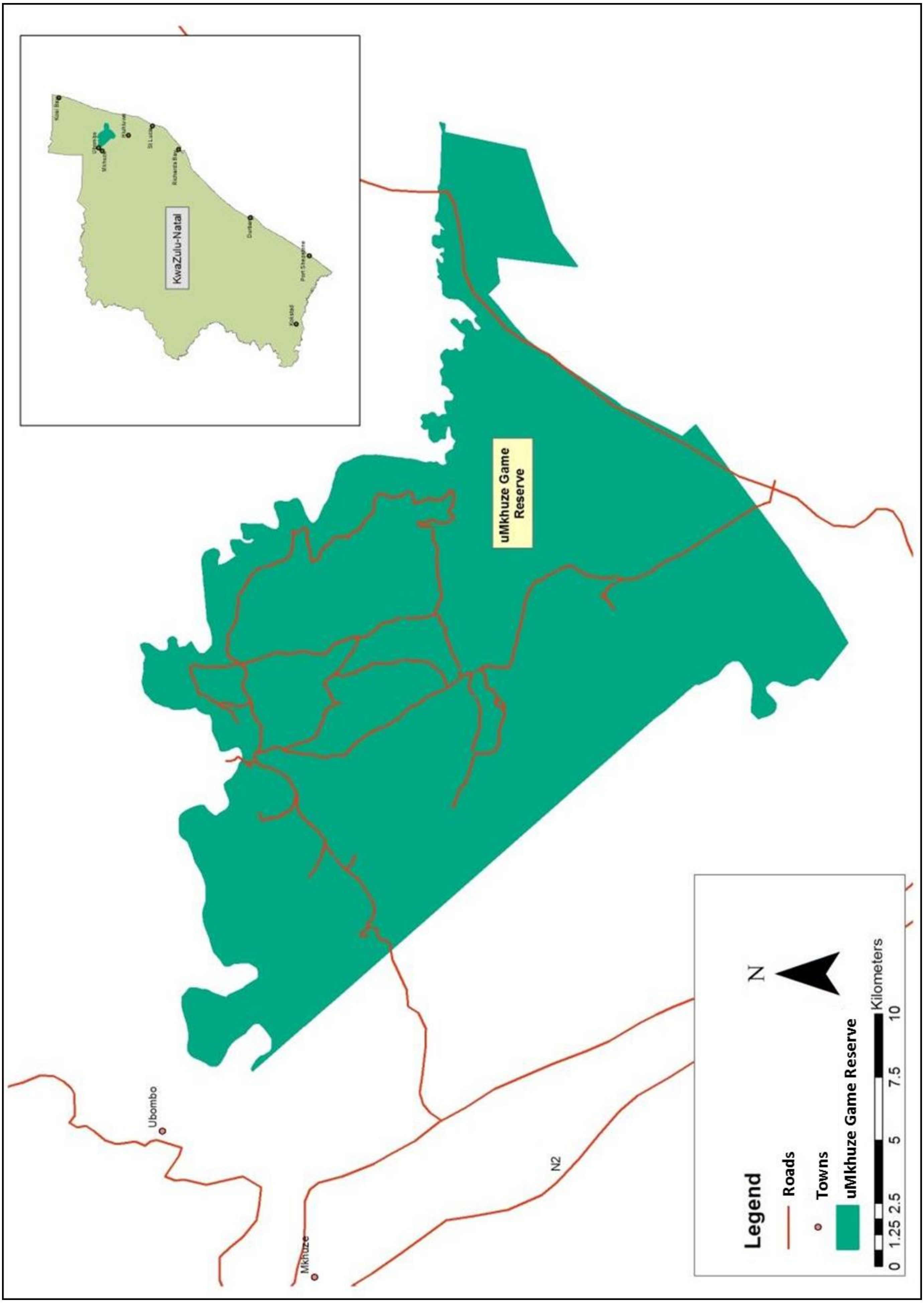


Figure 2.1 Location of uMkhuze Game Reserve in relation to the KwaZulu-Natal province.

2.5 CLIMATE

Climate plays an important role in the variability of growth within a species. The variability in climate, along with other variables like topography and soils, are responsible for the change in vegetation type. The climatic data during the period 1951 to 2012 presented in Table 2.1 were recorded from the main weather station, based at Mantuma Camp and were obtained from the Ezemvelo KZN Wildlife research section based at uMkhuze Game Reserve. The climate experienced in uMkhuze Game Reserve is best described as being warm to hot, humid and sub-tropical (Goodman 1990). The summer months from mid-September to the end of March generally coincide with the rainy season. The winter period (April to early September) can be described as warm and dry. Rainfall is highly seasonal with the highest rainfall figures being recorded in February while the lowest mean rainfall was recorded in July. At Mantuma Camp, during the period 1951 to 2012, a mean annual rainfall of 646 mm was recorded (Table 2.1). The mean annual temperature for this reserve is 22.8°C (1980 to 2000). Summers are hot and humid and the reserve experiences a mean summer temperature of 25.2°C with a maximum summer temperature of 43°C (Table 2.2). Mild to warm winters are experienced in this area with a mean daily winter temperature of 20.7°C. No frost has been recorded for this region (Camp 1995).

Table 2.1 Monthly rainfall figures for Mantuma Camp over the period 1951 to 2012 (mm) (Source: uMkhuze Game Reserve Research Station).

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
n	61	61	61	61	61	61	61	61	61	61	61	61	61
Mean	90.1	95.5	72.7	39.6	22.3	14.8	10.4	18	35.7	72.9	88.1	86.1	646.4
Min	1.2	3.0	0	0.7	0	0	0	0	0	4.0	7.1	0	270.7
Max	335.9	411.8	228.7	175.5	208.2	110.2	121.8	131.1	225.8	183.1	225.2	258.7	1065.8

Table 2.2 Monthly temperature figures for Mantuma Camp over the period 1980 to 2000 (°C) (Source: uMkhuze Game Reserve Research Station).

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
Avg. Max	31.8	31.3	30.8	29.1	26.5	24.9	25.3	26.0	27.2	28.4	29.0	30.8	28.4
Highest	42.0	43.0	40.1	37.5	36.1	33.1	35.8	37.4	40.0	39.5	38.4	41.0	38.7
Avg. Min	21.7	22.3	20.8	18.3	15.2	12.3	12.3	13.6	16.0	17.4	19.1	20.7	17.5
Lowest	16.0	16.0	11.1	9.2	9.4	6.0	6.5	5.6	8.4	10.2	12.8	13.4	10.4
Avg. Mon	26.9	26.1	25.6	23.5	21.0	18.6	18.6	19.8	21.5	22.8	24.0	25.6	22.8

2.6 VEGETATION AND SOIL

The uMkhuze Game Reserve falls within the Lowveld Bioregion of the Savanna Biome. Within this Bioregion, the dominant vegetation units include SVI16 (Southern Lebombo Bushveld), SVI19 (Western Maputaland Sandy Bushveld), SVI20 (Western Maputaland Clay Bushveld) and SVI21 (Makatini Clay Thicket) (Rutherford *et al.* 2006) (Figure 2.3). A variety of soil forms are represented here, ranging from those that are very sandy to those that are very high in clay. Several *Acacia* species are common to all these vegetation units.

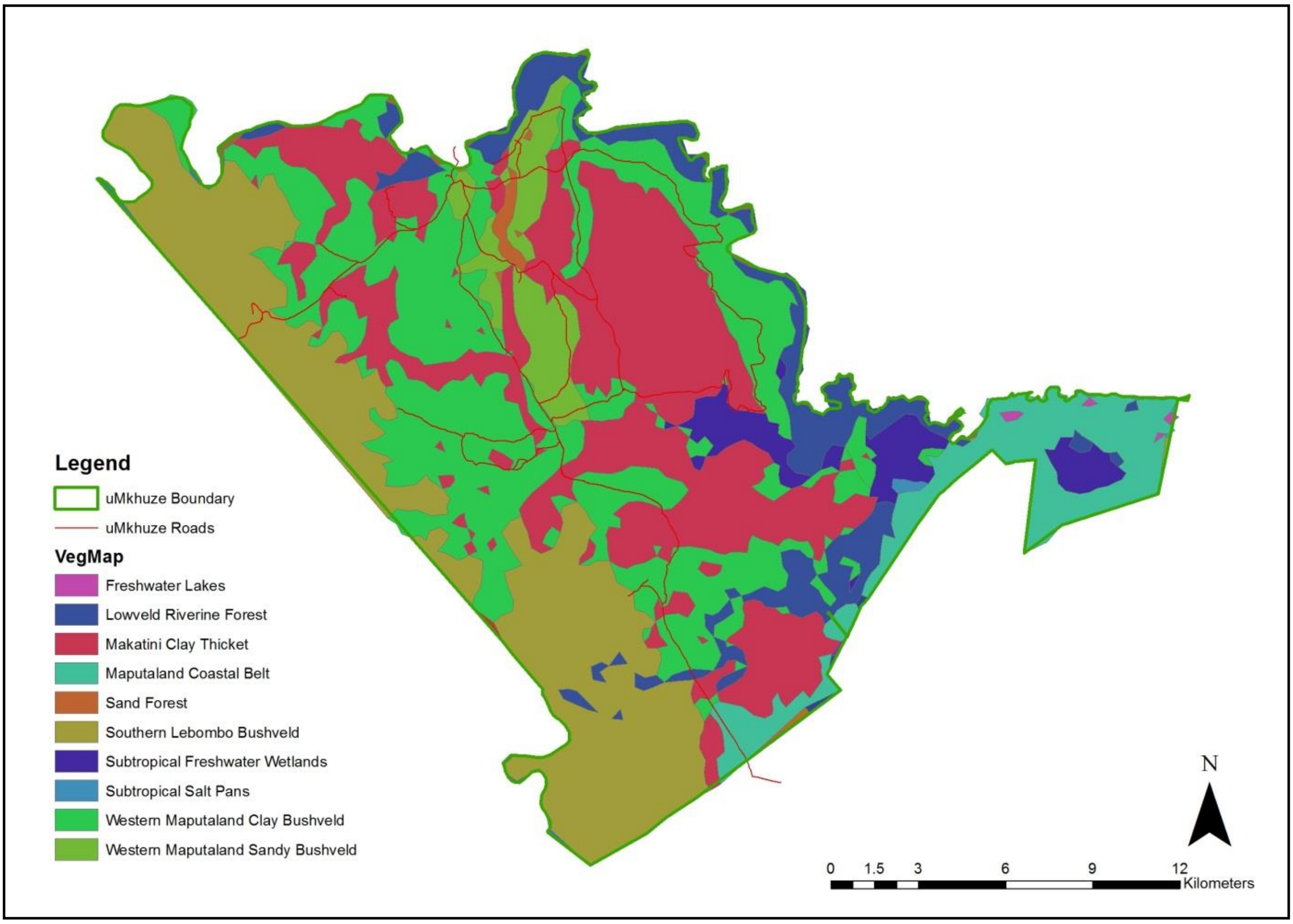


Figure 2.3 Vegetation Map illustrating the different VegMap units (Rutherford & Mucina 2006) of uMkhuze Game Reserve.

The Western Maputaland Sandy Bushveld is identified by a mixture of short, simple-leaved, bushland plants, although *Acacia* species are also identified as important plants in the area. Other plants include *Combretum* species, *Terminalia sericea* and *Ziziphus mucronata*. These soils are very carbonate rich, sandy soils. Due to the low clay content, it makes them very well drained as well. Examples of soils found in this unit are deep Shortlands, Huttons and Clovelly (Rutherford *et al.* 2006, Taylor *et al.* 2013).

The Western Maputaland Sandy Bushveld, is a vegetation unit identified by mixed, short woodland plants, many with compound leaves. The soil formations in this area are formed on shallow, cretaceous marine and coastal sediments from the Zululand group. These soils are often red in colour and range from clay loam soils to heavy red clay soils (Hutton, Bainsvlei and Shortlands). Inhoek and Valsrivier, soil forms (both high in clay as well), were also identified when a survey was done at a finer resolution (Taylor *et al.* 2013). A few plants that are likely to be found in this vegetation unit also include *Acacia* species as well as *Spirostachys africana* and *Ziziphus mucronata* (Rutherford *et al.* 2006).

The Makatini Clay Thicket (SVI21) comprises a bushland vegetation of a variety of short, simple leaved plants, similar to that of SVI19. *Euclea divinorum*, along with *Searsia* species are dominant within this area. *Acacia* species are also found in this vegetation type. Soils here are dominated by vertic and melanic topsoils that comprise a high clay percentage (Bonheim, Inhoek, Sepane and Valsrivier), although well drained soils (Shortlands and Clovelly) were also identified within this unit (Taylor *et al.* 2013). These soils are based on a cretaceous sandstone parent material (Rutherford *et al.* 2006).

On request from the reserve's research staff, a more detailed soil and vegetation survey was completed throughout the reserve by the Natural Resources Section of the KZN Department of Agriculture and Environmental Affairs (DAEA) in 2012 (Figure 2.4) (Taylor *et al.* 2013). This study was undertaken at a much finer scale (1 vegetation plot per 500 ha) and 12 vegetation groups were identified throughout the reserve. These are:

1 *Terminalia sericea/ Digitaria eriantha* Savanna
2 *Spirostachys africanus/ Enteropogon monostachyus* Thicket
3 *Ficus sycomorus/ Panicum maximum* Forest
4 *Acacia xanthophloea/ Panicum maximum* Floodplains
5 *Hyphaene coriacea/ Panicum maximum* Open Woodland
6 *Acacia nilotica/ Panicum maximum* Low Closed Woodland
7 *Acacia nilotica/ Panicum maximum* Low Open Woodland
8 Combretum apiculatum/ Themeda triandra Open Woodland
9 *Acacia* Low Thicket
10 *Dichrostachys cinerea/ Panicum maximum* Low Open Woodland
11 *Acacia* Low Open Woodland
12 *Euclea divinorum* Low Thicket

The description, composition and carrying capacity of these units are covered in detail in Chapter 4. The boundaries of these vegetation units (Figure 4.5) have a very strong link to the variety of soil forms found within the reserve (Figure 2.4). The dominant vegetation communities within the reserve comprise the *Combretum* veld, found on the shallow Mispah and Glenrosa soils in the western areas of the reserve. The *A. nilotica* thickets are located on the heavy clayed Valsrivier, Bonheim or Swartland soils and the Terminalia dominant vegetation on the sandier soil forms (*e.g*. Shortlands and Hutton) (Figure 2.4).

2.7 FAUNA

The uMkhuze Game Reserve contains mega-herbivores (elephant, hippo and white and black rhino) as well as a variety of antelope and other herbivores. The animal population numbers are calculated every second year through line transect censuses walked within the entire park. The line transect results, obtained from the uMkhuze Research Station, for large herbivores in uMkhuze Game Reserve, over a 28 year period (1984 to 2012) are presented in Table 2.3. The recommended ratios of animals should be 40% non-selective grazers (*e.g.* buffalo): 20% selective grazers (*e.g.* wildebeest): 20% mixed feeders (*e.g.* impala): 20% browsers (*e.g*. black rhino) (Bothma 2002). The ratio of non-selective grazers : selective grazers : mixed feeders : browsers during 2012 was 16% : 27% : 48% : 9%. This skewed ratio weighting was a result of extremely high impala (7 053) and nyala (4 813) numbers – both of which are mixed feeders. Due to current management policies, the numbers of non-selective grazers (*e.g*. buffalo, white rhino and zebra) are low and this impacts the current ratio significantly. This skewed ratio impacts on the stability of the ecosystem to an extent and could possibly affect the change in vegetation that the reserve has been experiencing over the years.

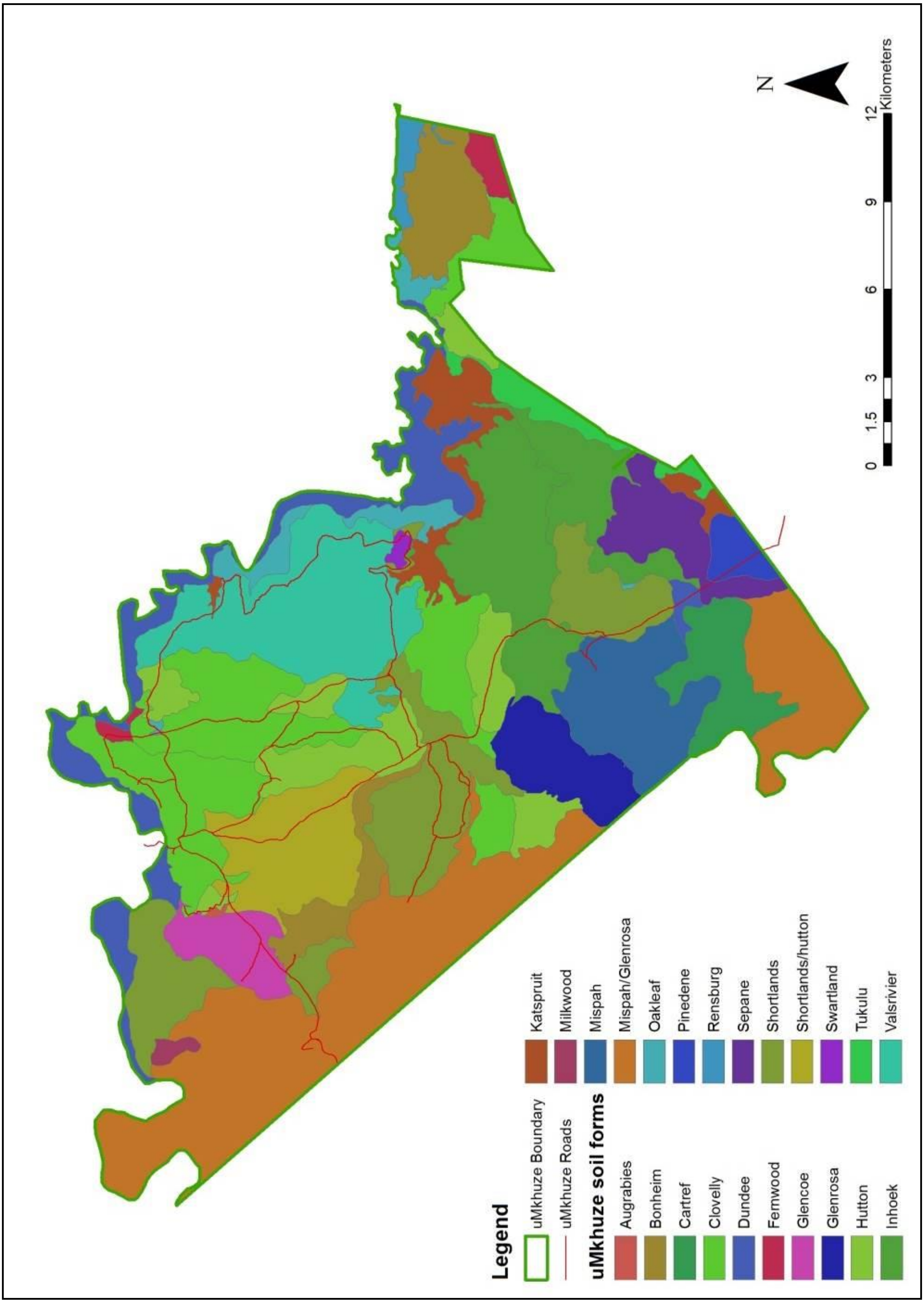


Figure 2.4 Basic soil forms found on uMkhuze Game Reserve (Taylor *et al.* 2013).

Table 2.3 Line transect animal census data for uMkhuze Game Reserve over the period 1984 to 2012. (Source: uMkhuze Game Reserve Research Station).

	1984	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*2000*	*2002*	*2003*	*2004*	*2005*	*2006*	*2008*	*2010*	*2012*
African buffalo *(Syncerus caffer)*																	120	103	113	223		300
African elephant *(Loxodonta africana)*										12	11	22	22	27	32	35	35	44	47	56	83	85
Black rhino *(Diceros bicornus)*						57	64	71	73	77	83	83	85	82	69	64	59	62	59	53	45	45
Burchells zebra *(Equus quagga)*	530	644	697	747	850	627	915	1344	1044	1089	990	1148	897	922	729	346	653	847	883	978	852	728
Giraffe *(Giraffa camelopardalis)*										115	116	112	162	158	53	62	51	53	45	70		100
Grey duiker *(Sylvicapra grimmia)*	532	531	851	684	650	534	742	599	361	338	299	251	311	168	263	232	241	286	246	350	511	273
Impala *(Aepyceros melampus)*	5900	5268	5098	5634	6997	5401	6909	7950	5165	6419	6298	5865	6237	6372	5428	4174	6000	8756	8908	6508	9050	7053
Kudu *(Tragelaphus strepsiceros)*							304	425			283	500	441	390	286	175	266	237	293	501	300	338
Nyala *(Tragelaphus angasii)*	2570	2409	4251	2875	4110	3288	4799	6264	2896	2506	2683	3086	3225	3458	5135	2959	2020	3391	3402	5000	5850	4813
Red duiker *(Cephalophus natalensis)*													191	95	378	305	328	323.76	345	977	1218	573
Suni *(Neotragus moschatus)*								192		161	156		267	151	311	318	359	406	380	577	350	319
Warthog *(Phacochoerus africanus)*	630	1150	590	2175	1500	1845	2245	2160	451	773	704	1149	1328	785	1003	218	458	535	177	450	1400	838
White rhino *(Ceratotherium simum)*								54			58	40	52	85	86	78	70	78	85		74	76
Wildebeest *(Connochaetes taurinus)*	410	684	473	672	1110	748	891	1748	1675	1747	2346	2439	2819	2332	3408	1655	1375	1847	1254	897	1550	2409

2.8 MANAGEMENT

2.8.1 Fire

Fire is used extensively within the reserve. In the early years of the park, fire was managed by block burning. This was done in the late winter/spring where the frequency was determined by the available fuel. The aim of this management procedure was to burn the entire block of vegetation and therefore the block was often re-ignited if the entire area had not burnt. During the 1984 to 1985 season, Point Source Ignition (PSI) burning was brought into the uMkhuze management plan. In this system, a single point or a very small front is ignited and the fire is then allowed to burn out naturally. No area is forced to burn (Mulqueeny 2005). This burning technique aims to be as natural as a fire lit by lightning and aims to promote spatial heterogeneity within a landscape.

2.8.2 Animal offtakes

Due to the high numbers of impala and nyala within the park, the management team of uMhkuze have focussed on managing these animals through their offtake programme. In this programme, a large proportion of impala and nyala (mixed feeders) have been removed from the reserve on a regular annual basis. Very few, or limited, animal numbers of the other species have been taken off the reserve over the last few years (Table 2.4). These data were also obtained from the Ezemvelo KZN Wildlife Research Section, based in uMkhuze Game Reserve.

Table 2.4 Annual animal offtake numbers for uMkhuze Game Reserve (2003 to 2012) (Source: uMkhuze Game Reserve Research Station).

	2003/2004	**2004/2005**	**2005/2006**	**2006/2007**	**2007/2008**	**2008/2009**	**2009/10**	**2010/11**	**2011/12**
Burchells zebra (Equus quagga)		0	64	5		5	5	5	9
Impala (Aepyceros melampus)		706	525	601		600	540	349	430
Kudu (Tragelaphus strepsiceros)		0	7	7		0	0	0	2
Red duiker (Cephalophus natalensis)		1	2	2		4	2	2	2
Suni (Neotragus moschatus)		1	2	2		2	1	1	1
Nyala (Tragelaphus angasii)		231	208	93		373	343	345	335
Wildebeest (Connochaetes taurinus)		185	137	77		5	5	5	5
Warthog (Phacochoerus africanus)		6	0	11		5	5	5	5
White rhino (Ceratotherium simum)	31	4	5	12		8	3	1	5

2.9 STUDY PLANT SPECIES

A. nilotica, the species under study, is a tree that tends to form thickets very easily (Coates Palgrave 2002) and is encroaching into a large part of northern KZN. With this issue being very prominent for many landowners, a greater understanding of the plant's processes is required to assist in the control of these thickets or encroached areas. *A. nilotica*, unlike other encroaching species within the reserve, such as *Euclea divinorum* and *Dichrostachys cinerea*, once it reaches maturity is usually a single stemmed tree. The dynamics and growth processes of a single stemmed tree are far less complex than those of a multi-stemmed tree. Thus developing an understanding of the growth processes of this tree can provide the baseline data for a typical tree that is prone to increasing in density and encroaching into an area.

Some of the main thickening species of concern within South Africa are those of the *Acacia* genus. Almost half of the South African *Acacia* species are declared indicators of bush encroachment in the Conservation of Agricultural Resources Act, No 43 of 1983 (Department of Agriculture 1983, Smit 2008). *Acacia nilotica* is one such species that is recognised on this list as a plant with a high potential to increase in tree density (Department of Agriculture 1983, Smit 2008). *Acacia nilotica* subsp. *kraussiana* is a spinescent, leguminous tree which is known to reach 6 to 10m in height and which grows in a variety of habitats including woodland and savanna (Coates Palgrave 2002, Boon 2010). It has a tendency to grow into large groups of individuals which form a thicket (Coates Palgrave 2002). For this reason *A. nilotica* has been recognized as one of Australia's worst rangeland weeds (Kriticos *et al.* 1999) . It is generally found in areas below 1 800 masl and is known to invade grasslands (Boon 2010). From a study conducted in Hluhluwe Game Reserve, *A. nilotica* trees tended to grow in the valley bottoms and on low hills (Bond *et al.* 2001). This plant is generally frost intolerant and is known to tolerate temperatures up to 50°C (Carter *et al.* 1991, Kriticos *et al.* 2003). Clayey soils are the preferred soil type of this species, although in high rainfall areas, sandy loam soils are also conducive to the growth of this plant (Carter *et al.* 1991). The wood of these trees is often used for fence posts and firewood (Coates Palgrave 2002, Boon 2010).

2.9.1 Flowering and seeds

These trees flower between September to January and have the characteristic yellow-balled flowers of many *Acacias* (Coates Palgrave 2002). Indehiscent pods are produced, approximately 8 to 17 cm in length, usually with 8 to 10 seeds, from around March to September (Kriticos *et al.* 1999, Coates Palgrave 2002, Boon 2010). These pods are edible and for this reason, the seeds are generally dispersed by mammals, especially herbivores such as elephants, antelope and cattle (Bond *et al.* 2001, Radford *et al.* 2001a). Cattle are the main agent of dispersion among domestic livestock, where up to 81% of seeds survive the digestion process, whereas in wildlife systems, ungulates are primary agents of dispersion. Only a 7.7 to 8.8% seed survival rate occurs with these wild ungulate animals (Miller 1994a). As cited in Miller (1994c), this herbivory also enables seeds to escape predators like bruchid beetles because the seeds are contained in dung pats which probably fall some distance away from high predator numbers found near the parent trees. Numbers of seeds are known to vary quite drastically from tree to tree and within sites. In Australia, *A. nilotica* is now recognized as a serious weed. Approximately 30 000 seeds per tree, as quoted by Radford *et al.* (2001b), were recorded in the riparian areas, whereas in non-riparian areas, fewer than 50 seeds per tree were recorded.

2.9.2 Seedlings

Many *Acacia* species, including *A. nilotica* are regarded as heliophytic since they require high levels of irradiance for growth (O'Connor 1995). The *A. nilotica* seedlings, defined in this context as those young plants that have recently germinated from a seed, are generally less that 50 cm tall and comprise a single meristem, are generally shade intolerant and therefore are rarely known to germinate under the canopy of the parent tree (Smith & Goodman 1986). The seeds are greatly benefited by passing through the digestive system of a herbivore and the germination of ingested seeds tend to be much higher than that of the undigested seeds (Miller 1994c). These seedlings rapidly develop a tap root to minimize competition with grasses and to acquire soil water from a lower level of the soil profile (Kriticos *et al.* 1999). Bond *et al.* (2001) recorded that, in Hluhluwe Umfolozi Park, *A. nilotica* seedlings were more abundant in short grasslands and tended to flourish on grazing lawns as the seedlings were then able to escape high fuel loaded fires. The germination of *A. nilotica* seedlings tends to be water dependent (O'Connor 1995) and therefore seedling recruitment is thought to be fairly sporadic and linked to years of wet seasons, similar to that of *Acacia tortilis* (Kennenni & van der Maarel 1990). As quoted by Midgley & Bond (2001), *A. nilotica* shows a steady recruitment rate and hence a seedling growth through different size classes and not in specific cohorts. Once seedlings are able to high/tall enough (<1.5 m) to escape the fire trap, they are more resistant to fire.

2.9.3 Mature plants

The growth rates of *A. nilotica* are highly variable and a tree can reach maturity from 2 to 12 years, depending on the conditions in which it is growing. The norm for tree maturity is between 5 to 7 years (Kriticos *et al.* 1999). Senescence for this species may occur anytime from approximately 25 to 60 years (Kriticos *et al.* 1999). The adult *A. nilotica* tree is very robust because it is fairly drought resistant and can withstand insect damage (Kriticos *et al.* 1999). In most adult trees, as cited by Midgley & Bond (2001), a savanna fire will not kill the plant; the apical regions of the plant may be damaged (top kill) which promotes resprouting or coppicing from the canopy or base of the plant.

Adult plants are known to have 5 of the 6 traits that make the plant difficult to control by insects described by Crawley (1989) in Kriticos *et al.* (1999). They have long growth periods, tough stems, high re-growth rates after defoliation, high tannin contents and therefore low food quality and "large moderately persistent seed banks" (Kriticos *et al.* 1999).

CHAPTER 3

PREDICTING THE DISTRIBUTION OF *ACACIA NILOTICA* IN KWAZULU-NATAL

3.1 INTRODUCTION

The first steps towards the management of a woody species that is prone to bush thickening, such as *Acacia nilotica*, are to understand the nature and extent of the problem and then to extrapolate this knowledge into the trends and predictions of the future distribution range of this species. In this chapter, an attempt is made to predict those areas that are at risk from the thickening and encroachment of *A. nilotica* in KwaZulu-Natal (KZN).

The KZN province is approximately 9 459 590 ha in size (Le Maitre *et al.* 2000) and rises steeply from sea level at the coast up to 3 449 masl on the Drakensberg escarpment. Its rainfall also varies widely from 255 to 1 923 mm per annum. Mean annual temperatures in KZN have a range of 7.6 to 22.9°C with an average of 15.25°C. Snow and frost also occur in this province (Camp 1995). With this sort of climatic and altitudinal range in the province, the issue of bush thickening/encroachment in parts of KZN has become of serious concern.

If land managers in KwaZulu-Natal had a better understanding of the potentially suitable habitat of *A. nilotica* and the environmental factors that influence it, they would be better prepared to manage the situation, if and when, thickening/encroachment presents a problem on their properties. With better knowledge of the ecology of this species, organisations that provide land users with advice and /or assistance on sustainable resource management (such as the Department of Agriculture and Environmental Affairs and Ezemvelo KZN Wildlife in KZN) could offer more informed and thus, effective, advice. For these reasons, it is important to understand the present and potential distribution of *A. nilotica*.

A fundamental concept in ecology is that of a niche. The niche-based concept was used originally by the naturalist, Grinnell, (1917), when it was defined as ‘to designate a place in an association occupied by a single species’. This definition was then further developed the British ecologist, Elton, who was the first to illustrate a functional concept of the word in 1927, when it was explained as ‘the status of an animal in its community’ (Whittaker *et al.* 1973). After this, there were many further interpretations and refinements of this definition. Finally, the terms 'species fundamental niche' and 'species realised niche' were proposed by Hutchinson (1957).

A 'species fundamental niche' (as defined by Hutchinson (1957)) is an n-dimensional hypervolume (an area with more than 3 dimensions) where "every point corresponds to a state of the environment which would permit the species to exist indefinitely" This, of course, has its limitations as it assumes that all points in each fundamental niche would have an equal probability for all species when the case is that there will normally be an optimal part of the niche surrounded by suboptimal zones. Further, the assumption was made that all environmental variables can be linearly ordered, which is not possible. This niche model is based on a "single instant in time" when, in fact, two species from two different time periods during the day (nocturnal and diurnal) could have very similar requirements to live and reproduce and therefore can fill the same niches. Finally, with this model, it is difficult to take the whole community into consideration at once as only a few species are used at the same time (Hutchinson 1957).

A 'species realised niche' is described as the area that remains after parts of the fundamental niche have been removed from the fundamental niche due to competition for food, shelter *etc*. (Whittaker *et al.* 1973). In other words, this is the 'space' in which the species actually lives. Since these models describe the suitability of a species in an ecological space, it often referred to as a "niche based model" (Phillips *et al.* 2006). The potential distribution described by this model is referred to as a species fundamental niche and describes an area where all the conditions of a species fundamental niche are satisfied. Due to human influence, biotic interactions and/or geographic barriers creating an unfavourable environment for a species, a realized niche is created. This is always smaller than the fundamental niche and is the actual area that a species really occupies. Few species actually ever occupy the whole area of a species fundamental niche (Phillips *et al.* 2006).

This niche concept is useful in this study of *A. nilotica* when it is attempted to map the areas of KZN where there is the potential for *A. nilotica* to occur. It seems as if this species is expanding its range – and, obviously, if this is the case, then some of the factors constraining it within the realised niche have been relaxed or altered in such a way that its realised niche is currently expanding. An example of this is the increase in temperature trends within South Africa (Kruger & Shongwe 2004). Since *A. nilotica* is currently found in the warmer regions of the province, these temperature increases may expand the realised niche of *A. nilotica* and hence the suitable range of the plant will also increase over time.

Niche-based models are important tools that are used for conservation, ecological and invasive species management (Anderson *et al.* 2003) and, in this study, also for conservation and agricultural purposes. This is done by linking environmental variables to species occurrence records in order to model species habitat requirements (Anderson *et al.* 2003, Kramer-Schadt *et al.* 2013). Species distribution models are able to:

1. Determine the change in habitat distribution due to global climate change.
2. Determine the predicted encroachment of an introduced species into an area. Previously efforts to control invasives have been undertaken mostly after a new invader species has been observed in an area. A fairly recent approach is to predict the habitat and behaviour of a species before it invades a given area. This is based on ecological niches where it is recognised that species will probably only be able to populate an area with habitat conditions similar to their native range or habitat (Peterson 2003). Further, three phenomena can also limit or restrict the distribution of a species:
    - Limited dispersal: this prevents a species being distributed from other suitable areas (Root 1998, Anderson *et al.* 2002).
    - Extinction: When species go extinct within a localised area, suitable uninhabited areas are left empty due to "demographic reasons" (Burkey 1995), and,
    - Competition: Competition between species can reduce the distribution of the one species that is slightly weaker in that particular area, thus limiting the size of the habitat of that species. (Anderson *et al.* 2002).
3. Test 'evolutionary hypotheses' where speciation processes are investigated through combining different layers of data and checking out where the overlapping patterns fall within the phylogeny of different species. This approach can also correlate environmental factors that are similar and relate them with speciation (Graham *et al.* 2004).
4. Species distribution models can be used to a great effect in the planning and management of conservation areas (Ferrier 2002).

The ultimate objective of predictive habitat modelling is to define the 'true proportion of pixels of potential presence' for each species under study (Anderson *et al.* 2003).

A number of niche based models have been developed over time to model the distribution of species and the methods of modelling are diverse; some use both presence and absence data, while others use presence-only data. Driving some models are forms of regressions such as those of the Generalized Additive Model (GAM) or Generalised Linear Models (GLM) (Austin *et al.* 1990). Some models have set-based approaches, where ranges of species along ecological dimensions are characterised such as BIOCLIM and DOMAIN (Carpenter *et al.* 1993), while other models use the maximum entropy approach – such as Maxent (Ortega-Huerta & Peterson 2008). The maximum entropy approach is used to estimate the predicted distribution by finding the distribution that is the closest to uniform (of maximum entropy), taking into account the constraint that the expected value for each pixel within the distribution must match its realistic average (Phillips *et al.* 2004).

The main objective of this study is to predict the present and future distribution and the ecological niche of *A. nilotica* in KwaZulu-Natal. This was done using Maxent, a presence-only method (Phillips *et al.* 2006, Elith *et al.* 2011). Presence-only methods are considered to be more useful as presence-only locality points are easier to collect. It is often very difficult to demonstrate when a species is absent from an area and false absences will then decrease the reliability of the model (Ortega-Huerta & Peterson 2008). Other presence-only based models are available, each one developing maps of species distribution in a slightly different way. Some of these other models include Biomapper, DOMAIN, weights of evidence, GARP and Floramap (Ortega-Huerta & Peterson 2008).
Further objectives of this study are:

- The development of a habitat profile from known sites where *A. nilotica* occurs, and
- Compilation of a potential habitat map of *A. nilotica* for KZN from known environmental conditions.

3.2 METHODS

The chapter describes how the predictive habitat distribution of *A. nilotica* was modelled. This was achieved by using existing distribution data to define its main habitat requirements. Following this, areas of suitable habitat throughout KZN were mapped. This predicts areas to which the plant will be likely to spread. To achieve this, a predictive species distribution model was created using the Maximum Entropy (Maxent) program. Species distribution models (or often referred to as ecological niche models) were also used to gain insights into the drivers (ecological or evolutionary) of a species in order to assist in predicting habitat suitability across large-scale areas though multivariate statistics.

The potential distribution of *A. nilotica* in KZN was modelled using the Maxent ecological niche modelling program. This modelling tool, created by Phillips (2005), is developed to map the potential geographic distribution and ecological niches of a specific species. Maxent is a popular tool because it works well with incomplete information, or data, that is irregularly surveyed within the study region (Phillips *et al.* 2006, Kramer-Schadt *et al.* 2013). It is unique in that it works from presence-only records in order to model the distribution (Elith *et al.* 2011). Maxent makes use of data collected where the species has occurred (occurrence records) and the environmental variables that most likely describe the factors that create a suitable environment for that species (Phillips *et al.* 2004). Some of the advantages of this distribution model are:

- All that is required is the presence-only data and the environmental variables in order to run the program,
- The program can run simultaneously with both categorical and continuous data,
- It uses efficient algorithms so that the optimal probability distributions are guaranteed (Phillips *et al.* 2006),
- The program, as well as an easy-to understand tutorial, are available (as a public domain program) free of charge off the Internet.

Maxent is regarded as one of the 'best distribution models in terms of its predictive performance" (Elith *et al.* 2006) and produces results that are robust with data that are often irregularly sampled.

In order to determine under which conditions *A. nilotica* is likely to occur within KZN, the Maxent program was used to model environmental variables using multidimensional statistics. In total, 690 geo-referenced distribution records, captured with a GPS, were collected randomly throughout KZN. These data points were obtained from the information gathered during vegetation surveys conducted by the Natural Resources Section of the KZN Department of Agriculture and Environmental Affairs. These co-ordinates were checked for correctness of latitude and longitude data and were saved in a .csv format to make it compatible with the program. These data were downloaded and run through the Maxent ver. 3.3.3. program (Phillips 2005). To reduce spatial autocorrelation, the Maxent program further removed duplicates from any grids, leaving a total of 324 geo-referenced sites with which to run the model. A subset of the data was used to create the model and a separate subset used to model the results. A 70 : 30% split was made, where 70% was used to train the model, while the further 30% of the records was used to test the quality of the model (Anderson *et al.* 2003, Phillips *et al.* 2006).

Environmental variables that were possibly important in the habitat requirements of this species were required to run the model. These were selected based on what was assumed to have the most influence in the definition of the habitat for the species. These environmental variables for the whole KZN province were obtained from Ezemvelo KZN Wildlife. These datasets were extracted from their 2001 and 2006 Environmental Management Framework Database and edited in ArcView. These data sets have been resampled to a 200 m x 200 m grid format and converted to ascii (asc.format) in order to comply with the Maxent program. These grid data sets illustrate the environmental variable that is specific for each pixel. Initially 6 variables that were thought to most influence species distribution were selected, and, after an iterative process to remove datasets that showed signs of spatial autocorrelation, four of these variables were retained. These were:

1) KZN mean annual precipitation, that is the average yearly rainfall of the province, measured in mm,
2) Geology, that is the different categories of parent material underlying the surface,
3) Mean minimum July temperature that is the historic yearly average of July temperatures, measured in °C, and
4) Elevation, that is the height of the earth's surface measured in metres above sea level (masl).

Clay percentage and frost frequency data sets were discarded from the model due to the possible presence of autocorrelation (clay percentage with geology and frost frequency with mean minimum July temperature).

These then, within the Maxent program, were related to the presence points of the species to establish the habitat and further the potential geographic distribution of *A. nilotica*. Five hundred iterations were run where the results were then averaged in order to produce the species distribution model.

Maxent probability responses can be set to be produced in raw (where the response is the exponential model of Maxent), logistic (where a probability of presence is estimated) or cumulative (regarded as the predicted omission rate) outputs (Phillips & Dudlik 2008). Following the advice of Phillips & Dudik (2008), the logistic probability response output was chosen. This is the default output response and produces a continuous variable that ranges from 0 to 1. High values in a particular cell indicate a high probability of habitat suitability for the species of study.

The statistical concern of autocorrelation was approached on a few occasions during this study as documentation does state that this could be an issue when using Maxent and similar distribution modelling programs (Elith & Leathwick 2009). It is particularly difficult to extrapolate what the plant's specific requirements are without having a slight chance of autocorrelation. Testing for spatial patterns within the data should be part of any species distribution model and either a Moran's I index or the Geary's c-test are the recommended tests for spatial autocorrelation (Dormann *et al.* 2007, Elith & Leathwick 2009). Through the iterative selection process of the environmental variables, an attempt has been made to prevent this from occurring and this has been substantiated by the Moran's I index.

3.3 RESULTS

The graphs developed by the training and test data points are presented in Figures 3.1 and 3.2. These points were used to run the Maxent program to predict *A. nilotica* potential habitat distribution.

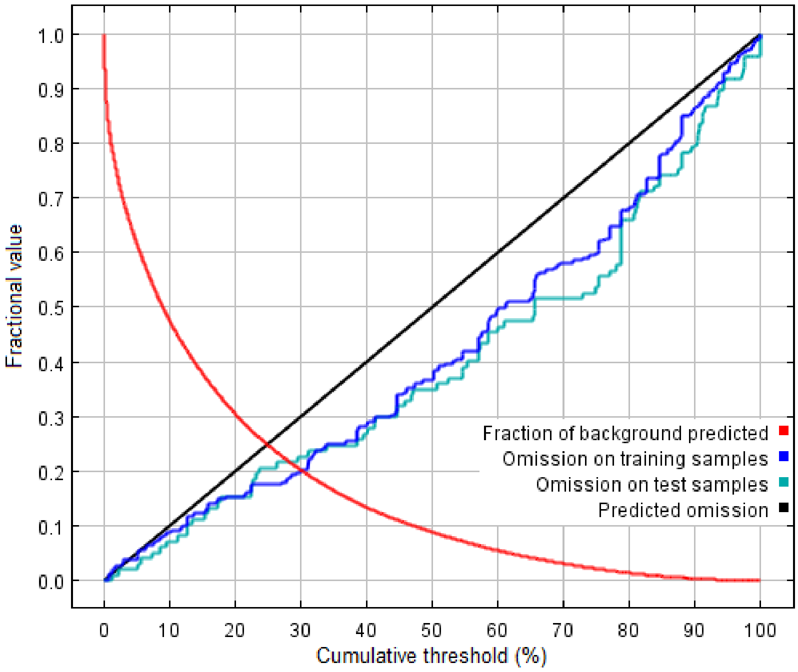


Figure 3.1 Omission rate and predicted area as a function of the cumulative threshold for the *A. nilotica* distribution model. The omission rate is calculated both on the training presence records and on the test records.

The straight black line in Figure 3.1, illustrates the predictive omission rate for the model. Omission rate is described as the 'fraction of test localities that fall into pixels not predicted as suitable for the species' whereas the predicted area is the 'fraction of all the pixels that are predicted as suitable for the species' (Phillips *et al.* 2006). The predictive rate compared to the omission rate graph shows that the ommission on both the training and test samples fall very close together. This indicates that the test and training data were not independent enough since the training and test locations were located within fairly close proximity of each other. A Moran's I test was done to determine if any spatial autocorrelation was found within these sample points. Spatial correlation occurs when sample points are too close together and they exhibit values that are more similar than those that are further apart, in other words the points close together are not independent from each other (Dormann *et al.* 2007). In this study the Moran's index was calculated to be 0.51. This indicates that the site locations are closer to the clustering side instead of the dispersion side. The closer the score is to 0, the more random the points are. A Moran score closer to -1 indicates where sample points are not clustered (*.i.e.* where they are widely spread over an area), while a Moran score closer to +1 indicates a clustering of sample points (ESRI 2013). In order to have a good model, a low omission rate, as seen here, is required (Anderson *et al.* 2003). The low omission rate illustrates that the Maxent model has predicted potential suitable habitat for *A. nilotica* with high success rates.

The results of the receiver operating characteristic curve to illustrate the performance of the Maxent model on potential *A. nilotica* distribution are presented in Figure 3.2.

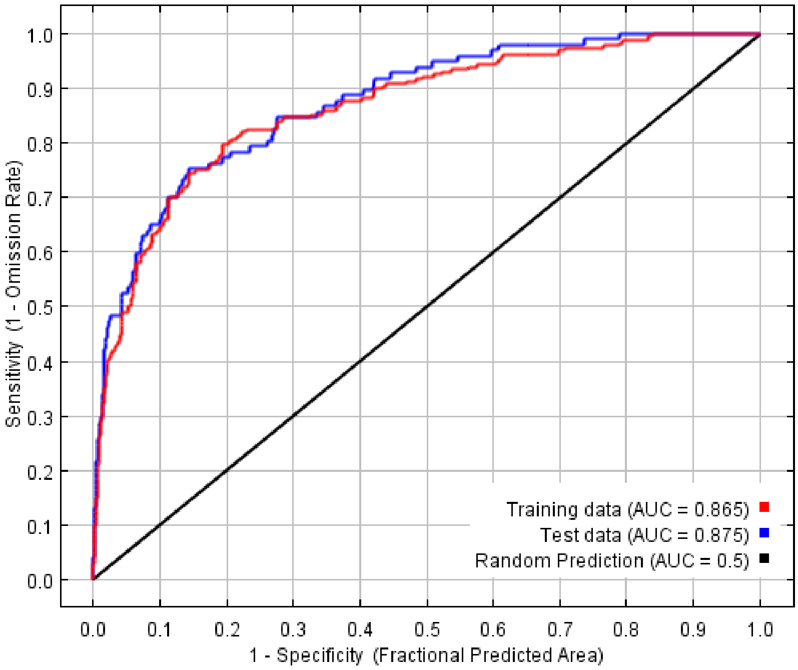
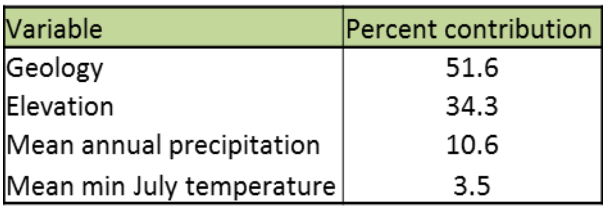


Figure. 3.2 Receiver operating characteristic (ROC) curve showing the performance of the model through the Sensitivity *vs* 1-Specificity for the *A. nilotica* model run through Maxent. Specificity here is defined using the predicted area of the species. High quality models show a ROC curve that rises quickly to the top left hand corner of the plot while poor quality data follows the line of random prediction or falls below it.

The area under the receiver operating curve (ROC-AUC) provides a measure of the performance of the model (Figure 3.2). The sensitivity describes the fraction of all the positive instances that are classified, while the specificity is defined as the fraction of negative instances. In this model, the red line indicates the fit of the model to the training data and the blue to the testing data. The black line indicates the random prediction. If any of these lines were to fall under the black line, the model would have a no better than random fit. The test data AUC is 0.875, indicating that the Maxent model had an 87.5% success rate and had a goodness of fit that is statistically significant ($p < 0.05$) and fairly good. This is also shown by the proximity of the test data line to the left hand axis. The closer the blue line is to the top left hand corner, the better the model is at predicting the presence of the species. Here too, the red and blue lines are very close to each other, indicating an autocorrelation of presence data.

Four environmental variables (geology, elevation, mean annual precipitation and mean minimum July temperature) were used to run the Maxent model. These, and the proportion that each of these variables contributed to this model, are presented in Table 3.1.

Table 3.1 Percentage contribution of each variable to the distribution model for *A. nilotica* developed in this study



Variable	Percent contribution
Geology	51.6
Elevation	34.3
Mean annual precipitation	10.6
Mean min July temperature	3.5

The KZN geology data set used in this model contributed heavily to predicting *A. nilotica* distribution. This indicates that geology plays a vital role in the distribution of *A. nilotica* and contributed to 51.6% to the outputs of the distribution model (Table 3.1). The second highest contributor to the model is elevation, with 34.3%, followed by mean annual precipitation and mean min July temperature (10.6% and 3.5% respectively). Substantiating response curves show that geology contributes highly to *A. nilotica* distribution patterns. Dominating geological formations selected by *A. nilotica* include Amphibolite, Siltstone and Lebombo and Nsuze Group Basalt. All these geologies are fine grained and have relatively high clay contents. From these response curves, ideal altitude for this species tended to fall in the 0 to 1 500 masl range. Any higher altitude illustrated a drastic drop in the predicted probability of suitable conditions for *A. nilotica*. Suitable rainfall conditions fall mainly below the 1 000 mm category. From the results derived from this model, mean minimum winter temperature where the plant is known to occur in is predicted to be on average 7°C and higher. The effect of the low contribution of winter temperatures to the model is discussed further in Section 3.4. It is important to remember that these values are not always optimal and depend entirely on the path that the Maxent model uses.

The results of the jackknife test of regularized training gain for *A. nilotica* are presented in Figure 3.3. This test gives alternative estimates of important variables for the model.

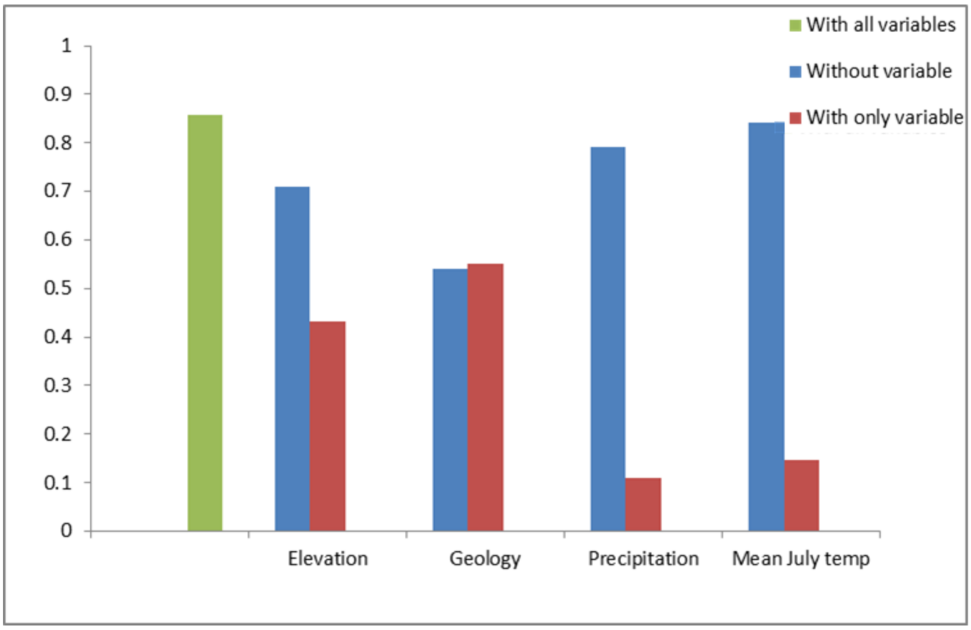


Figure 3.3 Results of the jackknife test of regularized training gain for *A. nilotica* giving alternative estimates of the important environmental variables that were used to create the distribution model.

These models were created by isolating each variable and running each variable independently. The jackknife of regularized training gain for *A. nilotica* (Figure 3.3) illustrates that geology, and secondly, elevation, have a reasonably good fit to the training data, while precipitation is not a good variable to use by itself in estimating *A. nilotica* distribution. This links in well to the contribution data mentioned in Table 3.1. Much of the suitable *A. nilotica* habitat is located in the central and northern regions of KZN (Figure 3.5). Reds and oranges indicate areas with higher probabilities of occurrence of *A. nilotica*. Green areas indicate a 25 to 50% probability, while the blue areas indicate habitats unsuitable for the plant. Many of the areas along the coast are comprised of soils too sandy for *A. nilotica* habitat and hence the continuous purple stretch along the coast. River valleys and low lying areas show good potential habitat areas as well. Apart from the Drakensburg and the coastal grassland areas much of the remainder of the natural rangelands/savannas within KZN falls into the higher *A. nilotica* probability shown on the map.

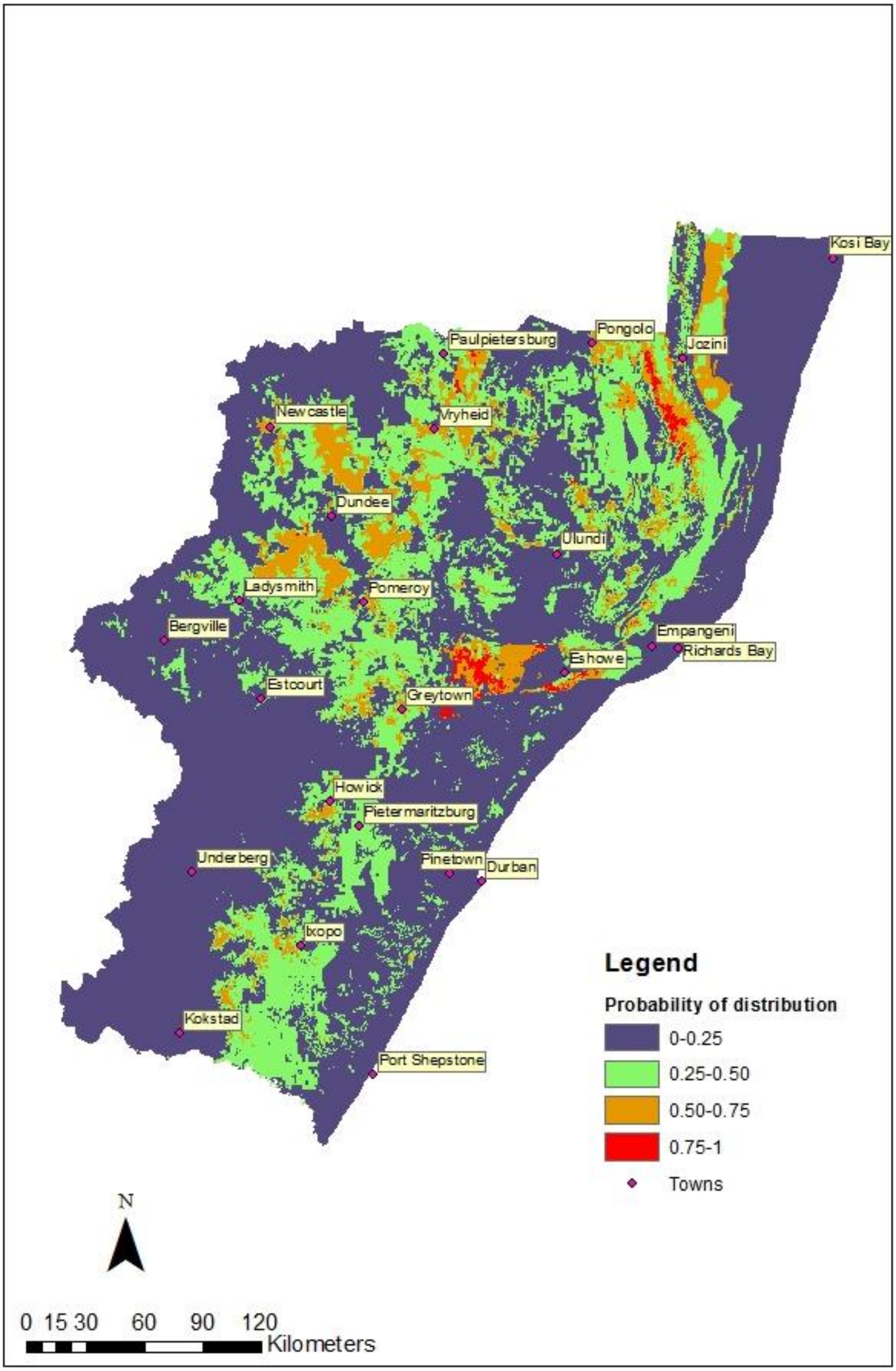


Figure 3.4 Modeled potential distribution of *A. nilotica* in Kwazulu-Natal. Probability scores were classified according to four categories: 0 to 0.25 probability, 0.25 to 0.50 probability, 0.5 to 0.75 probability and 0.75 to 1 probability of *A. nilotica* distribution potential.

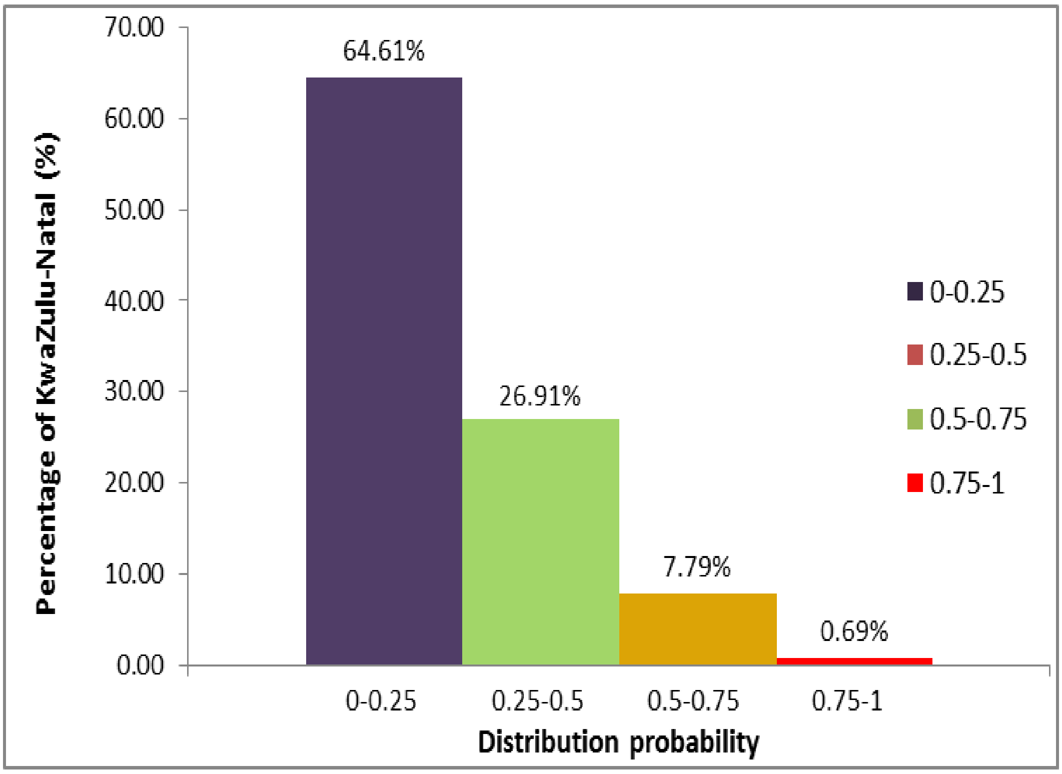


Figure 3.5 Approximate probability of *A. nilotica* distribution within KwaZulu-Natal. Probability scores were classified according to four categories: 0 to 0.25 probability, 0.25 to 0.50 probability, 0.5 to 0.75 probability and 0.75 to1 probability of *A. nilotica* distribution potential.

Results from Figures 3.4 and 3.5 indicate that a large portion of the province (64.6% or 6 069 072 ha) has a 0 to 25% probability of *A. nilotica* encroaching into these areas. A further 26.9% of KZN fall into the category where there is a 25 to 50% chance of *A. nilotica* occurring. The figures of highest concern are the moderate to high probabilities. In KZN, 7.8% of the area has been modeled into the high (a 50 to 75% probability) and 0.7% into the very high probability (75 to 100%) zones, together making up almost 8.5% (or 798 499 ha) of the province. This has severe consequences and both landowners and managers need to be aware of this issue. A change in one of these variables (such as an increase in temperature) can lead to a shift in this graph where the percent of moderate to high probabilities is likely to increase and low to no probability decreases. Although this currently is a fairly small fraction, KZN is a prime cattle farming area and areas that are degraded by the thickening of *A. nilotica* can potentially lead to an increase in rural poverty.

3.4 DISCUSSION

A map of KZN was produced using Maxent and illustrated the areas that have potentially suitable habitats for *A. nilotica*. This study has highlighted some of the more important drivers of this plant and has assisted in the prediction of the distribution on a very broad-scale map of the province. These drivers give insights into the abiotic conditions that are required for the plant to survive and further assist with the prediction of other areas with similar conditions and hence areas to which this plant could spread. As with all models, in time and with more data points, the distribution map will become more accurate. It was noticed that some of the large river valleys on the south coast, such as the Umkomaas and Umzimkhulu Rivers were not highlighted as much as they should have been on this map. This is probably due to the fact that far fewer occurrence localities were sampled in these areas and therefore extrapolation was not realistic. These results illustrate that *A. nilotica* has the possibility of becoming very widespread and could potentially occupy a large portion of KZN.

Many of the natural rangelands in KZN are under threat from the potential thickening of this plant. This has serious biodiversity management implications because it may result in a shift in ecological state. Areas encroached by woody plants, such as *A. nilotica*, will create an environment where competition for soil water is high. Typically, as woody plant density increases, so the production of the grass layer will be reduced. This reduction of grasses as a result of woody plant increase may be caused by an interruption in rainfall, accumulation of moribund plant litter, shading or root competition (Scholes & Archer 1997). In creating a shaded environment, the microhabitat of an area will change and a new microhabitat may arise that is unsuitable for the survival of many grass species. A transition from open savanna areas to closed woodland will have serious economic implications for the province’s agricultural sector. An increase in woody plants will affect the grazing capacity, which will result in fewer animals (beef cattle) being stocked per unit area.

Maxent, through modelling the distribution to illustrate where this plant occurs and where it could spread in the future, provides a tool for planning and prioritising actions and options when it comes to managing this species (Ward 2007). Changes in climate over time could have a definite impact on the predicted distribution of this species within the province. Understanding what environmental variables make an ideal habitat for this plant can also provide a better understanding of what would happen if the climate was to change. If there is an increase in temperature and fewer areas are exposed to frost during the winter season, more areas are likely to provide optimal *A. nilotica* habitats. On the other hand, from these model predictions, a slight decline in predicted habitat suitable for *A. nilotica* can be expected if the mean annual precipitation were to increase greatly over the expanse of KZN in time to come.

Since temperatures are expected to rise in the event of global warming (in extreme cases, of up to 5.8°C within this century) (Hannah *et al.* 2002), this could have a fairly profound impact on the distribution of this species in the future. It has shown that ideal habitat for this plant are areas where the soils are fairly high in clay, the altitude is lower (0 to approx. 1500 masl), have a slightly lower mean annual rainfall (up to 1 000 mm) and average min July temperatures that are greater than 3°C. This makes river valleys and the inland areas of northern KZN high potential *A. nilotica* habitat.

In KZN, the Department of Agriculture and Environmental Affairs has mapped the province into approximately 645 Bioresource Units (BRU) (Camp 1995). These are agricultural units showing areas of similar soil type, climate, altitude, terrain form and vegetation. The next stage of the BRU research in respect of *A. nilotica* would be to overlay the potential distribution map of *A. nilotica* onto the BRU map to get a better idea of which BRUs are under threat from *A. nilotica* tree thickening and encroachment. This together with a vigorous extension programme should alert farmers within these areas to the economic implications of this species and provide guidelines on how best to manage these areas to avoid this potential encroachment.

3.5 CONCLUSION

This model-based map will be particularly useful for conservation and rangeland planning for future control of the plant. In doing so, insights have been gained relating to the key determinants for its habitat selection illustrating the worrying fact that many of the natural rangelands in KZN are under threat from the thickening of this species and this map illustrates this clearly. The Maxent program has been proven to be easy to use and fairly accurate. One of the highlights of this program is that it is a public domain available program that is available free of charge through the Princeton University website. In the same way that it was used for *A. nilotica* in this research, this technique can be applied to other woody species that have a tendency of wooding up the KZN landscape (for example *Dichrostachys cinerea*, *Leucosidea sericea* and *Acacia sieberiana*) as well as woody alien invasive species. It is hence a useful technique that can be used effectively to maintain and to care for the natural rangelands of KZN.

CHAPTER 4

HISTORICAL AND CURRENT VEGETATION TRENDS IN UMKHUZE GAME RESERVE

4.1 INTRODUCTION

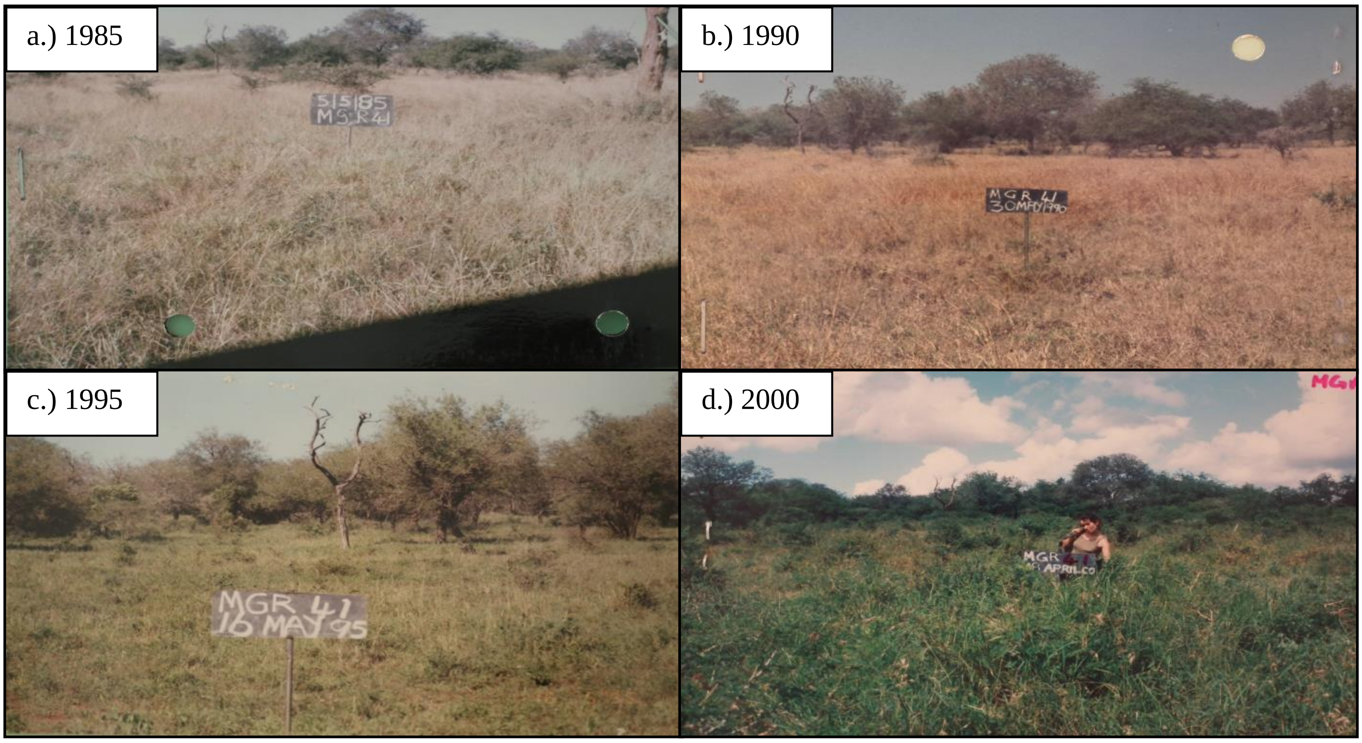
The encroachment and thickening of woody plants is not only a local, but also a global, concern to rangelands (Gray & Bond 2013). This phenomenon is a growing concern to many land users as it has serious implications for both the vegetation and the animals that utilize it. Within KZN, research studies have indicated that the concern of woody plant thickening has not been limited to uMkhuze Game Reserve and is also a concern within other Zululand game reserves, such as Hluhluwe-iMfolozi Park (Skowno *et al.* 1999, Walters *et al.* 2005) and Ithala Game Reserve (Gordijn *et al.* 2012) as well as in agricultural and communal areas (Wigley *et al.* 2009, Wigley *et al.* 2010) in parts of KZN. The problem of bush thickening is also reported in neighbouring north-eastern Swaziland (Roques *et al.* 2001) and several other savanna areas of Southern Africa (O'Connor 1995, Eckhardt *et al.* 2000, Kraaij & Ward 2006). The process of bush thickening has been ranked as the third most important pressure in the protected areas of both the uKhahlamba and the Zululand regions of KZN and was then (2003) ranked sixth in the assessment of current threats throughout the province (Goodman 2003).

Over the years, uMkhuze Game Reserve has had various management approaches. Goodman (1990) described the management history of uMkhuze in detail and this is summarised in Chapter 2. Some of the more radical management interferences include the once-off Nagana campaign in 1917, and the eradication programme of 1942 to 1950 to control the tsetse fly during which many thousands of herbivores were eradicated and the bush was cleared. A management decision to reduce stocking levels was implemented in 1963, when a “large scale animal population programme was initiated” (Mulqueeny 2005). This was motivated by concerns about the declining veld condition within the reserve. More recently animal stocking levels are controlled on a regular basis, through a culling and translocation programme (Mulqueeny 2005). Initially, burning of the veld was done using ‘block-burns’ where complete demarcated areas were burnt throughout. In 1984/85, the fire programme was altered and fires were ignited using the point source ignition (PSI) technique, where the fire management was altered to mimic a more natural process (Mulqueeny 2005). Fires in the reserve have been comprehensively monitored from 1963 till the present (2013) and animal control programmes are still implemented in a manner that mimics the impact that absent predators (such as lions) would have on the herbivore populations.

In 1983, a programme was initiated to take fixed point photographs on a regular basis, within the reserve so that a record of the visual vegetation changes could be kept for reference. Recently, one of the management concerns for the reserve is the thickening and encroachment of woody plants into the more open areas.

Figure 4.1 Vegetation change for Site MGR 24 over the period of 1985 to 2004. From 1985 to 1991 (Figure 4.1a and b) illustrates very little change in vegetation. Between the period of 1991 and 1997 (Figure 4.1c), a large number of young woody plants have encroached into the area. Seven years later, by 2004, these *A. nilotica* trees were large enough to have escaped the fire trap and are fully mature with seed pods visible (Figure 4.1d). (Note the large bush clumps that provide a reference to the succession in the upper right hand corner of each picture.)

During the period 1983 to 2004, and then repeated in 2011, the changes in vegetation structure within the reserve were documented using annual fixed-point photographs. The photos presented in Figures 4.1 and 4.2 clearly illustrate the vegetation changes in two of the monitoring sites, over these years, within the reserve. It is evident that there is thickening or encroachment of woody plants in these sites where *A. nilotica* is seen to be one of the main encroaching plant species. Little historic quantitative data on vegetative monitoring is available in the reserve, so to gain a better understanding of the thickening process this study was initiated to assess the dynamics and density of the woody plants within the reserve. A first step was to quantify where and to what extent *A. nilotica* occurred within these sites. These data will provide a baseline data set for any further woody plant monitoring within the uMkhuze Game Reserve.


a.) 1985

b.) 1990

c.) 1995

d.) 2000

Figure 4.2 Site MGR 41 illustrating the vegetation change over 15 years from 1985 to 2000. Figure 4.2a and b show very little change in the open savanna vegetation community from 1985 to 1990. During the period from 1990 to 1995 an obvious change was observed where, in the 1995 photo (Figure 4.2c), small woody plants are making an appearance. By the year 2000, (Figure 4.2d), woody plants, mainly *Acacia* species, have completely covered this open savanna and are at least 1 to 1.5 m in height. (Note the dead 2-branched tree in the photo succession).

The objectives of the study are:

- To describe, classify and map the plant communities within uMkhuze Game Reserve,
- To determine the density, phytomass and available browse within these communities, and
- To assess the approximate area and the degree of *A. nilotica* bush thickening within each vegetation community.

4.2 METHODS

4.2.1 Vegetation community map

The first step in measuring the current tree density was to identify the different vegetation communities, or homogeneous, areas occurring in uMkhuze. This was done by studying topographical features, slope and vegetation from van Rooyen (2003) and categorising them into different land categories. A broad scale map of the vegetation communities within the entire reserve was developed by van Rooyen (2003) This map was a result of a desktop study where vegetation boundaries were determined from aerial photographs and no field assessment was done, resulting in discrepancies and inaccuracies in the delineation of the boundaries. Since it was beyond the scope of this study to conduct an in-depth vegetation study of the reserve and to compile a detailed vegetation map, a simplified map of the plant communities was compiled to assist in the understanding of the spatial vegetation structure of the reserve. The map originally developed by van Rooyen (2003) was used as a baseline for which the boundaries were corrected and refined from actual field data. The collection of this field data formed part of a more detailed vegetation assessment (veld condition assessment and grass biomass data were also collected) and soil survey that was completed by Taylor *et al*. (2013).

4.2.2 Description of the vegetation communities

A total of 70 representative sampling sites were selected within the identified homogenous vegetation communities to account for the majority of heterogeneity in terms of Bioresource Group, woody vegetation density and aspect. The location of the survey sites are presented in Figure 4.4. The quantification the woody layer was done according to the BECVOL-3 procedure (Smit 2001). Vegetation pattern (Edwards 1983), vegetation health and soil indicators were also recorded for each sampling site to provide qualitative measures to describe the vegetation communities. The reserve was demarcated into different vegetation communities (Figure 4.5) and the survey results for each vegetation community will be discussed independently

The BECVOL-model follows a regression analysis approach using standard statistical least square regression analyses and the calculation of the tree biomass is based on the relationships between the spatial canopy volume of a tree and its true leaf dry mass and true leaf volume respectively (Smit in press). The spatial canopy volume is calculated from several measurements of the tree (Figure 4.3). The BECVOL-model differs from other methods relating tree dimensions to biomass by being able to provide estimates for both complete plants and plant portions by employing the calculation of partial canopy volumes (Smit in press). This is of particular importance in the estimation of available browse within different height strata.

Regarding estimates of the browseable component of woody plants, the previous version of the BECVOL-model (version 2) only estimated the leaves, whereas young, new season's shoots less than 0.5 cm in diameter also constitute an important component of the browseable part of woody plants (Smit in press). A fourth aspect that was not considered in the previous model is the importance of estimating the wood component of trees and shrubs. The most important addition to the BECVOL-3 model is thus the development of additional regression models for the estimation of the dry mass of the wood component in different diameter classes.

Important functional characteristics of the woody component are the browsing potential of trees and shrubs and the height of the vegetation within the site (Trollope 1990). At each survey site all rooted woody species within a 50 m x 2.4 m (125 m^2) belt transect were identified and their dimensions measured with the aid of a 2.4 m range rod. The measurements taken of each tree are illustrated in Figure 4.3.

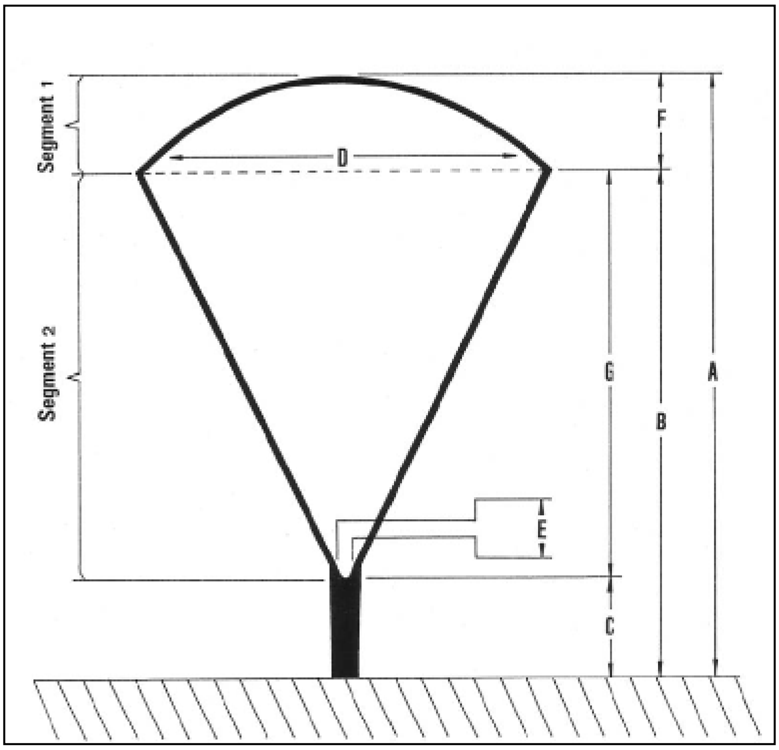


Figure 4.3 Schematic illustration of an ideal tree, its measurements and structure (Smit 1996).

Definitions for the symbols within Figure 4.3 are as follows:

A - Tree height (m);
B - Height of maximum canopy diameter (m);
C - Height of minimum canopy diameter (m);
D_1 - Maximum canopy diameter (m);
D_2 - Maximum canopy diameter (m);
E_1 - Minimum canopy diameter (m);
E_2 - Minimum canopy diameter (m);

4.2.3 Calculation of the browsing capacity

The browsing capacity was calculated for each vegetation community. The browsing capacity is defined as the area of land covered in woody vegetation that is needed to maintain one browser unit (ha/BU). A BU is defined as the metabolic equivalent of a kudu with an average body mass of 140 kg (Smit 2006). Maintenance must be for over a period of time and without any deterioration to the soil or the vegetation (Smit 2009). The browsing capacity was calculated from the tree biomass (leaves and shoots <5 mm in diameter) calculated with the BECVOL 3-model for each of the vegetation communities as described in the previous section (Section 4.2.2). From the leaf and shoot (<0.5 cm diameter) per hectare estimations, the browsing capacity of each vegetation community was calculated with the following formula (Smit 2006):

$$y = d \div \left[\frac{(DM_1 \text{ x } f_1 \text{ x } p_1) + (DM_2 \text{ x } f_2 \text{x } p_2) + (DM_3 \text{ x } f_3 \text{ x } p_3) \ldots\ldots}{r} \right]$$

where y = browsing capacity (ha BU^{-1})

BU = metabolic equivalent of a kudu with an average body mass of 140 kg
d = number of days in a year (365)
DM_1 = tree leaf and shoot DM yield ha^{-1} of species 1
DM_2 = tree leaf and shoot DM yield ha^{-1} of species 2
DM_3 = tree leaf and shoot DM yield ha^{-1} of species 3
…
f_1 = utilization factor for species 1
f_2 = utilization factor for species 2
f_3 = utilization factor for species 3
p_1 = leaf phenology of species 1
p_2 = leaf phenology of species 2
p_3 = leaf phenology of species 3
…

r = daily fodder DM required per Browser Unit(BU) (2.5% of body mass of 140 kg) = 3.5 kg/day)

The utilization factor, expressed as a decimal value, represents that part of the available leaf and shoot material that can be consumed. Actual consumption is limited by browsing preferences of the animals. Limited scientific information currently exists on which to base the utilization factor (f), but indications are that it is very low. In the case of black rhinoceros it can be as low as 8% ($f = 0.08$), and up to about 20% or more ($f = 0.20$) for other browsers (Smit 2006). The estimated percentage leaf presence (p = phenology) for the various plant groups can theoretically vary from 100% ($p = 1.0$) in the case of evergreens to 0% ($p = 0.0$) during winter for the early deciduous group. However, there are indications that browsers may utilize the tips of shoots and twigs, even if no leaves are present. This implies that the value of p will always be above 0 (Smit 2006).

Since the amount of browse available is dependent on the vegetative phenology of all the woody plants within the community, and that plant phenology is seasonal, a browse capacity was derived for each month of the year. Within these community groups, 3 distinct browsing heights were recognized: 1.) 0 to 1.5 m (*e.g.* grey duiker and impala), 2.) <2 m (*e.g.* kudu and black rhino) and 3.) <5 m (*e.g.* giraffe and elephant). A browsing capacity was calculated for each browsing height category. All vegetation communities were seen to follow a similar trend, where the browse capacity is at its highest during the summer months and lowest in the late winter and early spring.

4.3 RESULTS AND DISCUSSION

4.3.1 Identified vegetation communities

The vegetation map with indication of the location and boundaries of the identified vegetation communities within the uMkhuze Game Reserve is presented in Figure 4.5

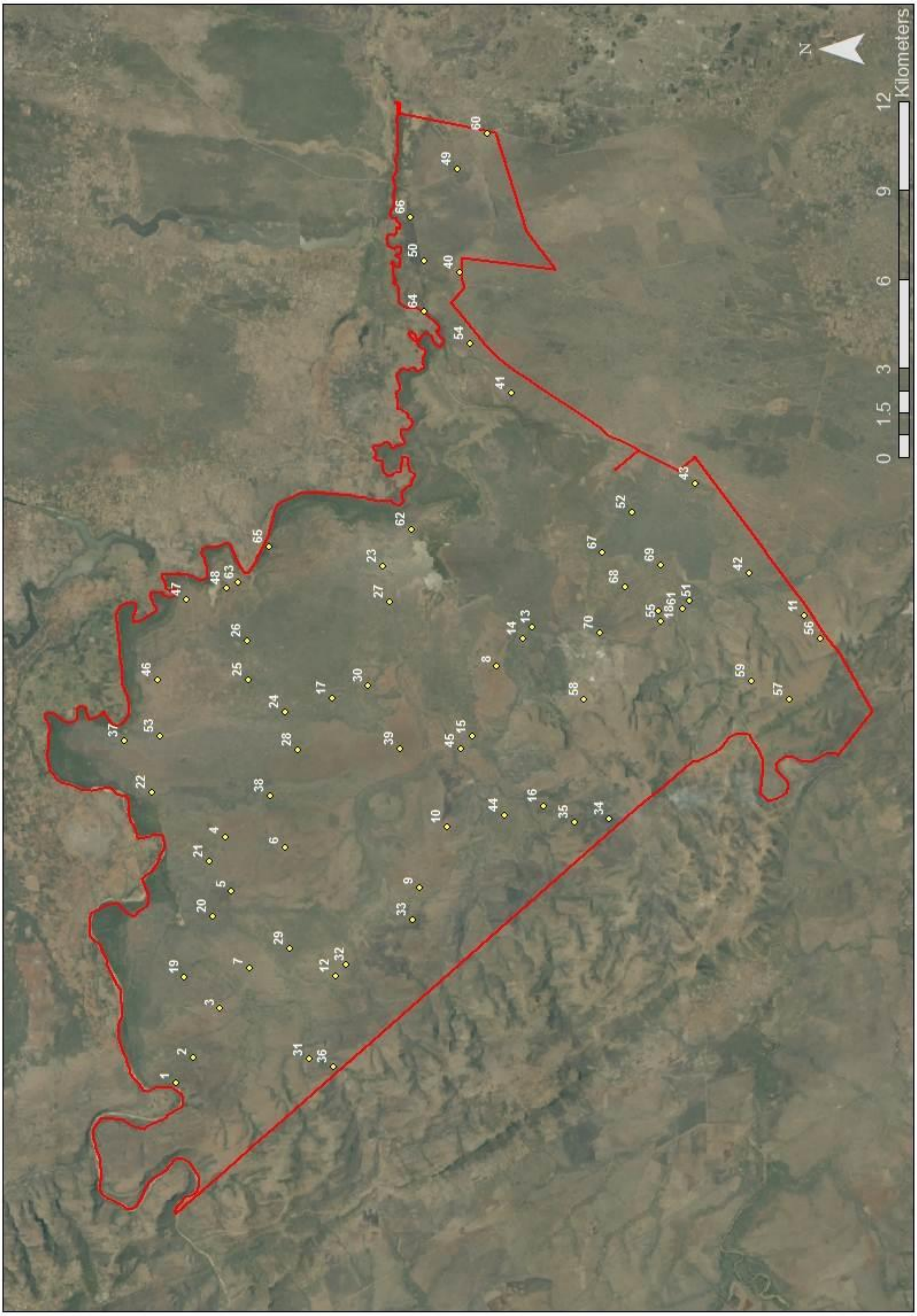


Figure 4.4 Location of vegetation survey points within the uMkhuze Game Reserve

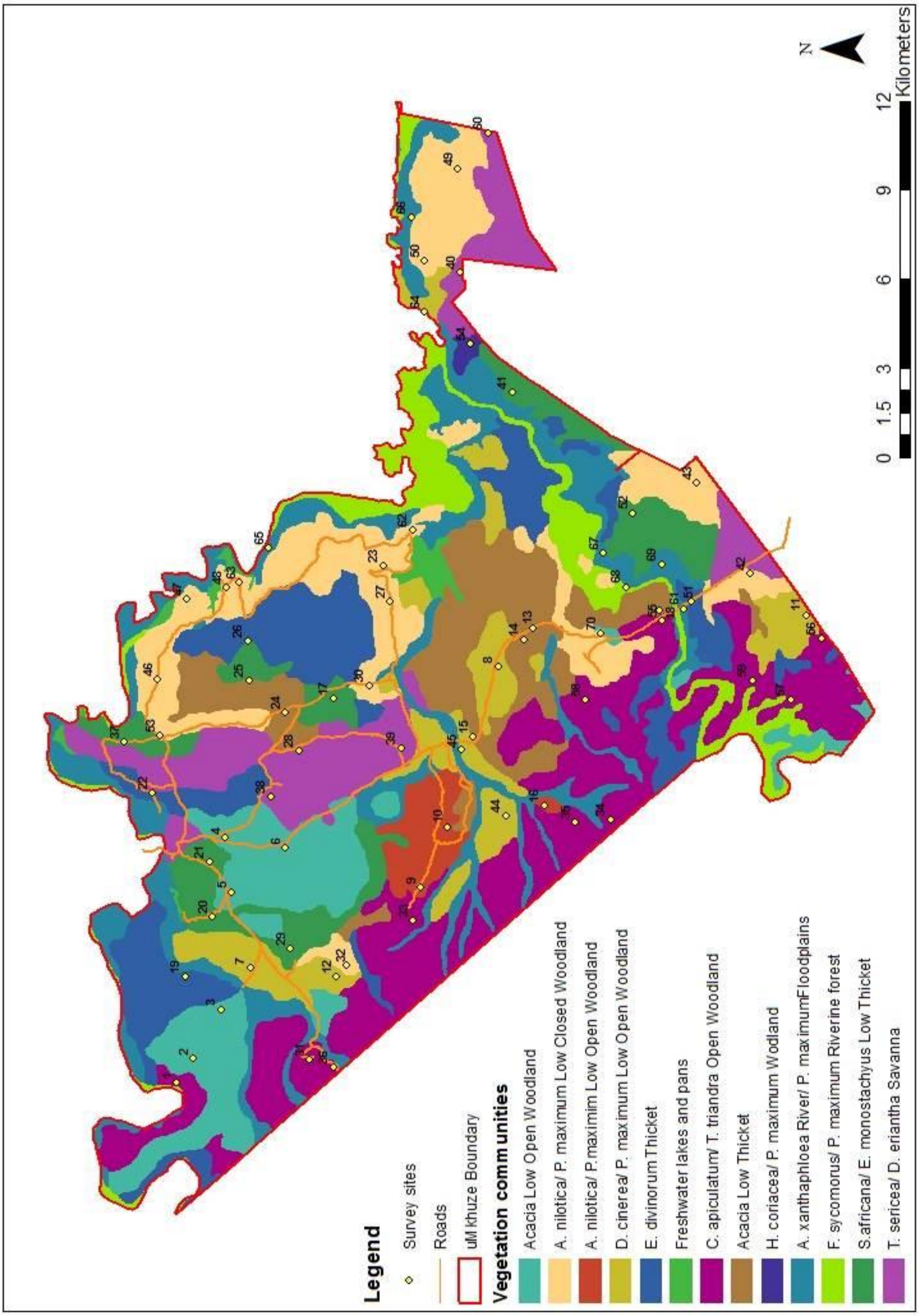


Figure 4.5 Vegetation communities of uMkhuze Game Reserve (Taylor *et al.* 2013). Numbers on the map represents the location of each study site.

A total of 12 (excluding freshwater lakes and pans) vegetation communities were identified (Figure 4.5). Dominant communities comprised *Combretum apiculatum/ Themeda triandra* woodland (16%), *Acacia xanthophloea/ Panicum maximum* floodplains (13%) and *Acacia nilotica/ Panicum maximum* low closed woodlands (12%) (Table 4.1).

4.3.2 Description of the vegetation communities

The mean species richness of trees within each vegetation community of the uMkhuze Game Reserve is presented in Figure 4.6 and will be discussed in the description of each vegetation community.

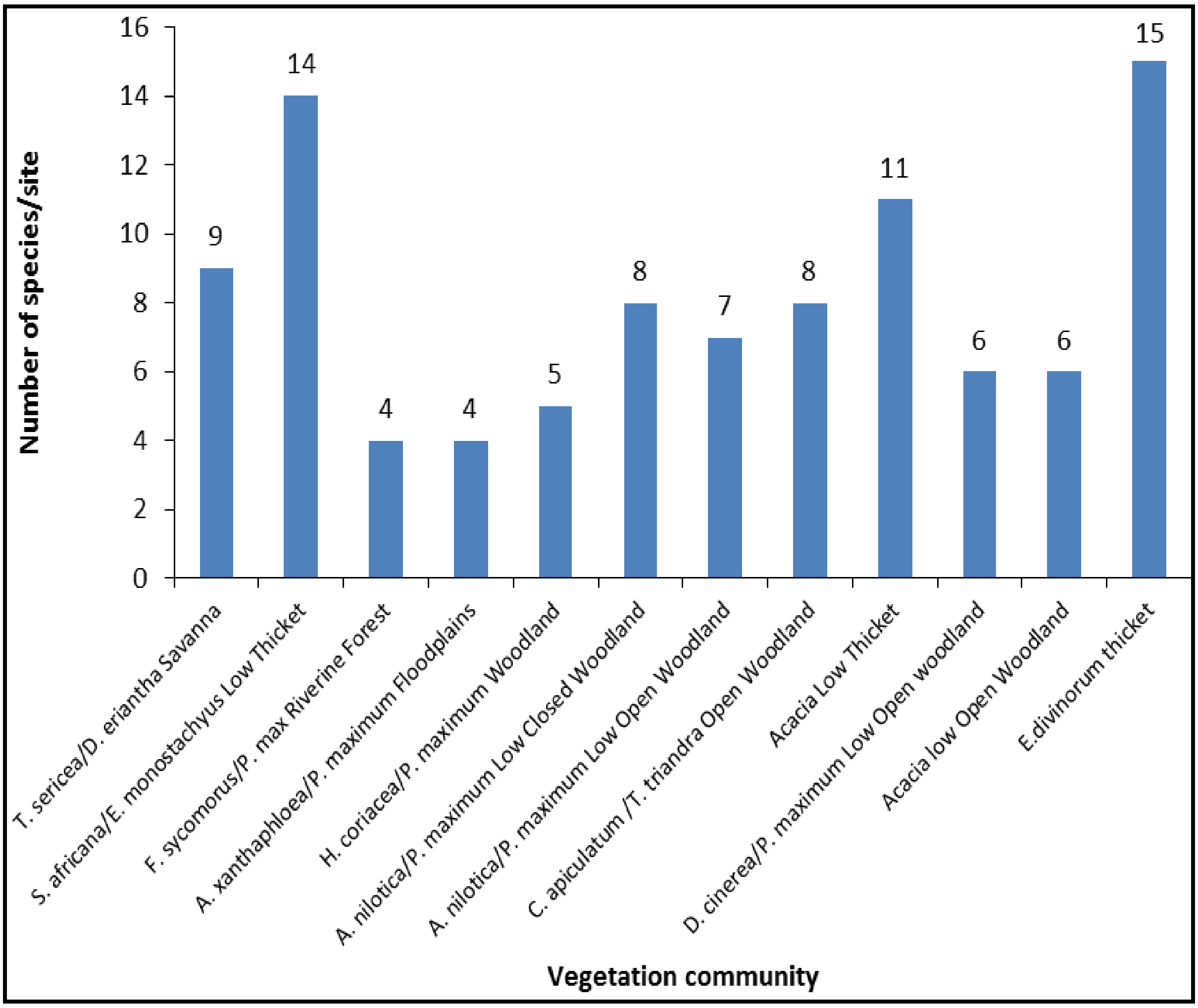


Figure 4.6 Mean species richness of trees within each vegetation community of uMkhuze Game Reserve.

The structural composition of the woody vegetation of each vegetation community of the uMkhuze Game Reserve is presented in Figure 4.7 and will be discussed in the woody vegetation composition, structure and density section of each vegetation community. This data was derived from the secondary calculations produced by the BECVOL program (Appendix A).

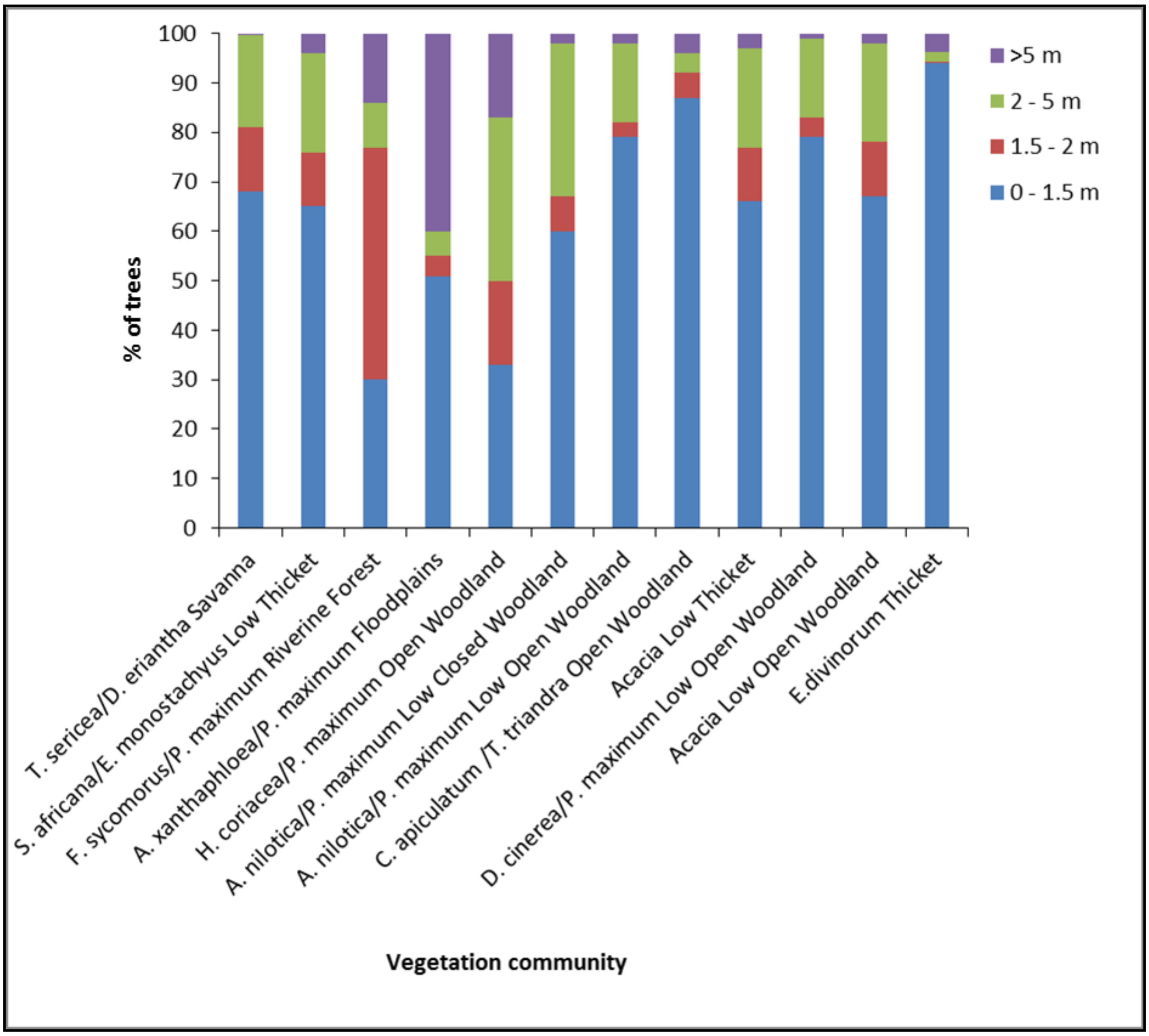


Figure 4.7 Structural composition for each vegetation community in relation to different tree height classes in the uMkhuze Game Reserve**.**

The mean estimated dry leaf mass of the woody vegetation of each vegetation community of the uMkhuze Game Reserve is presented in Figure 4.8 and will be discussed in the woody vegetation composition, structure and density section of each vegetation community.

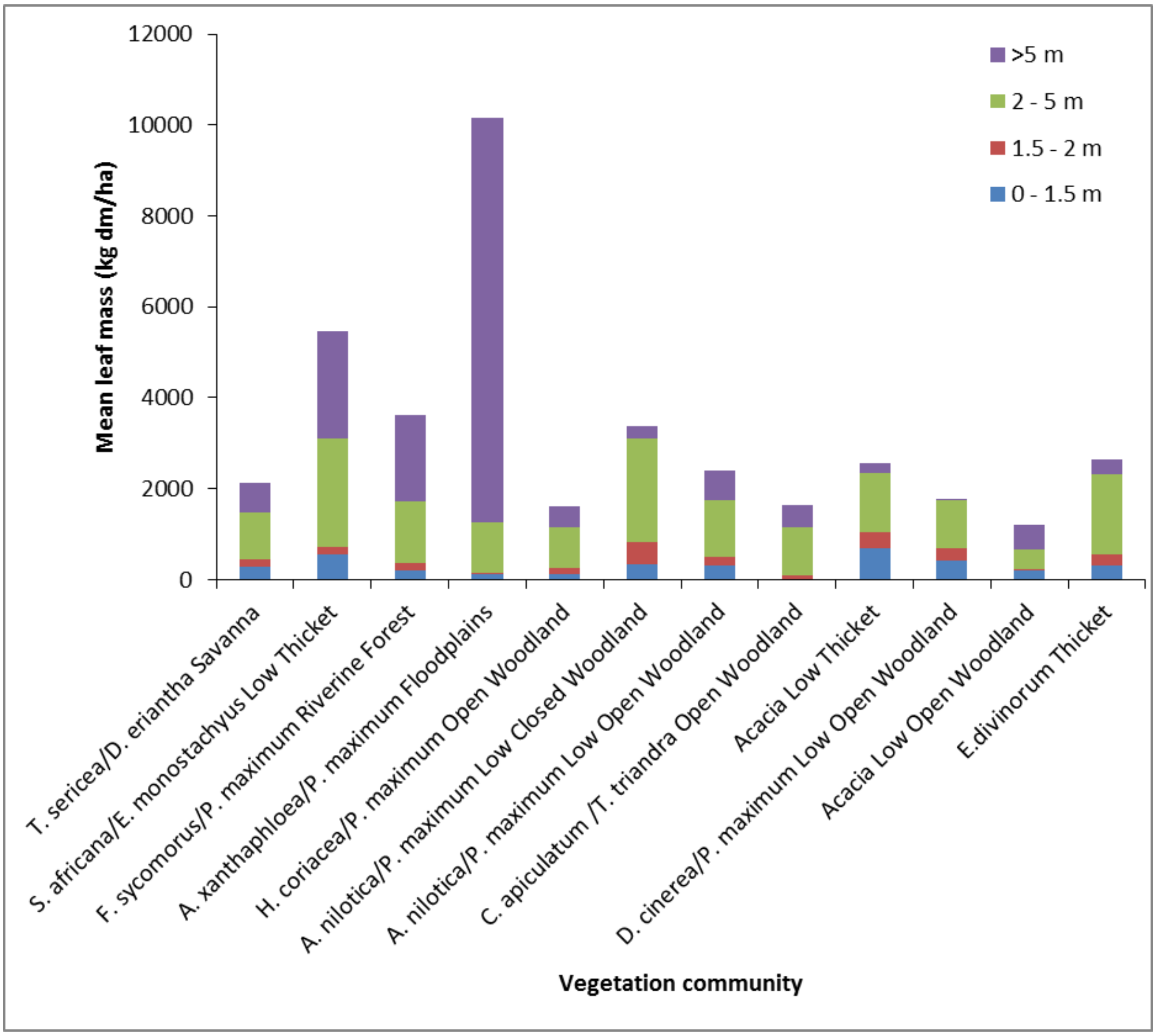


Figure 4.8 Mean estimated dry leaf mass for each vegetation community within the uMkhuze Game Reserve. (<1.5 m = estimated leaf dry mass below 1.5 m; 1.5 to 2 m = estimated leaf dry mass between 1.5 and 2 m; 2-5 m = estimated leaf dry mass between 2 and 5 m and >5 m = estimated dry leaf mass above 5 m).

4.3.2.1 Terminalia sericea/Digitaria eriantha Savanna

4.3.2.1.1 General description

A photograph of the vegetation typical to the *Terminalia sericea/ Digitaria eriantha S*avanna (*T. sericea/ D. eriantha S*avanna) vegetation community is presented in Figure 4.9.

Figure 4.9 Vegetation typical to the *Terminalia sericea/ Digitaria eriantha* Savanna vegetation community.

This vegetation community occupies 8% (or 2 945 ha) of the total area of the reserve (Figure 4.5). The undulating landscape that this community lies within tends to have very deep, well drained Aeolian formed soils. Unstructured Hutton and Clovelly soils dominated. Vegetation structural classification by Edwards (1983) describes this area mainly as woodland (ranging from Low Open Woodland to a Short Closed Woodland). Six vegetation transects were surveyed within this vegetation community.

4.3.2.1.2 Woody vegetation composition, structure and density

The woody vegetation species composition for this vegetation community is dominated by *Terminalia sericea*, *Combretum apiculatum* and *Carissa tetramera*. Other conspicuous species included *Balanites maughamii, Strychnos spinosa* and *Sclerocarya birrea.* The dominating height classes were those trees within 0 to 1.5 m high, where a mean of 68% of the trees were recorded. Very few trees (0.2%) were recorded above 5 m (Figure 4.7). The woody structure of this vegetation community tended to comprise approximately 13% in the lower canopy (1.5 to 2 m height class) and 18% in the 2 to 5 m height. In terms of biodiversity, this vegetation community has a fairly average tree species richness among sites, and, on average, 9 different tree species were identified (Figure 4.6). The observed tree densities for this unit ranged between approximately 1 360 and 13 520 plants/ha with an average of 5 174 plants/ha (Table 4.1).

The mean Evapotranspiration Tree Equivalents (ETTE/ha) for this unit is calculated to be at 10 347 ETTE/ha and the mean dry leaf mass is estimated to be 2 314 kg DM/ha, of which 27% is calculated to be located above the 5 m height class and is hence regarded as unavailable to any browsing herbivore (Table 4.1). Within the available browsing height (<5 m), 293 kg DM/ha (12%) available leaf mass is located within the <1.5 m height class, 162 kg DM/ha (7%) in the 1.5-2 m height class, and the remainder 1018 kg DM/ha (44%) in the 2-5 m height class (Figure 4.8). Total dry wood mass for this vegetation community is 30 155 kg DM/ha. The majority of woody shoots less than 0.5 cm in diameter are found within the 2-5 m height of the tree.

Table 4.1 Abundance of *A. nilotica* in terms of coverage, tree density, Evapotranspiration Tree Equivalents (ETTE) and leaf mass within the various vegetation communities. Numbers in red indicate those vegetation communities with highest (above 10%) density, volume and leaf mass.

Vegetation community	**Area of reserve_ha (%)**	***A. nilotica* density_pl/ ha (%)**	**Total tree density pl/ha**	***A. nilotica* volume ETTE/ha (%)**	**Total tree volume ETTE/ha (%)**	***A. nilotica* total leaf mass <5m_kgDM/ha**	**Total leaf mass <5m_kgDM/ha**
T. sericea/D. eriantha Savanna	2945 (8%)	0 (0%)	5174	0 (0%)	10347	0 (0%)	1691
monostachyus Low Thicket	2864 (7%)	22 (0.3%)	6869	5 (0.02%)	24420	1 (0%)	3239
F. sycomorus/P. maximum Riverine Forest	2268 (6%)	0 (0%)	940	0 (0%)	15899	0 (0%)	1709
A. xanthaphloea/P. maximum Floodplains	4642 (13%)	33 (2.4%)	1364	18.4 (0.04%)	41771	43 (3.3%)	1269
H. coriacea/P. maximum Open Woodland	79 (0.2%)	0 (0%)	500	0 (0%)	7544	0 (0%)	1139
A. nilotica/P. maximum Low Closed Woodland	4135 (12%)	971 (26.2%)	3702	6466 (44.4%)	14567	1520 (48.7%)	37118
A. nilotica/P. maximum Low Open Woodland	752 (2%)	662 (17.4%)	3814	1993 (18.8%)	10613	289 (16.6%)	174
C. apiculatum /T. triandra Open Woodland	5570 (16%)	87 (2%)	4272	176 (2%)	8703	41 (2.8%)	1451
Acacia Low Thicket	2348 (9%)	224 (6%)	3744	1393 (12.4%)	11253	327 (14%)	2339
D. cinerea/P. maximum Low Open Woodland	2512 (7%)	94 (2.1%)	4413	719 (9.4%)	7625	169 (9.7%)	1749
Acacia Low Open Woodland	3120 (8.5%)	250 (6.7%)	3729	145 (2.8%)	5238	33 (4.9%)	671
E.divinorum Thicket	4129 (11%)	0 (0%)	3511	0 (0%)	11590	0 (0%)	2316
Freshwater lakes and pans	339 (0.9%)	---	---	---	---	---	---

4.3.2.1.3 Browsing capacity

The browsing capacity for the woody plants within the *Terminalia sericea/ Digitaria eriantha* Savanna community type is presented in Figure 4.10.

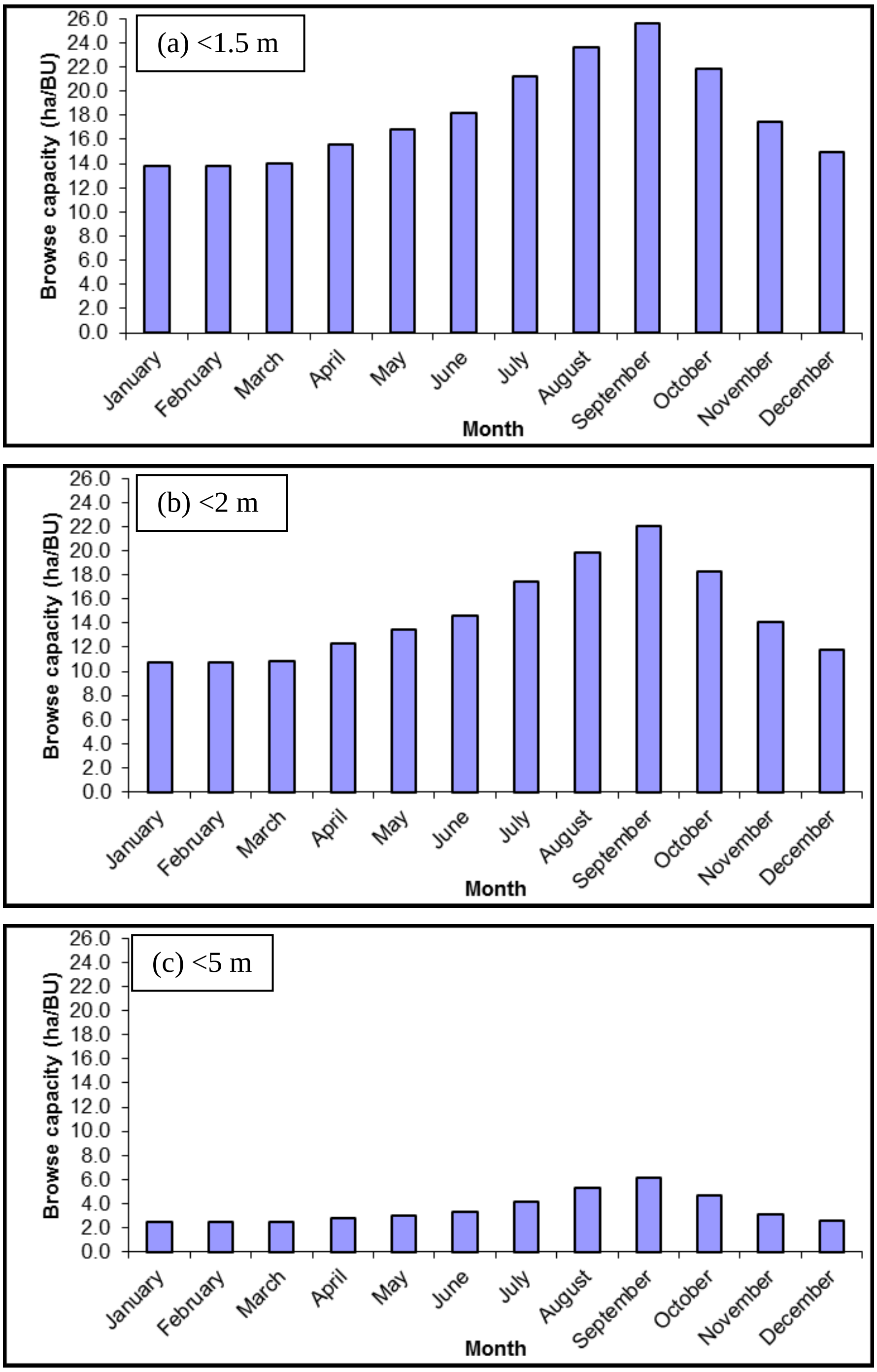


Figure 4.10 Browsing capacity for the three different height classes ((a) <1.5 m, (b) <2 m and (c) <5 m) within the *Terminalia sericea/ Digitaria eriantha* Savanna community type.

A distinct trend is visible throughout the three different browse classes where the browsing capacity is at its highest during January, February and March and at its lowest during September. Figure 4.10 illustrates the trends of the browsing capacity over the different months and provides the mean browsing capacity for each month. Within the <1.5 m height class, the browsing capacity is at its greatest during the summer months where it is recorded at 13.8 ha/BU, while during the critical period, it drops to 25.6 ha/BU. An 11.3 ha/BU difference is recorded between the peak and its lowest in the <2 m height class. Only a 4.7 ha/BU difference in available browse was calculated in the <5 m height class.

4.3.2.2 Spirostachys africana / Enteropogon monostachyus Thicket

4.3.2.2.1 General description

A photograph of the vegetation typical to the *Spirostachys africana* / *Enteropogon monostachyus* Thicket (*S. africana* / *E. monostachyus* Thicket) vegetation community is presented in Figure 4.11.

Figure 4.11 Vegetation typical to the *Spirostachys africana* / *Enteropogon monostachyus* Thicket vegetation community

One of the smaller vegetation management units are the *S. africana/E. monostachyus* Thickets. This community covers approximately 2 864 ha (7%) of the reserve and is scattered on the flatter areas throughout the entire reserve (Figure 4.5). This vegetation community is identified to be on a variety of soil types ranging from the well-drained Aeolian Clovelly, Hutton and Fernwood soil form, to the heavy-clayed black Bonheim soils of igneous origin. The well-drained soils are the most popular substrate for this habitat type. These soils are all generally very deep (all sites being greater than 500 mm deep) thereby allowing tree roots to grow down deep into the soil. The vegetation patterns of this unit, as described by Edwards (1983) are low thickets or woodlands, illustrating a low closed canopy cover within this vegetation community. Eight survey sites were surveyed within this vegetation community.

4.3.2.2.2 Woody vegetation composition, structure and density

In terms of biodiversity, this vegetation community has the greatest tree species richness among sites, and, on average, 14 different species were identified (Figure 4.6). Tree species that contributed most to the total density within this vegetation community were identified as *Spirostachys africana* and the three *Euclea* species: *E. undulata*, *E. divinorum* and *E. crispa*. Other conspicuous trees in this community were *Ziziphus mucronata* and *Pappea capensis*. The observed tree densities for this unit ranged between approximately 3 760 and 12 750 plants/ha with a high mean density of 6 869 plants/ha (Table 4.1). The thickets were dominated by trees in the >1.5 m height class (65%) and 11% in the 1.5 to 2m category, 20% in the 2 to 5 m height category and only 4% of the trees were taller than 5 m (Figure 4.7).

Considering that this vegetation community scored highest in the tree density category, it is expected of it to have a high ETTE/ha. The second highest mean ETTE/ha estimation of 24 420 ETTE/ha was calculated for this vegetation community (Table 4.1). This indicates that trees within this community grown in close proximity to one another with large tree canopies. The mean dry leaf mass is estimated at 5 475 kg DM/ha. Just over half of this quantity (59%) is available for browsers. Ten percent (544 kg DM/ha) of this leaf mass is located within the 0 to 1.5 m category. Within 1.5 to 2 m, 162 kg DM/ha (7%) browse is available and 44% (2 397 kg DM/ha) in the 2 - 5 m height range (Figure 4.8). Total available dry wood mass is estimated at a high 121 251 kg DM/ha. Very few (2% or 2 431 kg DM/ha) of the woody shoots are estimated to be less than 0.5 cm in diameter and most of the woody biomass is calculated from woody stems with diameters greater than 20cm where 103 627 kg DM/ha are in stems > 20 cm in diameter.

4.3.2.2.3 Browsing capacity

A large grouping of plants within this community are non-deciduous and therefore phenology of these plants remains fairly constant throughout the year. This explains for the low seasonal change in browsing capacity in both the <1.5 m (9.3 ha/BU-16.3 ha/BU) and <2 m (7.5 to 13.7 ha/BU) categories. Within the <5 m category, the range is even lower (0.8 to 1.4 ha/BU). This is supported by the fact that, apart from *S. africana*, the other big trees within these sites (*e.g. Euclea divinorum*, *E. undulata* and *Croton menyhartii*) are non-deciduous. This vegetation community produces the highest browsing capacity in both <1.5 m and <5 m height classes (means of 12.2 ha/BU and 1.1 ha/BU respectively) indicating that available browse is in abundance throughout all height classes within this group (Figure 4.12). The browsing capacity for the woody plants within the *Spirostachys africana* / *Enteropogon monostachyus* Thicket community type is presented in Figure 4.12.

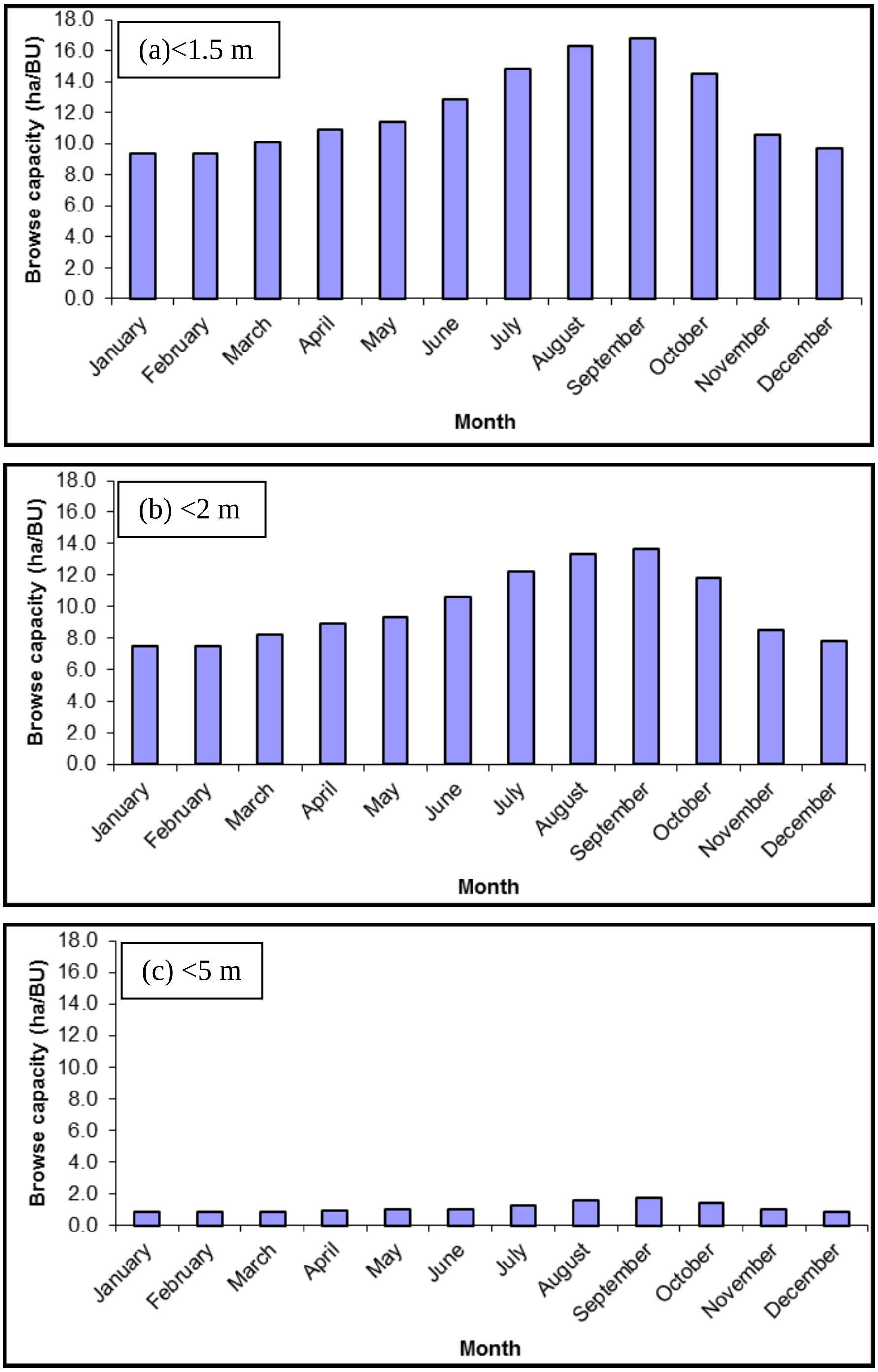


Figure 4.12 Browsing capacity for the three different height classes ((a) <1.5 m, (b) <2 m and (c) <5 m) within the *Spirostachys africana / Enteropogon monostachyus* Thicket vegetation community type.

4.3.2.3 Ficus sycomorus/Panicum maximum Riverine forest

A photograph of the vegetation typical to the *Ficus sycomorus/Panicum maximum* Riverine Forest (*F. sycomorus/P. maximum* Riverine Forest) vegetation community is presented in Figure 4.13.

Figure 4.13 Vegetation typical to the *Ficus sycomorus/Panicum maximum* Riverine Forest vegetation community.

4.3.2.3.1 General description

Another smaller community within the reserve, this 2 268 ha (6%) area of vegetation is found all along the main river paths within the reserve (Figure 4.5). This vegetation grows on deep (>800 mm) soils of alluvial origin (Dundee and Oakleaf). As described by Edwards (1983), this vegetation community is mainly classified as tall open woodland. Only 2 transects were surveyed within this riparian area.

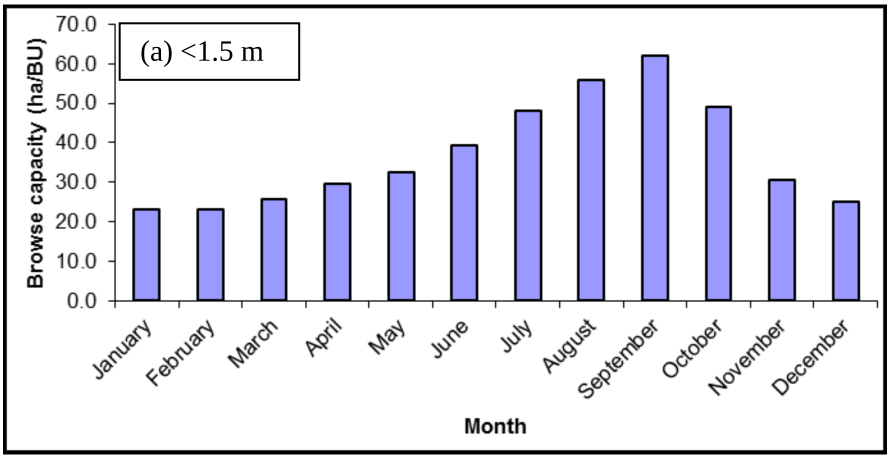
4.3.2.3.1 Woody vegetation composition, structure and density

Species richness recorded for these sites was ranked as one of the lowest within the reserve, with an average of 4 species recorded for each site (Figure 4.6). Dominating tree species that contributed most to the total density within this vegetation community were identified as *Ficus sycomorus*, a tree symbolic to the riverine areas within uMkhuze. Alien invasive species, *Chromolaena odorata* and *Lantana camara* were also evident within these sites and should be managed accordingly to prevent further infestation. The structure of these riverine areas tended to comprise very tall trees, which made up almost 14% of the vegetation. A 30% mean of the trees fell below the 1.5 m height class. The trees at 1.5 to 2m and 2 to 5 m canopy heights contributed to 47% and 9% respectively.

The riverine forest is very low (mean of 940 plants/ha) in tree density and fairly high in ETTE/ha (15 899 ETTE/ha), suggesting that it is a vegetation community with few extremely large trees (Table 4.1). The mean estimated leaf mass for these riverine forests is 3 616 kg DM/ha and only 47% of this is available to any form of browsers. Only 198 kg DM/ha (5%) of the estimated leaf mass is utilizable to animals under 1.5 m. Only 154 kg DM/ha leaf mass is estimated to be available to animals in the 1.5-2 m category, while 1357 kg DM/ha (38%) dry leaf mass is available in the 2 to 5 m height class (Figure 4.8). Available dry wood mass for twigs <0.5 cm in diameter, is calculated at 96 004 kg DM/ha. According to BECVOL calculations, only 1 186 kg DM/ha of these shoots are found very low to the ground (0 to 1.5 m), a low 227 kg DM/ha is estimated in the 1.5 to 2 m class. The majority (80 240 kg DM/ha) of dry wood mass is expected to be found in the stems that are > 20 cm in diameter.

4.3.2.3.2 Browsing capacity

This *Ficus sycomorus* dominated community comprises a far lower number of trees per unit area (although they are mostly very tall) than most groups. This is depicted by the much lower browsing capacity of the <1.5 m category (mean of 37.1 ha/BU) compared to the mean of 12.6 ha/BU in the <2 m category or the very high browsing capacity mean on 3.3 ha/BU in trees <5 m. The result of Ficus trees losing all their leaves over late winter is illustrated in the more than three times drop in browsing capacity throughout the <5 m class (*i.e.* from 1.9 ha/BU to 6.5 ha/BU) (Figure 4.14). The browsing capacity for the woody plants within the *Ficus sycomorus/Panicum maximum* Riverine Forest community type is presented in Figure 4.14.



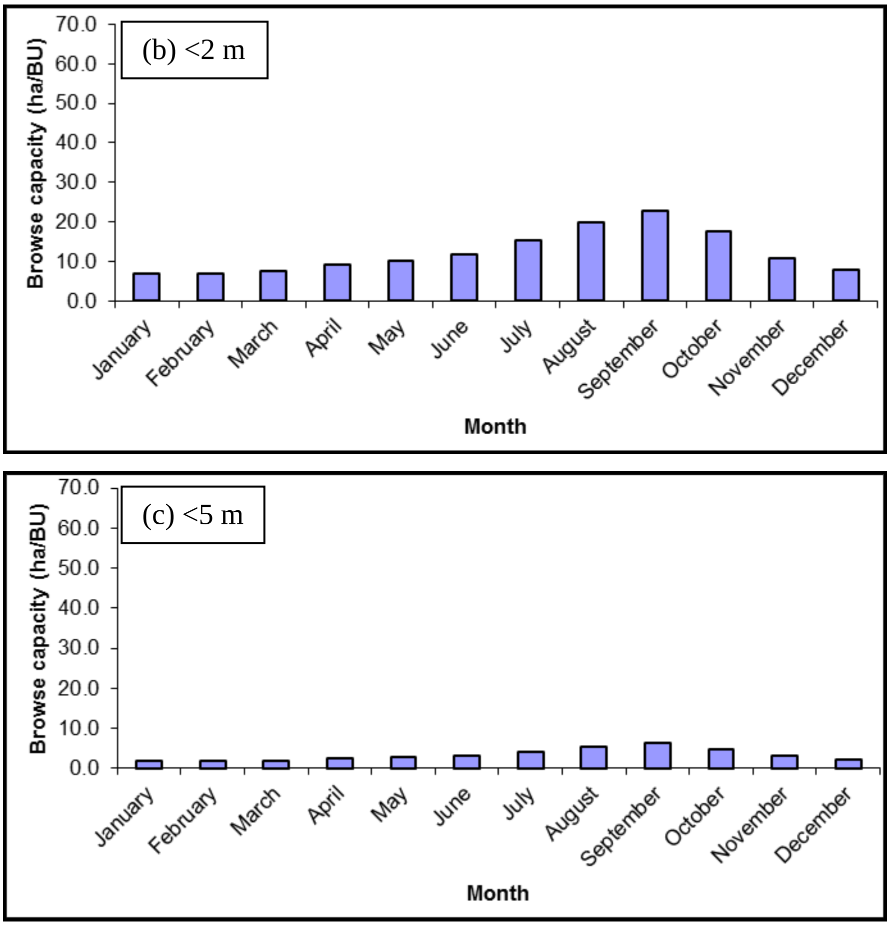


Figure 4.14 Browsing capacity for the three different height classes ((a) <1.5 m, (b) <2 m and (c) <5 m) within the *Ficus sycomorus/Panicum maximum* Riverine Forest vegetation community type.

4.3.2.4 Acacia xanthophloea/Panicum maximum River Floodplains

A photograph of the vegetation typical to the *Acacia xanthophloea/Panicum maximum* River Floodplains (*A. xanthophloea/P. maximum* River Floodplains) vegetation community is presented in Figure 4.15.

Figure 4.15 Vegetation typical to the *Acacia xanthophloea/Panicum maximum* River Floodplains vegetation community.

4.3.2.4.1 General description

On the flatter floodplain areas, tall *Acacia xanthophloea* trees dominate the area. Within this fairly large area of 4 642 ha (12.7% of the reserve) soils were a combination of Aeolian (Dundee) and Igneous (Inhoek) formations. The soils in this area tended to be very deep (> 800 mm) and of high clay consistency (15 to 55%) thereby allowing deep root growth of these tall trees. The vegetation patterns dominating this vegetation community, as classified by Edwards (1983) can be described as Tall Forest or Tall Open Woodland, indicating that the predominant tree height class fell between the 10- 20 m height class, with a 1 to 10% canopy cover. Five transects were surveyed within the floodplain area.

4.3.2.4.2 Woody vegetation composition, structure and density

Tree species richness recorded for these sites were some of the lowest within the reserve, on average, with 4 tree species being identified within these areas (Figure 4.6). Tree species that contributed most to the total density within this vegetation community were identified as *Acacia xanthophloea*. Other conspicuous woody plants within this area were *Azima tetracantha*. The structure of this vegetation community comprised a large portion (51%) of trees with a canopy height at 0 to 1.5 m and 40% of the site consisted of very high *A. xanthophloea* trees above the 5 m height class. A very low portion of the trees had a canopy height between 1.5 to 5 m, where only 4% fell into the 1.5 to 2 m height class and 5% at a canopy height within 2 to 5 m (Figure 4.7). A fairly high range was noted in the tree density between sites of this community, where tree density varied from 320 trees/ha in Site 61, to 2 750 plants/ha in Site 64. On average, the mean tree density for this vegetation community was 1 364 plants/ha (Table 4.1).

The structure of the floodplain areas is such that a few tall *A. xanthophloea* trees dominate this community with a few other woody plant species. This is illustrated by the low mean species richness of 4 species per site (Figure 4.6). Tree density for this community is fairly low (1 364 trees/ha) while the leaf biomass/ha (ETTE/ha) figures are at the opposite extremes (Table 4.1). The leaf biomass/ha (ETTE/ha) of 41 771 ETTE/ha is the highest among all vegetation groups. This portrays the structure of the community to having relatively few, but very large trees, indicative of an area dominated by *A. xanthophloea*. The majority (8 884 kg DM/ha or 88%) of the dry leaf mass falls above the available browse height (> 5 m) and therefore cannot be regarded of any use for browsers within the reserve. A low 115 kg DM/ha was recorded for the 0 to 1.5 m height class, while only 38 kg DM/ha is estimated within the 1.5 to 2 m zone. Within 2 to 5 m, a slightly higher leaf mass was recorded (1 116 kg DM/ha to 11%) (Figure 4.8). Total available dry wood mass, as expected with such big trees, scores the highest values amongst all the vegetation classes. These floodplain areas are estimated to produce approximately 322 829 kg DM/ha, and the majority of wood mass being produced from stems > 20 cm in diameter. Here an estimated 477 305 kg DM/ha wood is produced. Within the shoots with a diameter > 0.5 cm, a very low portion (178 kg DM/ha) is produced in the area under 1.5 m of the trees, and 132 kg DM/ha in the 1.5 to 2 m height. Within 2 to 5 m, 824 kg DM/ha is estimated. The rest of the small shoots are found within 5 m and above of the trees in this vegetation community.

4.3.2.4.3 Browsing capacity

Acacia xanthophloea/Panicum maximum River Floodplains are another vegetation community comprising mainly very tall deciduous trees. This is observed by the extremely low browsing capacity in both the <1.5 m and the 2 m browse groups. In the peak growing season the browsing capacity of browse available lower than 1.5 m is at its highest of 191.9 ha/BU. This is then lowered to 381.5 ha/BU over September. This is the lowest browsing capacity within the entire reserve. A very similar trend is seen with the browse <2 m (Figure 4.16). The structure of these trees is such that the leaf cover is mostly found in the upper canopy area of these trees (which tends to be right at the top of these tall-growing trees. These results are accredited to the fact that very few young *A. xanthophloea* trees were recorded within these sites and hence the canopies of these trees were all very high up. The browsing capacity for the woody plants within the *Acacia xanthophloea/Panicum maximum* River Floodplains community type is presented in Figure 4.16.

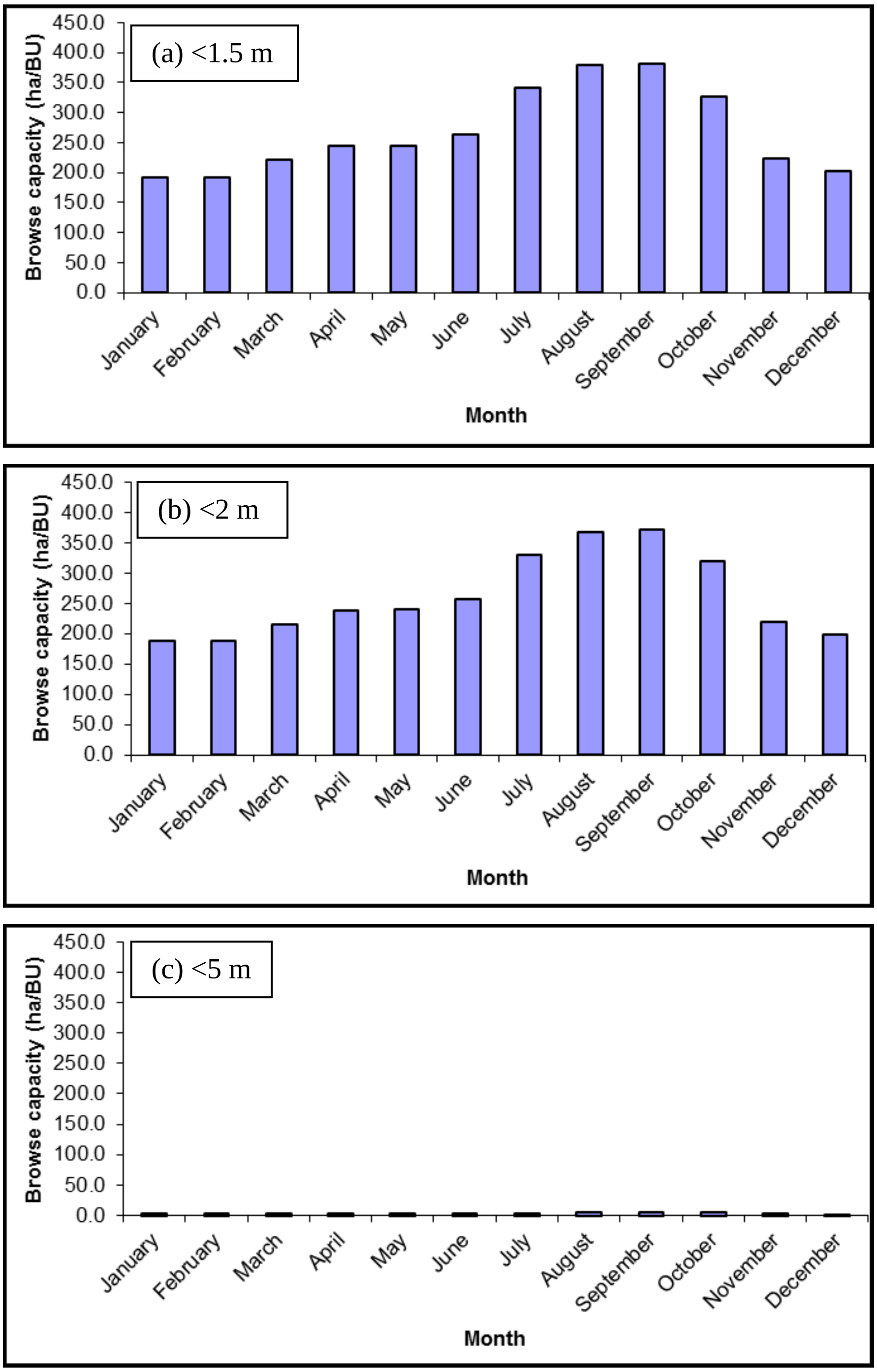


Figure 4.16 Browsing capacity for the three different height classes (<1.5 m, <2 m and <5 m) within the *Acacia xanthophloea/Panicum maximum* River Floodplains vegetation community.

4.3.2.5 *Hyphaene coriacea /Panicum maximum Woodland*

A photograph of the vegetation typical to the *Hyphaene coriacea /Panicum maximum* Woodland (*H. coriacea /P. maximum* Woodland) vegetation community is presented in Figure 4.17.

Figure 4.17 Vegetation typical to the *Hyphaene coriacea /Panicum maximum* Woodland vegetation community.

4.3.2.5.1 General description

This small patch of *Hyphaene coriacea* dominated veld occupies 79 ha of Aeolian derived landscape in the far south east portion of the reserve (Figure 4.5). Soils within this region have very little structure (Huttons), are low in clay (10-15%) and are very deep (>800 mm). This Low Closed Woodland, as described by Edwards (1983) contains vegetation mainly in the 2 to 5 m height class due to the abundance of *H. coriacea*, a low growing palm species. Since it occupies such a small area of the reserve, only one transect was surveyed within this veld management unit.

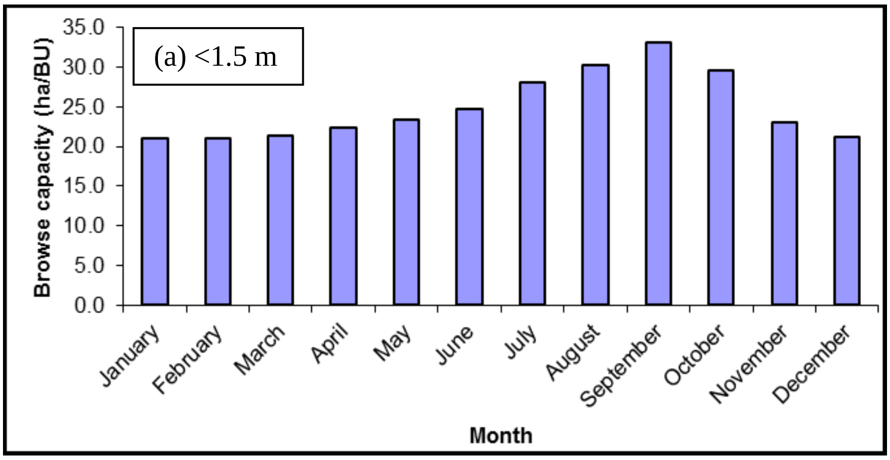
4.3.2.5.2 Woody vegetation composition, structure and density

The woody vegetation species composition for the palm veld is dominated by *H. coriacea*, (the Ilala palm), while other conspicuous species are *Sclerocarya birrea* and *Terminalia sericea*. The structure of these palm veld communities tends to comprise 33% of the trees in the 0 to 1.5 m and 17% in the 1.5 to 2 m height class. The *H. coriacea* palm occupied much of these classes. Other trees such as the *T. sericea* contributed to the taller canopy classes (2 to 5 m and 5 m). These classes contributed the same values as with the 0 to 1.5 m and 1.5 to 2 m with a mean of 33% and 17% respectively (Figure 4.7). In terms of biodiversity, the palm veld region (Plot 54) has a fairly low tree species richness among sites, where only 5 indigenous tree species were identified (Figure 3). The observed tree density for this unit was calculated to be 500 plants/ha (Table 4.1).

These woodlands are recorded to have the lowest tree density (500 plants/ha) and second lowest tree leaf biomass/ ha (7 544 ETTE/ha) within the reserve. These results are as expected, since visually, the majority of these trees are short, and small canopied *H. coriacea*, which grows in a very sparse vegetation pattern. A low dry leaf mass (1 671 kg DM/ha) is also recorded for this site (Table 4.1). From this total leaf mass, an estimated 125 kg DM/ha is found below 1.5 m, 130 kg DM/ha between 1.5 to 2 m and 884 (53%) within 2 to 5 m. The remaining 32% is estimated to be in the high branches, above 5 m. Wood mass, at 21 031 kg DM/ha is also the lowest of all the vegetation communities. 17 214 kg DM/ha of this is found in branches > 20 cm in diameter.

4.3.2.5.3 Browsing capacity

The Ilala palm (*Hyphaene coriacea)* is an evergreen tree of low palatability and is found in abundance within these vegetation communities. *Strychnos madagascarensis*, a taller, completely deciduous tree is often found in these communities. The combination of the two dominating tree species illustrated a fairly small range between browse capacities during seasonal change. In the lower than 1.5 m category, this ranges from 21.1 to 33.1 ha/BU. A much higher browsing capacity is estimated for the 2 to 5 m browse class where there was only a 5 ha/BU difference between the growing and winter seasons (10.2 to 16.2 ha/BU). Browsing capacity was, again, a lot higher in the above 5 m category where only a slight range from 2.3 to 4.1 ha/BU was estimated (Figure 4.18). The browsing capacity for the woody plants within the *Hyphaene coriacea /Panicum maximum* Woodland community type is presented in Figure 4.18.



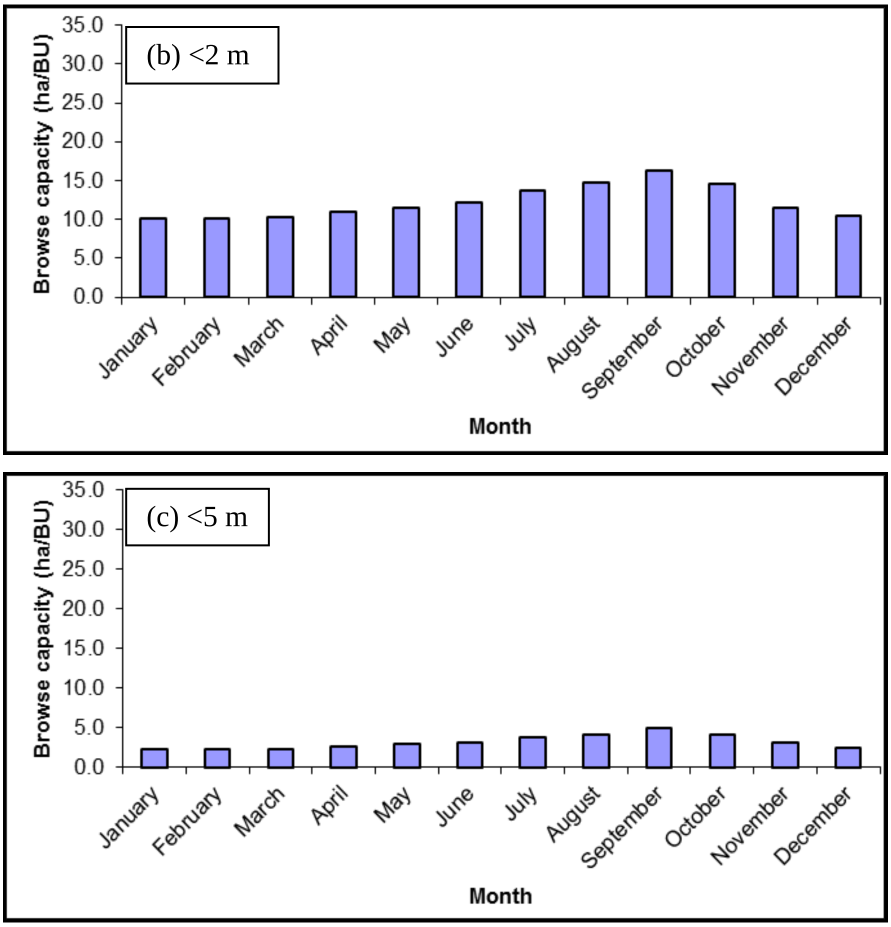


Figure 4.18 Browsing capacity for the three different height classes (<1.5 m, <2 m and <5 m) within the *Hyphaene coriacea /Panicum maximum* Woodland vegetation community.

4.3.2.6 Acacia nilotica/ Panicum maximum Low Closed Woodland and Acacia nilotica/ Panicum maximum Low Open Woodland

A photograph of the vegetation typical to the *Acacia nilotica/ Panicum maximum* Low Closed Woodland (*A. nilotica/ P. maximum* Low Closed Woodland) and *Acacia nilotica/ Panicum maximum* Low Open Woodland (*A. nilotica/ P. maximum* Low Open Woodland) vegetation communities are presented in Figures 4.19 and 4.20.

Figure 4.19 and 4.20 Vegetation typical to the *Acacia nilotica/ Panicum maximum* Low Closed Woodland (left) and *Acacia nilotica/ Panicum maximum* Low Open Woodland (right) vegetation community.

4.3.2.6.1 General description

The *Acacia nilotica/ Panicum maximum* Low Closed Woodland (LCW) and *Acacia nilotica/ Panicum maximum* Low Open Woodland (LOW) have been grouped together for convenience purposes as species composition and description of the two groups are very similar. The LCW is one of the larger (4135 ha/ 12%) vegetation communities within the reserve, while the LOW is the second smallest covering a total area of approximately 2% or 752 ha (Figure 4.5). These vegetation communities occur on the flatter areas throughout the reserve, mainly on heavy clayed soils of igneous origin. Soils are generally deep (>500 mm) and of the Valsrivier/Swartland or Hutton soil form. The LOW differed from the LCW in terms of the difference in canopy cover (LCW generally had a 10 to 75% canopy cover while LOW experiences a 1 -10% canopy cover) by Edwards (1983). A total of 16 LCW sites and 4 LOW sites were identified through the survey. There is a good possibility that, over time, and through succession, the LOW sites would thicken up to become LCW.

4.3.2.6.2 Woody vegetation composition, structure and density

The assessment of species richness for the LCW sites was ranked fairly high over the 10 sites, with an average tree richness of 8 (Figure 4.6). This is only one higher than the average species richness scored for the LOW, where an average of 7 species was recorded (Figure 4.6). Tree species which contributed most to the total density were similar in both vegetation communities. *Euclea divinorum, Acacia nilotica* and *Dichrostachys cinerea* are regarded as the dominating species within all the sites. Other species characteristic of these units included *Ziziphus mucronata*. Within the LCW, tree density ranged from 640 to 6 800 plants/ha. The mean tree density of 3 702 plants/ha is calculated for this vegetation community (Table 4.1). The LOW has a much lower tree density range (3 000 to 5 083 plants/ha) with a mean of 3814 plants/ha (Table 4.1). Structurally, these vegetation communities were very similar with the dominating tree height being in the 0 -1.5 m category (60% in LCW and 79% in LOW). Seven percent of the community structure for the LCW fell in the 1.5- 2 m height class while 3% for LOW (Figure 4.7). Trees of a 2 to 5 m height contributed to 31% and 16% within the LCW and LOW woodland respectively. Finally, only 2% of the trees were found to be in the 1.5 to 2 m height classes for LCW and 2% for the LOW (Figure 4.7).

The volume of the trees varied considerably between the LCW and the LOW. A high leaf biomass of 14 567 ETTE/ha is expected in the LCW, while a slightly lower 10 613 ETTE/ha in the more open *Acacia* woodlands (LOW). When comparing the two groups, there was not a large difference between the LCW and LOW. Within these categories, a total dry leaf mass of 3 369 kg DM/ha is estimated for the LCW and 2 404 kg DM/ha for the LOW. In both groups, the majority of the leaf mass is recorded 2 to 5 m above ground level. A mean of 67% (or 2 273 kg DM/ha) and 1 234 kg DM/ha (51%) of leaf mass is estimated for the LCW and LOW respectively. A low 10% and 13% leaf mass is estimated for the canopy leaf mass within the LCW and LOW, lower than 1.5 m while a mean of 500 kg DM/ha (15%) and 200 kg DM/ha (8%) is the mean predicted leaf mass for the tree canopies within the 1.5 m to 2 m height class. Woody plant mass for the LCW, as expected, is a lot higher than in the LOW (88 499 kg DM/ha for LCW and 54 473 kg DM/ha for the LOW. Along with the ETTE, this indicates that, in general, tree volume in the LCW is greater than that in the LOW. At a branch level of 0 to 1.5 m above ground level, relatively the same low wood mass is recorded for both LCW and LOW (395 and 304 kg DM/ha respectively). The big difference in wood stem mass is observed above 1.5 m in both these vegetation communities. In the LCW, a mean wood mass of 664 kg DM/ha is estimated for the 1.5 to 2 m group. In the LOW, a much smaller 246 kg DM/ha is recorded, and the 2 to 5 m above ground level category predicts approximately half the weight of the LCW estimates at 1 518 kg DM/ha. As with all the other vegetation groups, the woody plant mass of branches > 20 cm in diameter contribute greatly to the overall tree biomass. A mean of 71 597 kg DM/ha and 44 177 kg DM/ha is the estimated mean for the LCW and LOW respectively.

4.3.2.6.3 Browsing capacity

Both these vegetation communities displayed very similar trends although the browsing capacity within the 1.5 m height class of the low open woodlands declined far more steeply over winter (26 ha/BU to 124.5 ha/BU) than with the LCW (10.2 ha/BU to 25.7 ha/BU). This occurs since a higher portion of *E. divinorum* inhabits in the denser areas of the LCW than that of the LOW (Figure 4.21). As mentioned before, *E. divinorum* is non-deciduous and therefore is not affected as much by seasonal phenology because it does not lose its leaves during the winter season. Within the lower than 2 m category, the browsing capacity ranged from 3.7 to 10.7 ha/BU in the LCW while the LOW produced a browsing capacity ranging from 14.3 ha/BU to a low 54.0 ha/BU. Within the 2 to 5 m height of browse, an estimated range of 1.5 to 4.3 ha/BU and 2.8 to 9.6 ha/BU was expected for the LCW and LOW respectively (Figure 4.22 and 4.23).

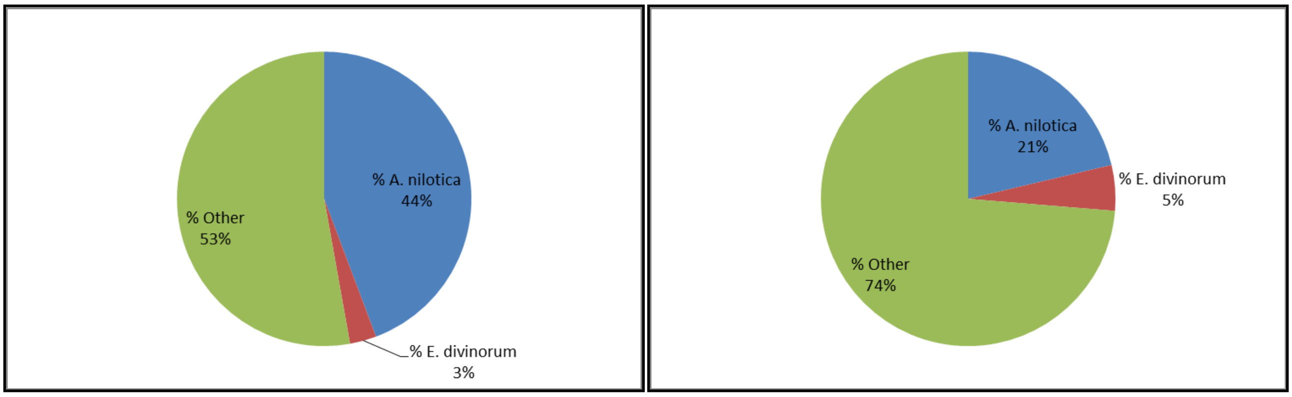
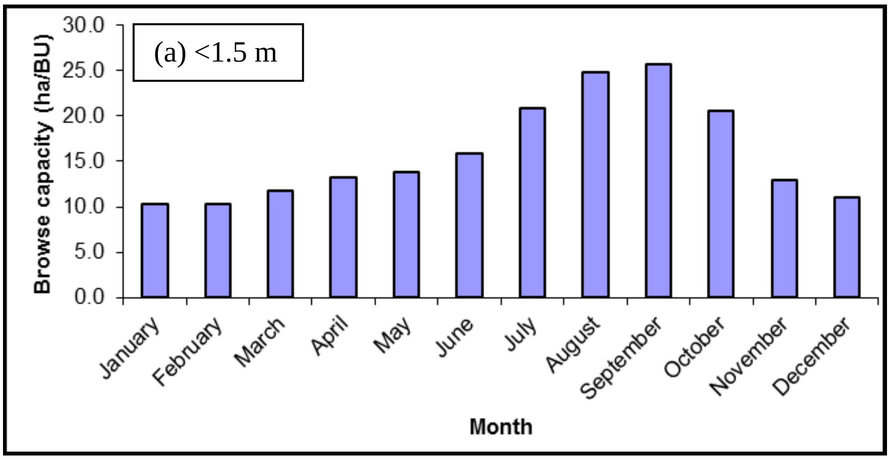
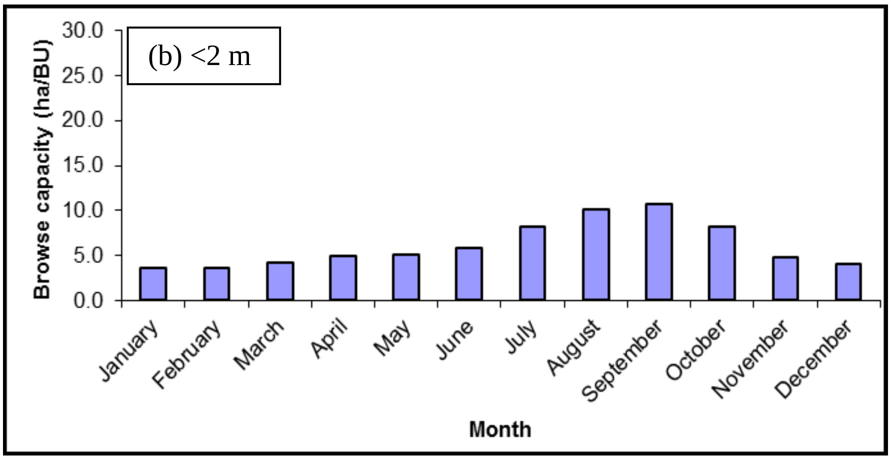


Figure 4.21 Contribution of *A. nilotica* and *E. divinorum* to the Low Closed (a) and Low Open (b) Woodland community within the reserve.

The browsing capacity for the woody plants within the *Acacia nilotica/ Panicum maximum* Low Closed Woodland community type is presented in Figure 4.22.





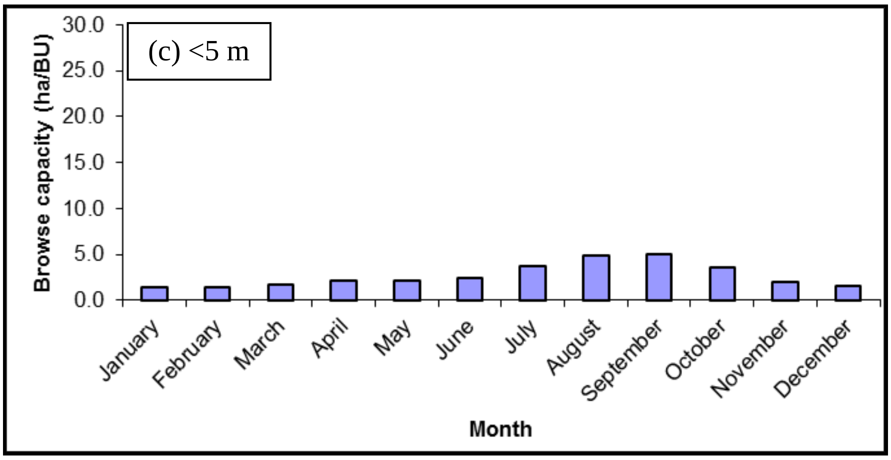
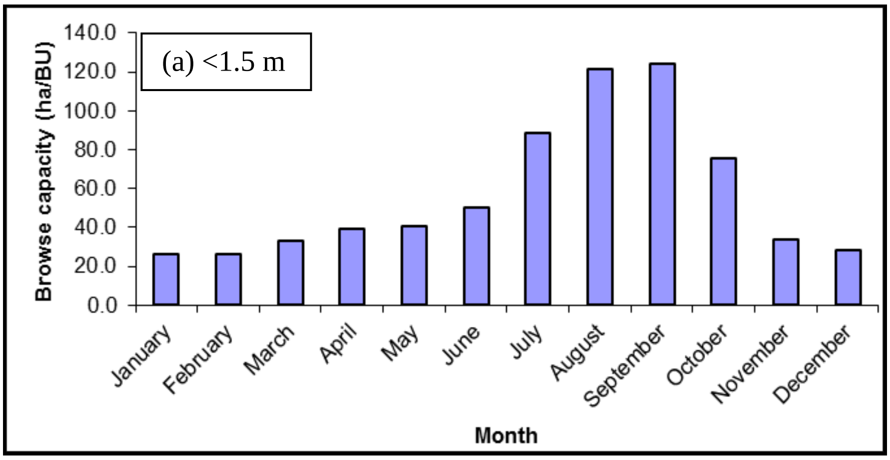


Figure 4.22 Browsing capacity for the three different height classes (<1.5 m, <2 m and <5 m) within the *Acacia nilotica/ Panicum maximum* Low Closed Woodland vegetation community.

The browsing capacity for the woody plants within the *Acacia nilotica/ Panicum maximum* Low Open Woodland community type is presented in Figure 4.23.



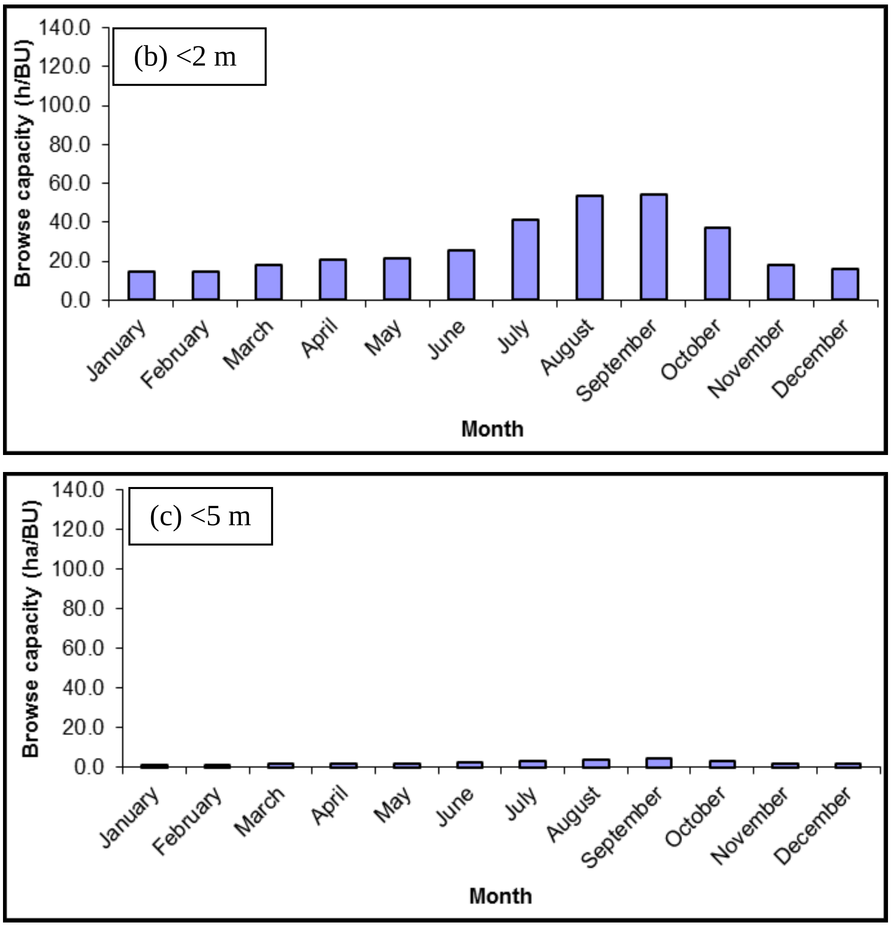


Figure 4.23 Browsing capacity for the three different height classes (<1.5 m, <2 m and <5 m) within the *Acacia nilotica/ Panicum maximum* Low Open Woodland (LOW) vegetation community.

4.3.2.7 *Combretum apiculatum/ Themeda triandra* Open Woodland

A photograph of the vegetation typical to the *Combretum apiculatum/ Themeda triandra* Open Woodland vegetation community is presented in Figure 4.24.

Figure 4.24 Vegetation typical to the *Combretum apiculatum/ Themeda triandra* Open Woodland (*C. apiculatum/ T. triandra* Open Woodland) vegetation community.

4.3.2.7.1 General description

The *C. apiculatum/ T. triandra* Open Woodland is the largest homogenous vegetation community found on the reserve, totalling an area of approximately 5 670 ha (or 16% of the reserve) (Figure 4.5). This vegetation occurs on the upper westerly regions of the reserve, in the Lebombo mountains. Soils found here were of igneous origin and included Mispah, Cartref and Glenrosa soil forms. These soils are found to be fairly shallow (200 to 500 mm) and well drained. These soil properties often promote stunted vegetation growth, and limited tree growth. The vegetation pattern of this community, as described by Edwards (1983), is predominantly Open Woodland. A total of 11 survey sites were surveyed within this vegetation community (Figure 4.5).

4.3.2.7.2 Woody vegetation composition, structure and density

The woody vegetation species composition for the *C. apiculatum/ T. triandra* open woodland is dominated by *C. apiculatum*, and *Sclerocarya birrea*. Other conspicuous species included *Ziziphus mucronata* and *Acacia gerrardii*. Kudu lilies (*Adenium spp.*) were also very conspicuous on the hill slopes of Site 58. The structure of these woodlands tended to comprise many smaller trees (approximately 87%) in the lower canopy (0 to 1.5 m) height class. A few dominant large (> 5 m) trees formed the highest canopy and made up for a further 4%. Very few trees (4%) were recorded in the 1.5-2m height class, while 5% contributed to the 2 to 5 m height class (Figure 4.7). In terms of biodiversity, this Open Woodland area contained on average, 8 different woody plant species (Figure 4.6). The observed tree densities for this unit ranged between 1 520 in Site 1 and 8 880 plants/ha in Site 57 with a mean of 4 272 plants/ha (Table 2). A high mean volume of 8 702 ETTE/ha is estimated for the sites within this community (Table 4.1).

Dry leaf mass for *C. apiculatum* veld is fairly low with an estimated mean of 1 938 kg DM/ha (Table 4.1), of which 313 kg DM/ha (16%) is estimated to fall within the height of 0 to 1.5 m and 99 kg DM/ha in the middle zone of available browse (1.5 to 2 m). 1 038 kg DM/ha (54%) fell within 2 to 5 m from the ground and 488 kg DM/ha (25%) above the 5 m zone, and of no browse potential to any browsers (Figure 4.8). Stems/ twigs with a diameter of less than 0.5 cm produced an average of 34 458 kg DM/ha, of which an estimated mean of 292 kg DM/ha falls below the 1.5 m height mark. A low mean is found within 1.5 to 2 m above ground level, while a high mean of 1 163 kg DM/ha with 2 to 5 m above ground level. The remainder (32 895 kg DM/ha dry wood mass) is found above 5 m. A high proportion (28 325 kg DM/ha) of branches > 20 cm diameter are also recorded on these trees.

4.3.2.7.3 Browsing capacity

In all the height classes within this vegetation community, a very steep trend in browsing capacity is observed. This vegetation community has a slightly higher browsing capacity than many of the others and has a very similar browsing capacity between the <1.5 m and <2 m heights. This vegetation group comprises fairly tall *Combretum* trees and shorter saplings and shrubs within 1.5 m. Very few trees fall into the 1.5 to 2 m category which explains the similar values. In the <1.5 m category, the browsing capacity ranges from 20.3 ha/BU to 64.5 ha/BU while the <2 m has a range from 13.9 ha/BU to 44.8 ha/BU (Figure 4.25). A large difference is noted in the <5 m height zone where the browsing capacity ranges from 2.8 ha/BU to 9.6 ha/BU. Fluctuations of the browsing capacity between seasons are fairly large since the dominating species, C. *apiculatum* is deciduous and many of the other species (*e.g. A. gerrardii* and *S. birrea*) within this category are also deciduous. The browsing capacity for the woody plants within the *Combretum apiculatum/ Themeda triandra* Open Woodland community type is presented in Figure 4.25.

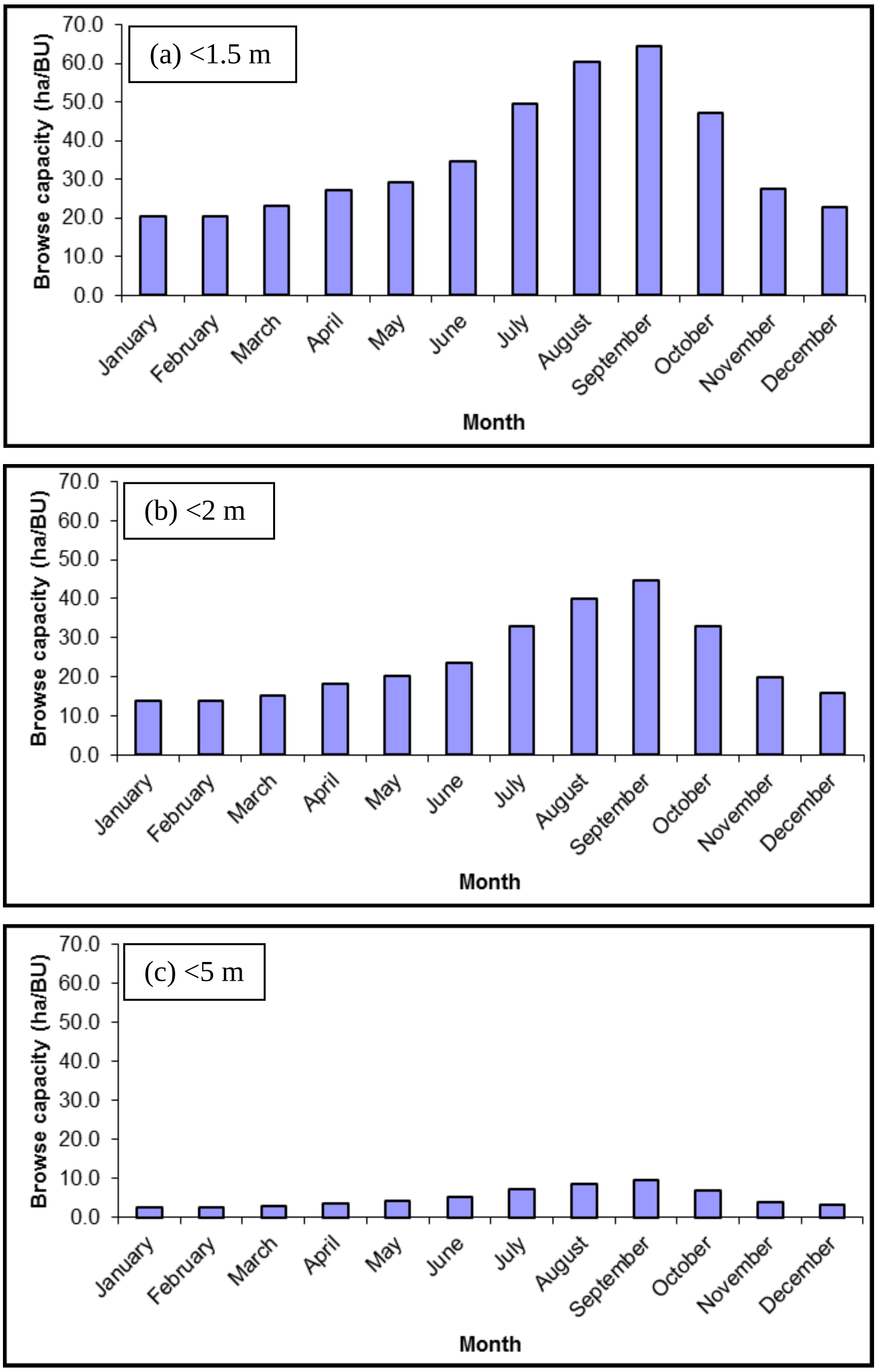


Figure 4.25 Browsing capacity for the three different height classes (<1.5 m, <2 m and <5 m) within the *Combretum apiculatum/ Themeda triandra* Open Woodland vegetation community.

4.3.2.8 Acacia Low Thicket and Acacia Low Open Woodland

Photograph of the vegetation typical to the Acacia Low Thicket and Acacia Low Open Woodland vegetation communities are presented in Figure 4.26 and 4.27.

Figure 4.26 and 4.27 Vegetation typical to the Acacia Low Thicket (LT) (left) and Acacia Low Open Woodland (LOW) (right) vegetation community.

4.3.2.8.1 General description

These two communities were also combined for descriptive purposes due to the similar occurrence of plant species within the sites. Fairly high (approx. 3 248 ha/ 9%) proportions of the reserve were identified as Low Thicket (LT) and Low Open Woodland (LOW) (2 512 ha/ 7%) (Edwards 1983) (Figure 4.5). These vegetation communities consisted largely of a variety of *Acacia* species (including *Acacia nigrescens*, and *A. nilotica*) and *Gymnosporia heterophylla*. These units fall in a combination of very high clay (35-55%) Inhoek soils to slightly lower clay (15-35%) Hutton and Shortlands and Milkwood soil forms, all of igneous origin. These soils are also very deep (>500 mm). The vegetation pattern, as described by Edwards (1983) is classified as a Low Thicket, where an encroachment of thorn trees has occurred. A total of 6 survey sites were surveyed within this vegetation community. The classification of Low Open Woodland describes an area where the average tree is between 2- 5 m tall and a 1 to 10% canopy cover.

4.3.2.8.2 Woody vegetation composition, structure and density

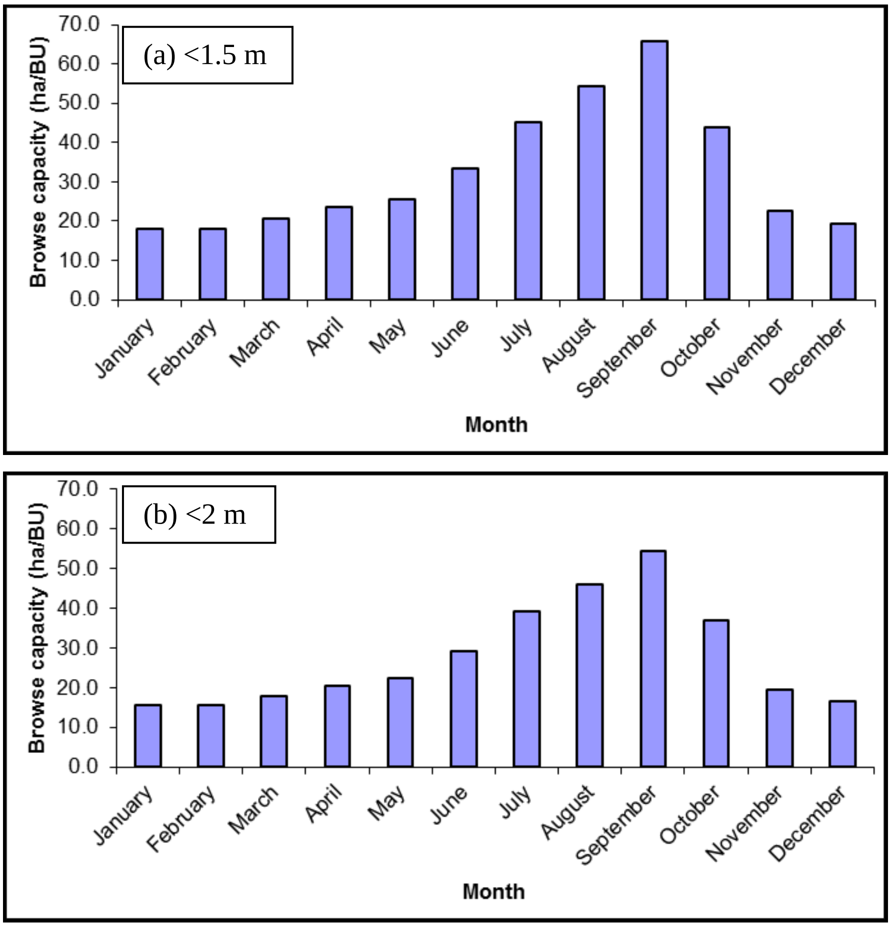
Species richness recorded for the LT scored a much higher mean value of 11 compared to the 6 species richness scored in the LOW (Figure 4.6). A mixture of *Acacia* species were found within these sites in the LT, although the *A. grandicornuta, A. luederitzii* and *Euclea divinorum* contributed largely to the tree density calculations. Other species that were found in the area were *A. nilotica, Sideroxylon inerme* and *Salvadora angustifolia*. *Acacia nigrescens* and *A. nilotica* were more prominent in the LOW. Within the LT tree density ranged from 1 760 to 6 080 plants/ha. A mean tree density of 3 744 plants/ha is calculated for this vegetation community (Table 4.1). The LOW is slightly different with a much lower tree density range (2 400 to 7 417 plants/ha) with a mean, not much lower to that of the LT, of 3 729 plants/ha (Table 4.1). Structurally, these vegetation communities were very different with the dominating tree height being less than 1.5 m in the LT, scoring 66% of all the tree height in the vegetation structure, while the dominating height class is the 0 to 1.5 m above ground level (94%) in the LOW. Only 0.2% is estimated for 1.5 to 2 m in the LOW and a higher 11% for the 1.5 to 2 m height category of the LT (Figure 4.7). In the LOW, approximately 2% of the vegetation fell in the 2 to 5 m category, while 20% was found in the LT. Finally, in the canopy class above 5m, a mean of 4% was estimated for the LOW, and only 2% for the thicket community.

These thicket areas are recorded to have an estimated tree volume of 11 253 ETTE/ha, whereas the LOW recorded the lowest tree volume within all site with 5 238 ETTE/ha. One of the reasons for this is that it has a very low canopy cover and therefore takes up a much smaller volume. Mean dry leaf mass for the *Acacia* low thicket is calculated at a 2 574 kg DM/ha, of this 678 kg DM/ha (26%) is allocated to the 0 to 1.5 m above ground level category. A mean of 366 kg DM/ha (14%) is predicted for 1.5 to 2 m and (1 295 kg DM/ha) of the dry leaf mass is estimated to fall between 2 to 5 m on the trees. Finally the other 9% (236 kg DM/ha) fell above the 5 m mark. Compared to the thicket, the open woodland, has a very low dry leaf mass (1 209 kg DM/ha), the lowest among all the vegetation classes. Of this a mean of 201 kg DM/ha (17%) leaf mass falls below the 1.5 m height (Figure 4.8). A very low estimate of 2% (20 kg DM/ha) is calculated for 1.5 to 2 m and the majority of leaf mass is predicted to be found in the tree canopy, 2 m and above. A 449 kg DM/ha (37%) and 539 (45%) are estimated for the canopy, 2-5 m and higher than 5 m above ground. The mean total available dry wood mass between the thicket and the open woodland were very similar in density. The mean estimate of wood mass for the thicket was 43 107 kg DM/ha while the LOW had an estimate of 48 484 kg DM/ha. Within the thicket, 710 kg DM/ha fell below 1.5 m, while only 145 kg DM/ha for the LOW only had 145. The 1.5 to 2 m height class experienced very low wood mass for both the LT and the LOW; where 438 kg DM/ha and a low 21 kg DM/ha, respectively, are predicted. The 2 to 5 m class within the LT has a much higher expected leaf mass with 1 725 kg DM/ha, within the LOW, a low 684 kg DM/ha is predicted. The majority of the leaf mass is seen to be above the 5 m height in the trees where 40 233 and 47 634 kg DM/ha are predicted for the LT and LOW. A high production of woody mass is expected from the branches greater than 20 cm in diameter. In the LT, the expected woody mass here is 32 024 kg DM/ha, while in the LOW, 41 165 kg DM/ha is estimated.

4.3.2.8.3 Browsing capacity

The Low Thicket produces a graph with a very steep seasonal incline and decline. Within this vegetation community, the browsing capacity is at its lowest in September and then starts to rise again in October, to a higher browsing capacity in December, January and February. When available browse is lower than 1.5 m, the browsing capacity ranges from 11 ha/BU to 19.2 ha/BU While the range within browse 2 m and below is slightly higher (6.7 to 11.0 ha/BU). Finally, in the higher browse classes (<5 m), a higher browsing capacity of 1.2 ha/BU is seen in the growing season. The browsing capacity is at its lowest of 2.1 ha/BU during the critical period in September (Figure 4.29).

Within the LOW, a distinct trend is seen throughout the 3 different browse classes where the browsing capacity is at its highest during January/February and March and its lowest in September. Figure 4.28 below illustrates the trends of the browsing capacity over the different months and provides the mean browsing capacity for each month. Within the <1.5 m height class, the browsing capacity is at its best during the summer months where it is recorded at 18.1 ha/BU while during the critical period, it drops to 65.7 ha/BU. A 38.8 ha/BU difference is recorded between the peak and its lowest in the <2 m height class. A 15.1 ha/BU difference was calculated in the <5 m available browse (with a range from 6.6 to 21.7 ha/BU). The browsing capacity for the woody plants within the Acacia Low Open Woodland community type is presented in Figure 4.28.



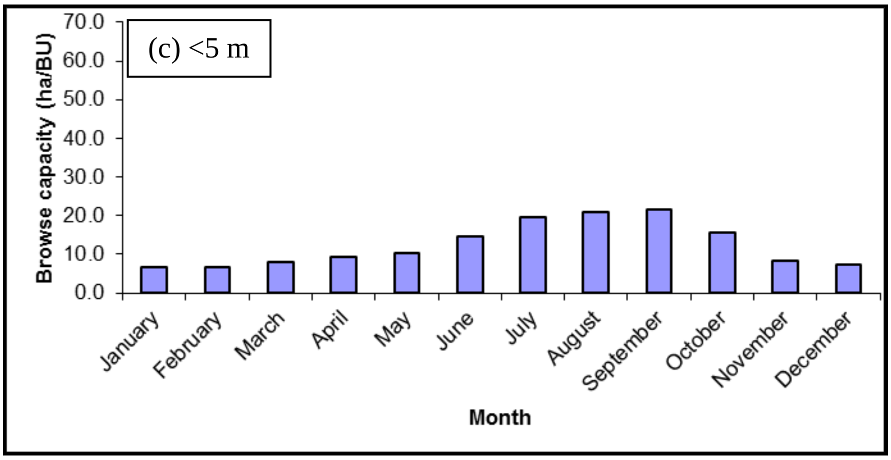
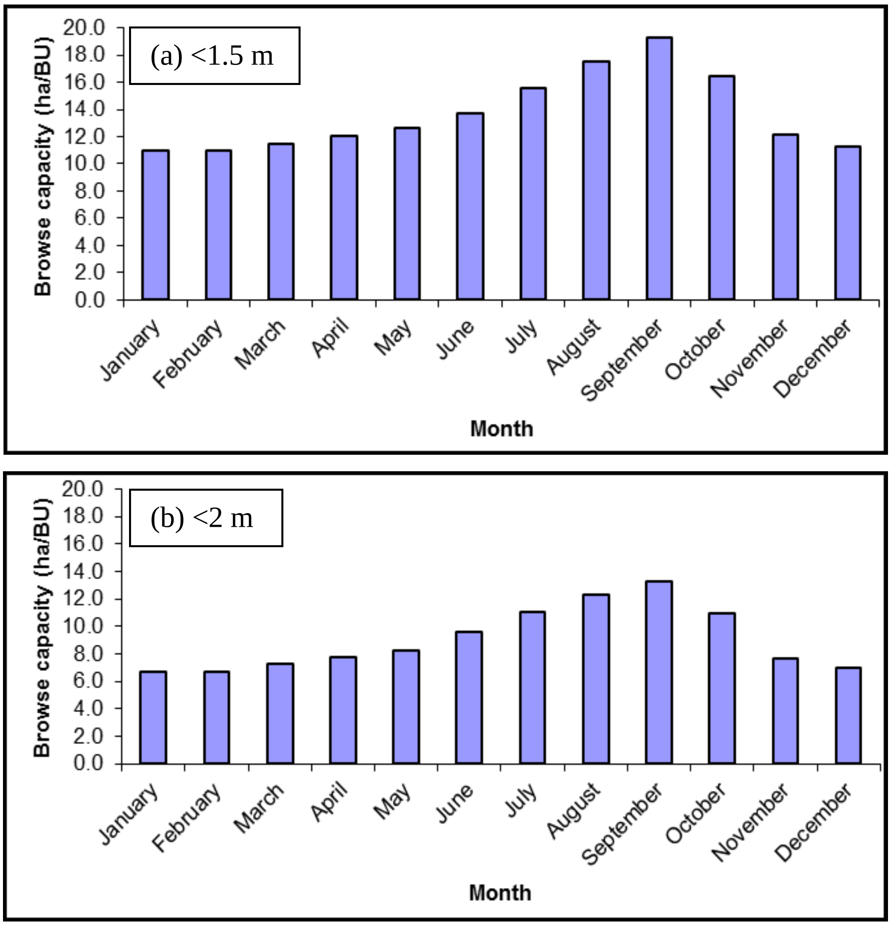


Figure 4.28 Browsing capacity for the three different height classes (<1.5 m, <2 m and <5 m) within the Acacia Low Open Woodland vegetation community.

The browsing capacity for the woody plants within the Acacia Low Thicket community type is presented in Figure 4.29.



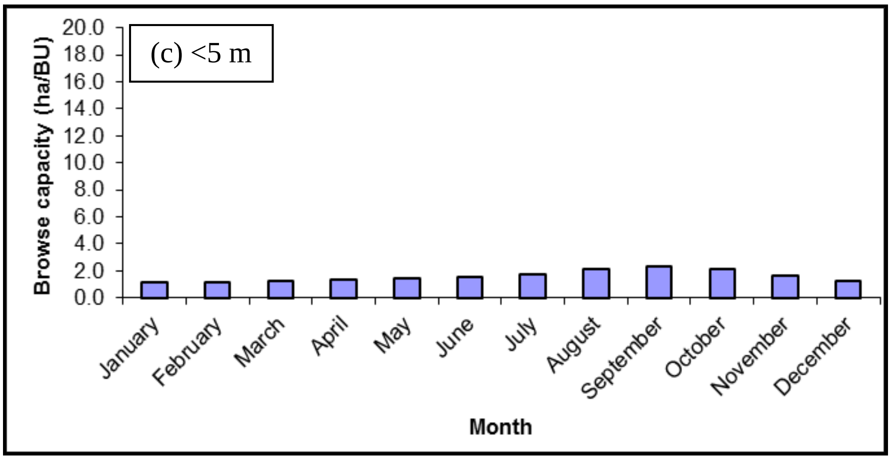


Figure 4.29 Browsing capacity for the three different height classes (<1.5 m, <2 m and <5 m) within the Acacia Low Thicket vegetation community.

4.3.2.9 *Dichrostachys cinerea/Panicum maximum* Low Open Woodland

A photograph of the vegetation typical to the (*D. cinerea/P. maximum* Low Open Woodland) vegetation community is presented in Figure 4.30.

Figure 4.30 Vegetation typical to the *Dichrostachys cinerea/Panicum maximum* Low Open Woodland vegetation community.

4.3.2.9.1 General description

Scattered in fairly flat areas around the reserve, *D. cinerea / P. maximum* Low Open Woodland comprises 3 120 ha of uMkhuze Game Reserve (Figure 4.5). These are on soils of igneous origin that are fairly shallow (0 to 400 mm) soils. Examples of soils found in this area are Glenrosa and Glencoe soil forms. These areas described as Low Open Woodland in Edward's classification (Edwards 1983), indicate that the dominant trees were in the 2 to 5 m height class with a 1 to 10% canopy cover. A total of 6 survey sites were identified and fell within this vegetation community.

4.3.2.9.2 Woody vegetation composition, structure and density

The woody vegetation species composition for *D. cinerea / P. maximum* Low Open Woodland is dominated by *D. cinerea.* Other conspicuous species included *S. birrea*. The structure of these forests tended to comprise many small trees (approximately 79%) in the lower canopy (0 to 1.5 m height class). A few woody plant species (4%) created the 1.5 m to 2 m canopy. A couple (16%) of dominant large (>2m) trees formed the 2 to 5 m canopy. Very few trees (1%) were recorded above 5 m (Figure 4.7). In terms of biodiversity, a very low tree species richness of 6 indigenous tree species is recorded on these sites (Figure 4.6). The observed tree densities for this unit ranged between 1 917 and 9 200 plants/ha with a mean of 4 413 plants/ha (Table 4.1).

A mean tree volume of 7 625 ETTE/ha has been calculated for these sites dominated with *D. cinerea*. Available browse in the form of dry leaf mass for this area is low and with a predicted 1 753 kg DM/ha (Table 4.1). The majority of this (60%) falls within the 2 to 5 m zone above the ground, where it is estimated to be 1 049 kg DM/ha. Within the other available browse classes, only 418 kg DM/ha (24%) fell within 1.5 m from the ground, and 282 kg DM/ha (1%) within the 1.5 to 2 m height. Dry leaf mass above the height of 5 m is minimal and a mean of only 4 kg DM/ha is recorded (Figure 4.8). A lower wood mass is predicted within this LOW and a mean of 33 691 kg DM/ha is estimate for shoots and twigs with a diameter of less than 0.5 cm. Much of this biomass falls above 5 m of the tree (31 227 kg DM/ha). The rest of the trees within the LOW contribute very little to the wood mass. The 0 to 1.5 m section of the tree contribute a mean of 434 kg DM/ha while the 1.5 to 2 m section contributed a mean of 380 kg DM/ha. Finally, the 2 to 5 m section contributes 1 650 kg DM/ha. Branches > 20 cm in diameter provide a mean wood mass of 25 083 kg DM/ha to the LOW system.

4.3.2.9.3 Browsing capacity

The *Dichrostachys cinerea/Panicum maximum* Low Open Woodland produces a browsing capacity graph with a very steep seasonal incline and decline. All three height classes are very similar in browsing capacity. Within this vegetation community, the browsing capacity is at its lowest in September and then starts to rise again in October, to a higher browsing capacity in December, January and February. When available browse is lower than 1.5 m in height, the browsing capacity ranges from 20.4 ha/BU to 67.9 ha/BU While the range within browse 2 m and below is slightly higher (17.6 to 62.4 ha/BU). Finally, in the higher browse classes (< 5 m), a higher browsing capacity of 16.6 ha/BU is seen in the growing season. The critical period for this community is during September when browsing capacity bottlenecks down to 59.9 ha/BU. The browsing capacity for the woody plants within the Acacia Low Open Woodland community type is presented in Figure 4.31.

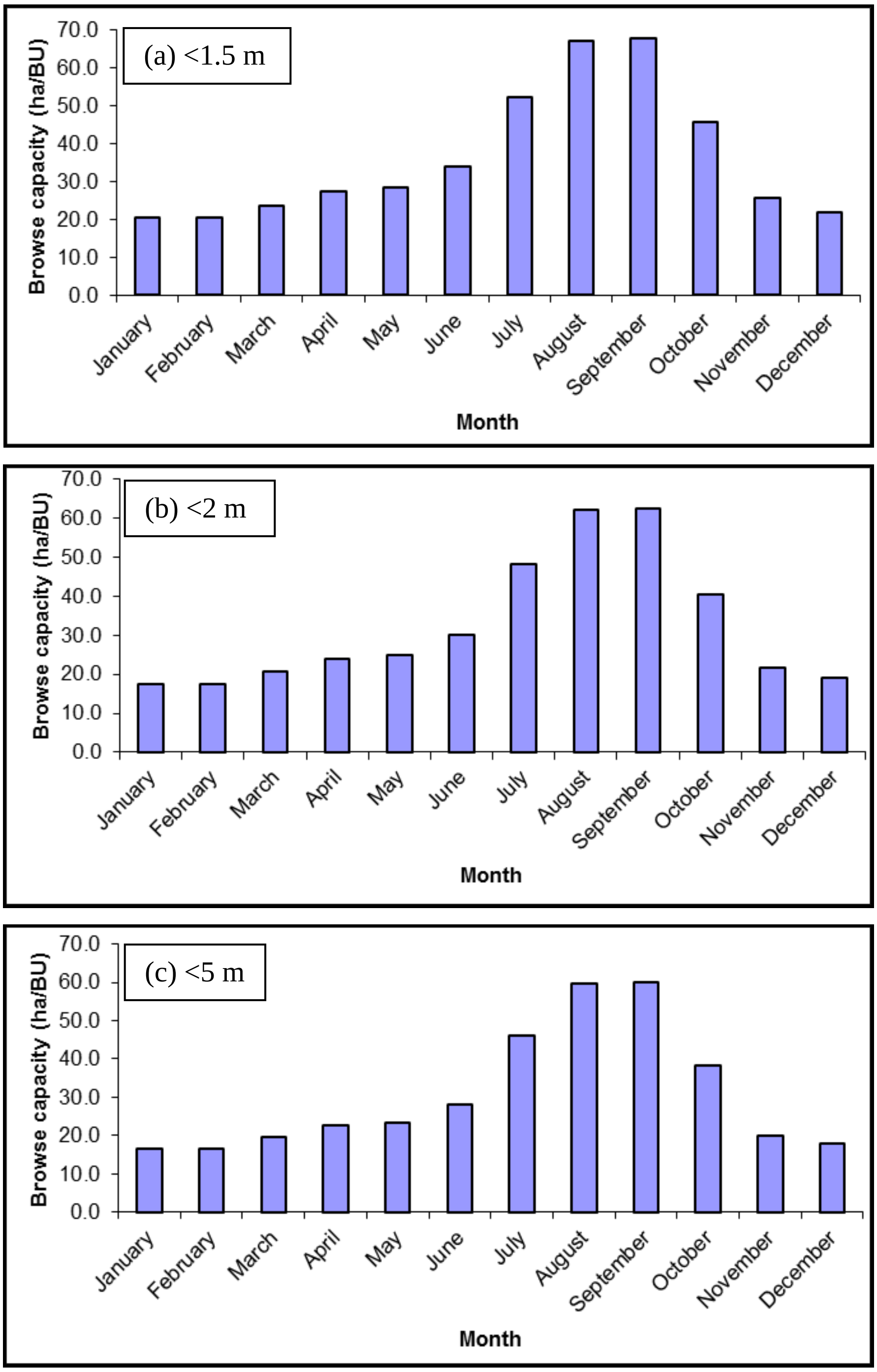


Figure 4.31 Browsing capacity for the three different height classes (<1.5 m, <2 m and <5 m) within the *Dichrostachys cinerea/Panicum maximum* Low Open Woodland vegetation community.

4.3.2.10 *Euclea divinorum* Thicket

A photograph of the vegetation typical to the *Euclea divinorum* Thicket (*E. divinorum* Thicket) community is presented in Figure 4.32.

Figure 4.32 Vegetation typical to the *Euclea divinorum* Thicket vegetation community.

4.3.2.10.1 General description

Approximately 11% or 4 129 ha of the reserve comprises this vegetation community (Figure 4.5). This community occurs in large patches, scattered throughout the reserve. This vegetation community tends to occur on a variety of soils ranging from heavy black clayed Inhoek soils to duplex Valsrivier and all the way through to deep well drained Shortlands soils. These soils are all generally greater than 500 mm in depth. The vegetation pattern of these units, as described by Edwards (1983), is predominantly a Low Thicket. This vegetation community includes trees of 2 to 5 m in height with low 1 to 5 m shrubs. Low Thickets generally have a 10-100% canopy cover.

4.3.2.10.2 Woody vegetation composition, structure and density

Tree species richness recorded for these sites was ranked as some of the highest within the reserve, with an average of 15 species recorded among sites (Figure 4.6). Dominating tree species that contributed mostly to the total density within this vegetation community were identified as *E. divinorum*. Other important trees within these sites were *Croton steenkampianus*, *Spirostachys africana* and *Sideroxylon inerme*. Tree density within the 2 sites ranged from 702 plants/ha in Site 19 and 6 320 plants/ha in Site 51 (with a mean of 3 511 plants/ha (Table 2). Structurally, these sites comprised 64% of the total tree height in the 0 to 1.5 m height class, 10% in the 1.5 to 2 m category, 21% in the 2 to 5 m category and only 4% of the total tree height was above 5 m (Figure 4.7).

A very high mean tree volume of 11 590 ETTE/ha defines this area as fairly dense (Table 4.1). This corresponds with the high mean dry leaf mass of 2 635 kg DM/ha (Figure 4.8). In this vegetation community, the majority of the leaf mass falls within the upper section of available browse (2 -5 m). Within this category, an estimated 1 752 kg DM/ha (or 67%) of leaf mass was calculated. In the lower available browse sections (0 to 1.5 m and 1.5 to 2 m), a mean of 311 kg DM/ha and 253 kg DM/ha available dry leaf mass is recorded. Above the 5 m mark, where leaf accessibility for browsers is limited, only 319 kg DM/ha (12%) is estimated as available. Total wood mass available on branches <0.5 cm in diameter is estimated at 44 216 kg DM/ha. Within 0 to 5 m from the ground, the mean wood mass is predicted to be 307 kg DM/ha. 1.5 to 2 m above the ground, the group presents a mean wood mass, similar to that of the 0 to 1.5 m category, of 279 kg DM/ha. It is calculated that branches within 2 to 5 m above ground level produce a mean of 2 210 kg DM/ha. Finally branches above the 5 m mark produce a high 41 403 kg DM/ha of wood mass. As with all the other vegetation communities, branches with a diameter of greater than 20 cm contribute greatly to the wood biomass of the trees in the system. Here, 34 615 kg DM/ha biomass is predicted.

4.3.2.10.3 Browsing capacity

In the height classes of <1.5 m and <2 m the browsing capacity has have a very similar trend, where the browsing capacity rises steeply over the winter periods. The <5 m category shows a far more gentle incline over July, August and September. This vegetation community is located within the higher browsing capacity category of vegetation communities. This vegetation group comprises a varied height *of E. divinorum* trees and shorter saplings and shrubs within 1.5 m. In the <1.5 m category, the browsing capacity ranges from 22.3 to 34.7 ha/BU while the <2 m has a range from 12.3 to 19.8 ha/BU. A large difference is noted in the <5 m height zone where the browsing capacity ranges from 4.5 ha/BU to 6.1 ha/BU. Fluctuations of the browsing capacity between seasons in the higher height classes are fairly low since the dominating tall species; *E. divinorum* is non-deciduous and therefore does not lose its leaves (Figure 4.33). The browsing capacity for the woody plants within the *Euclea divinorum* Thicket community type is presented in Figure 4.33.

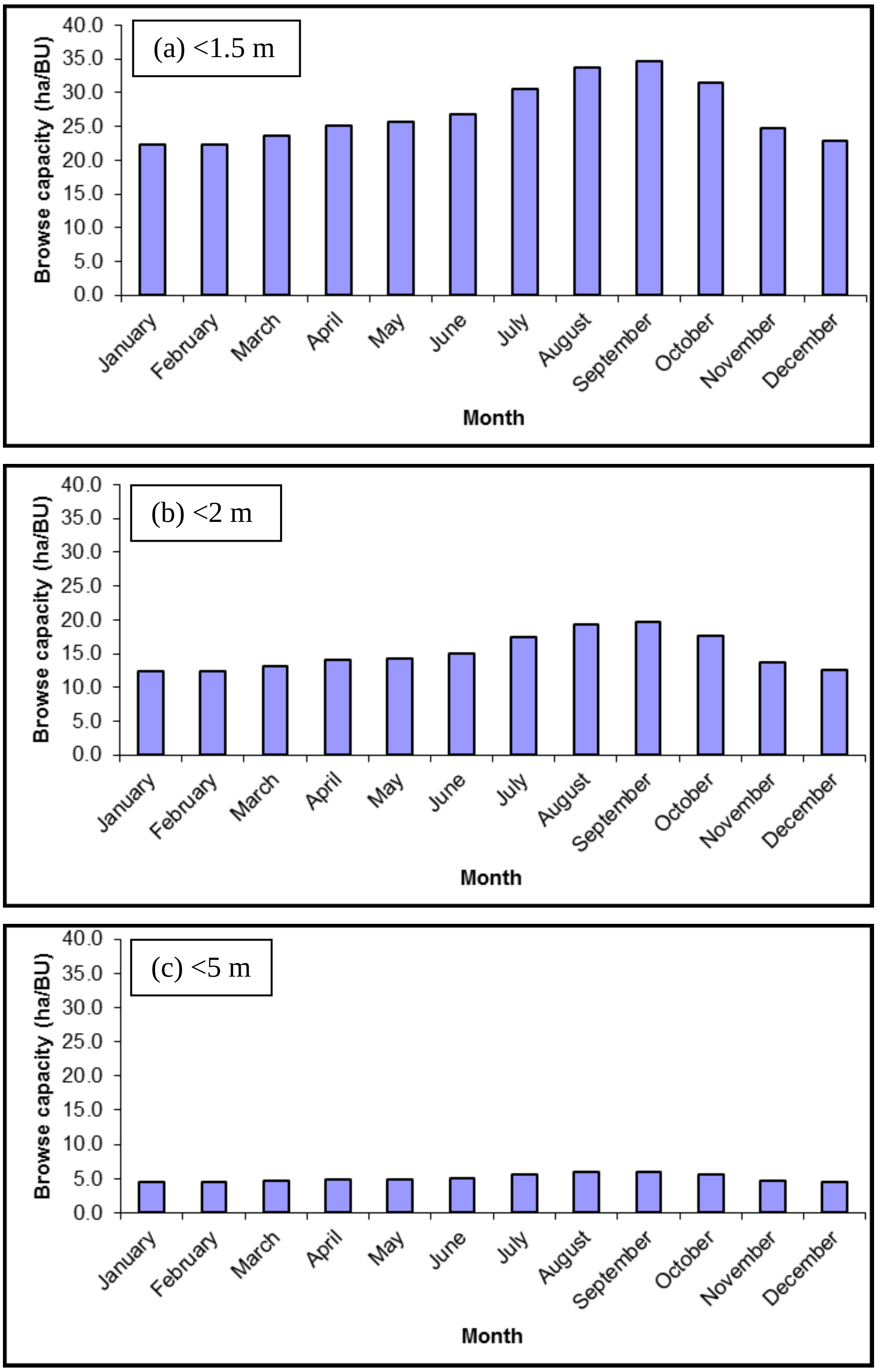


Figure 4.33 Browsing capacity for the three different height classes (<1.5 m <2 m and <5 m) within the *Euclea divinorum* Thicket vegetation community.

4.3.3 Estimation of *Acacia nilotica* abundance

Based on the BECVOL belt transect woody plant data collected for purposes of compiling the vegetation community map of the reserve, it was possible to compile an estimate of the abundance of *A. nilotica* within the reserve. The data of this analysis is presented in Table 4.1.

The two main *A. nilotica*-dominant communities, as their names suggest, are the *A. nilotica/ P. maximum* low closed and low open woodlands (Figure 4.5). Combined, they contribute 14% to the total area of the reserve. Within these two communities, *A. nilotica* comprised 26.2% and 17.4% of the tree density, respectively, while the remainder being short woody shrub species (*e.g. Carissa bispinosa* and *Azima tetracantha*). In total 8 of the 12 vegetation communities in the reserve have the potential to contain *A. nilotica* (Table 4.1 (repeat)). This covers a total area of 36 703 ha (73%) of the reserve. The remaining areas that lack *A. nilotica* are those areas that are either too sandy (such as the Sandforest areas) or too wet (riverine areas). Of the 3 118 kg DM/ha of available browse within the *A. nilotica/ P. maximum* low closed woodlands, 48.7% of this is from *A. nilotica*. *A. nilotica* provides valuable browse for herbivores, although it must be remembered that they are highly seasonal and are of very little use during the late winter and early spring.

Table 4.1(repeat) Abundance of *A. nilotica* in terms of coverage, tree density, Evapotranspiration Tree Equivalents (ETTE) and leaf mass within the various vegetation communities. Numbers in red indicate those vegetation communities with highest (above 10%) density, volume and leaf mass.

Vegetation community	Area of reserve_ha (%)	*A. nilotica* density_pl/ ha (%)	Total tree density pl/ha	*A. nilotica* volume ETTE/ha (%)	Total tree volume ETTE/ha (%)	*A. nilotica* total leaf mass <5m_kgDM/ha	Total leaf mass <5m_kgDM/ha
T. sericea/D. eriantha Savanna	2945 (8%)	0 (0%)	5174	0 (0%)	10347	0 (0%)	1691
monostachyus Low Thicket	2864 (7%)	22 (0.3%)	6869	5 (0.02%)	24420	1 (0%)	3239
F. sycomorus/P. maximum Riverine Forest	2268 (6%)	0 (0%)	940	0 (0%)	15899	0 (0%)	1709
A. xanthaphloea/P. maximum Floodplains	4642 (13%)	33 (2.4%)	1364	18.4 (0.04%)	41771	43 (3.3%)	1269
H. coriacea/P. maximum Open Woodland	79 (0.2%)	0 (0%)	500	0 (0%)	7544	0 (0%)	1139
A. nilotica/P. maximum Low Closed Woodland	4135 (12%)	971 (26.2%)	3702	6466 (44.4%)	14567	1520 (48.7%)	37118
A. nilotica/P. maximum Low Open Woodland	752 (2%)	662 (17.4%)	3814	1993 (18.8%)	10613	289 (16.6%)	174
C. apiculatum /T. triandra Open Woodland	5570 (16%)	87 (2%)	4272	176 (2%)	8703	41 (2.8%)	1451
Acacia Low Thicket	2348 (9%)	224 (6%)	3744	1393 (12.4%)	11253	327 (14%)	2339
D. cinerea/P. maximum Low Open Woodland	2512 (7%)	94 (2.1%)	4413	719 (9.4%)	7625	169 (9.7%)	1749
Acacia Low Open Woodland	3120 (8.5%)	250 (6.7%)	3729	145 (2.8%)	5238	33 (4.9%)	671
E.divinorum Thicket	4129 (11%)	0 (0%)	3511	0 (0%)	11590	0 (0%)	2316
Freshwater lakes and pans	339 (0.9%)	---	---	---	---	---	---

4.3.4 Tree thinning

When assessing the number of trees to be retained in a tree thinning operation for the specific purpose of restoring the production potential of the herbaceous layer for grazers, the general "rule of thumb" stipulates that the median number of ETTE/ha (Evapotranspiration Tree Equivalents) should not exceed 10 times the mean annual rainfall (Smit *et al.* 2013). In the case of uMkhuze Game Reserve, with a mean annual rainfall of 646mm, a target tree figure of 6 460 ETTE/ha is estimated. In open, structured savanna and riparian areas, trees are generally larger and therefore it is expected that the tree densities (plants/ha) will be lower than the ETTE/ha. Based on the mean equivalent ETTE-values of woody plants of various sizes (Table 4.2) (Smit *et al.* 2013), the ideal number of plants/ha should thus not exceed 1 846 plants/ha.

Table 4.2 Mean equivalent ETTE-values of woody plants in 6 height classes calculated from all the trees measured in the study area.

Height classes (m)	ETTE value - all	ETTE value - *A. nilotica*
0 - 1	0.2	0.03
>1 - 2	0.8	1.2
>2 - 3	3.5	6.9
>3 - 4	9	12.5
>4 - 5	13.3	20.2
>5	54.7	25

The thinning of trees must allow for growth of the remaining trees to occur and therefore the suggested remaining ETTE value is initially lower than the target threshold value. Over a period of time, trees will increase in size, although the density will remain fairly constant. Based on these criteria and the values presented in Table 4.1 it is evident that the tree biomass in the majority of the vegetation communities (with the exception of the *F. sycomorus/ P. maximum* riverine forests, *A. xanthophloea/ P. maximum* floodplains and *H. coriacea/ P. maximum* open woodlands) within the reserve exceeds the threshold tree biomass. Since uMkhuze is a game reserve that focuses primarily on biodiversity conservation of both fauna and flora and where browsers play an important ecological role in the reserve, a physical tree thinning procedure is not as important as in other grazing-only areas and therefore should not be considered a priority within the reserve.

The map presented in Figure 4.5 illustrates the 12 basic vegetation communities represented within uMkhuze Game Reserve. These vegetation community boundaries illustrate similar results to that of Goodman (1990) where in the sandy soils the semi-deciduous, simple broad-leaved woodlands are found. These also generally have their canopy cover in the lower strata and trees such as *T. sericea* and *H. coriacea* are prolific. In soils where the clay content is higher, mixed woodland of simple leaved trees (*e.g. S. africana*) predominate. In areas where duplex soils are common, the compound leaved trees (*Acacia senegal* and *D. cinerea*) become dominant. Few broad-leaved woody plants still occur in these communities (*e.g. E. divinorum*). Within the even heavier clay soils, a woodland dominating in *Acacia* species, especially *A. nilotica* is expected, while the heavy melanic and vertic soils produce a dense low thicket of mostly *A. nilotica*. Finally, the younger, shallow soils tend to accommodate more grass cover and the broad leaved trees like *Sclerocarya caffra* and *C. apiculatum* are common.

The soil boundaries within the reserve influence the boundaries for the vegetation communities to a great extent and the location of the vegetation communities are very much in common with the previous vegetation study done in the reserve. When compared to the study over 20 years ago (Goodman 1990) results of the dry woody biomass of this study indicate that there is a general increasing trend of dry woody biomass. Mean woody biomass for the reserve in the 1980s was calculated at 40 560 kg DM/ha (Goodman 1990). Current records for the reserve indicate that this mean has almost doubled in just over 20 years, when the mean is currently at 78 183 kg DM/ha. The range in 1990 for this woody biomass is between 15 120 and 82 740 kg DM/ha, currently the woody biomass ranges from 21 031 kg DM/ha to 322 829 ha DM/ha. An outlier of the group is from the *A. xanthophloea* riverine forest. If this community is excluded the range is reduced to 21 031 to 96 004 kg DM/ha and hence shows a more feasible increase in woody plants. These results indicate that there has been an increase in woody plant biomass and hence plant density over these 22 years. Unfortunately no historic analysis has been done on leaf biomass. The methods used to collect and analyse this data differs greatly where Goodman (1990) used a technique to estimate cover abundance while the BECVOL technique which was used in this current analysis to assess available leaf mass and hence available browse. Both have shown to give a reliable estimate of woody biomass although the BECVOL technique may be less time consuming and more accurate due to actual measurements being taken.

From this study it is clear that *A. nilotica* does have a tendency to encroach into other vegetation communities and thicken up areas within its natural habitat, but it is not the only woody plant species that is involved in these processes. Within the uMkhuze Game Reserve, both *D. cinerea* and *E. divinorum* currently have a tendency to encroach into new areas as well as thicken up in areas that are currently inhabited by these species. Other species, such as *S. africana* and *T. sericea* are very site specific and therefore do not show signs of encroachment into other areas, although from this study, have shown to have a great density of these species within the areas of ideal habitat.

4.4 CONCLUSION

For the purpose of this study it was necessary to compile an updated vegetation map for uMkhuze Game Reserve since the existing map was compiled during the 1980s based on aerial photos taken in the 1970s (Goodman 1990). Since the 1980s, there have been major changes in the vegetation of the reserve, mainly due to woody plant thickening and encroachment. With the aid of new and updated technology (*e.g*. GIS, GPS and fully rectified digital aerial photography) quantitative vegetation data was collected as part of this study. From data collected at seventy representative sites located throughout the park (Figure 4.3) an updated vegetation community map was compiled. This enabled the area within the park covered by each community to be measured.

The quantification of the plants in the 70 plots enabled the separation of the vegetation of uMkhuze Game Reserve into twelve discrete communities. As with the original vegetation of Goodman (1990), these communities are strongly linked to the soil boundaries within the reserve. Different communities require different management practices such as veld maintenance, controlled burning, animal stocking densities, woody plant control and alien plant eradication.

Using an updated version of the BECVOL-model, an estimation of woody plant density, phytomass and browsing capacity of each plant community, was done. These measurements, either for each community will be useful for the calculation of more scientifically based stocking densities and sustainable herbivore species ratios. The data will also provide a baseline for future monitoring of the dynamics of woody plant vegetation within the reserve and for comparing trends in similar rangelands.

Three vegetation communities, namely *Acacia nilotica/ Panicum maximum* Low Closed Woodland, *Acacia nilotica/ Panicum maximum* Low Open Woodland and Acacia Low Thicket were identified as having the highest abundance of *A nilotica*. Combined, the three vegetation units cover 23% of the reserve. In addition, this study demonstrated clearly that the woody plant biomass in the reserve has doubled since Goodman (1990) first estimated the total woody plant biomass.

CHAPTER 5

PHENOLOGY AND BRANCH GROWTH OF *ACACIA NILOTICA*

5.1 INTRODUCTION

In a highly variable seasonal environment such as that found in the uMkhuze Game Reserve, *Acacia nilotica* goes through marked seasonal phenophases. Different tree species have been classified into different categories according to how much canopy they lose during the winter (Williams *et al.* 1997). There are four main categories that define leaf loss; these are evergreen, brevi-deciduous, semi-deciduous and fully deciduous. Evergreen describes a tree that retains its full canopy throughout the year, while during the dry season brevi-deciduous trees lose not more than 50 % of the canopy. Semi-deciduous trees lose more than 50 % during the dry season, while the fully deciduous trees lose all their leaves in the dry season and remains leafless for at least a month afterwards (Williams *et al.* 1997). *A. nilotica* is fully deciduous (winter deciduous) and, depending on the region of the province, the length of time it remains leafless, varies. There is a period during the year when the tree is covered in new green leaf buds: This marks the time when obvious growth is taking place. During different seasons within a year, trees are in full bloom with yellow ball-shaped flowers, or with very few to no leaves. In the study on plant phenology in the west African savanna (de Bie *et al.* 1998), the definition of phenology was described according to Leith (1974) as ‘the study of timing of recurrent biological events, the causes of their timing with regard to biotic and abiotic forces and the interrelation among phases of the same or different species’. In this chapter, a study on the timing of leafing, flowering, fruiting and branch growth in *A. nilotica* in the uMkhuze Game Reserve is presented. This seasonality of the tree plays an important role in the available forage for herbivores throughout the year and this insight provides valuable information for the management and control of both the tree species and the browsing herbivores.

This seasonal behaviour of trees is influenced by temperature, rainfall (Higgins *et al.* 2011) and photoperiod (Rossatto 2013). The photoperiod is defined as the amounts of light and darkness in a 24 hour day (Jackson 2009). The annual change in photoperiod is created by the rotation of the earth around the sun throughout the year. This creates longer days in summer and shorter days in winter

(Jackson 2009). Photoperiods have been found to control many of the development responses in plants where the general effect is that long days increase plant growth rates, while short days reduce the growth rates. Often short days also assist with the formation of flower buds (Downs & Borthwick 1956). Tree water status (Reich & Borchert 1984, Sayer & Newbery 2003) is another determinant of phenophase change, especially in the seasonal tropics (Williams *et al.* 1997). Water stored in the stem of the tree allows the initiation of new leaf production before the rains start (Reich & Borchert 1984). Trees of different sizes are likely to access different sources of water and therefore have different phenological patterns. It is for this reason that plant phenology in areas of more extreme seasonal variation will show larger signs of phenological change than those in areas with very slight seasonal variation.

In any natural area, this seasonal variation can affect the browsing animals that utilize these trees (Janecke & Smit 2011). During the growing season, branches are sprouting and trees are covered in leaves, which ensure that available browse is abundant. As the seasons change the tree phenology changes as well. During the dry winter months the deciduous tree species drop their leaves and branching/sprouting is reduced or halted. The reduction of leaf, flower and seed biomass during this period results in the drastic lowering of browseable material that can support a much lower density of browsers. Since *A. nilotica* has the potential to encroach unwantedly into open rangeland areas, knowledge of the growth patterns of this species may be useful for the effective management of this species. To understand the phenology of *A. nilotica*, the leaf, flower and seed phenological patterns of the species in uMkhuze Game Reserve were studied over a period of 13 months.

The main objective of this study is to evaluate the influence of rainfall, photoperiod and temperature on the phenology and growth of *A. nilotica*. This was achieved by:

- Assessing the monthly changes in the phenophase of the plant, and
- Measuring the shoot growth of the plant at monthly intervals and linking this to specific environmental variables.

5.2 STUDY AREA

The study was conducted in the uMkhuze Game Reserve on sites that experienced severe thickening of *A. nilotica* at the time of the study. Study sites were chosen within an 8 x 4 km area of uMkhuze Game Reserve; these sites were used so as to keep natural variability regarding topography and soil as low as possible (Figure 5.1). These sites were chosen at differing density levels and age classes to get an idea of the dynamics of the population as a whole. Sites were chosen within 500 m from the road to make accessibility easier since the occurrence of dangerous game species had to be taken into consideration. Sites were also chosen further than approximately 50 m from the road edge to prevent any variation that could have occurred due to tree thinning for aesthetic purposes. The selected sites were similar in soil, geology, and topography. Soils in the selected sites contained a high (>20%) clay content and were located in the north-eastern part of the reserve where the topography was generally flat.

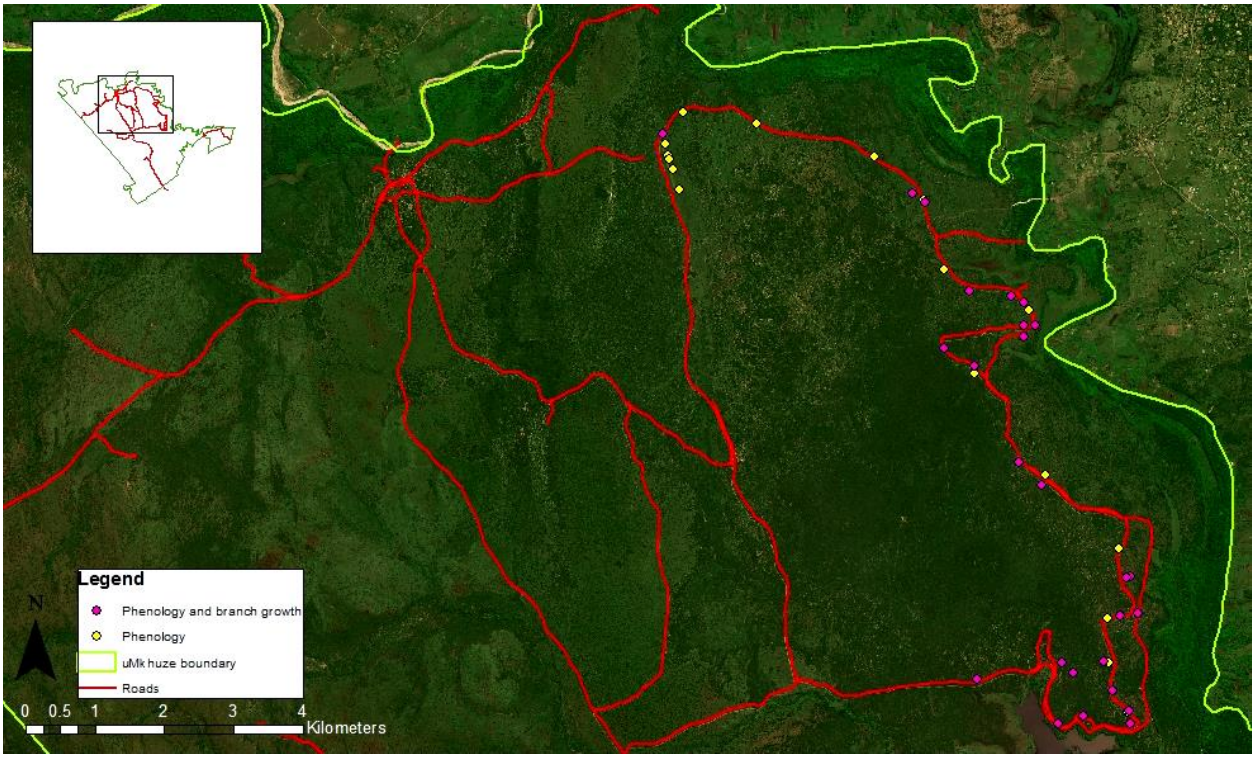


Figure 5.1 Location of trees used for phenology survey. Pink points indicate trees used in both the branch growth and leaf, flower and seed pod phenology studies while yellow points indicate trees used in leaf, flower and seed pod study only. Inset map illustrates the sites in relation to the entire reserve.

The data in Figure 5.2 illustrate the variability in mean monthly temperature and total monthly rainfall over the study period. The rainfall data were taken from the two rain gauges that were in the study area. The temperature data were taken from the weather station located at Mantuma Camp within the reserve.

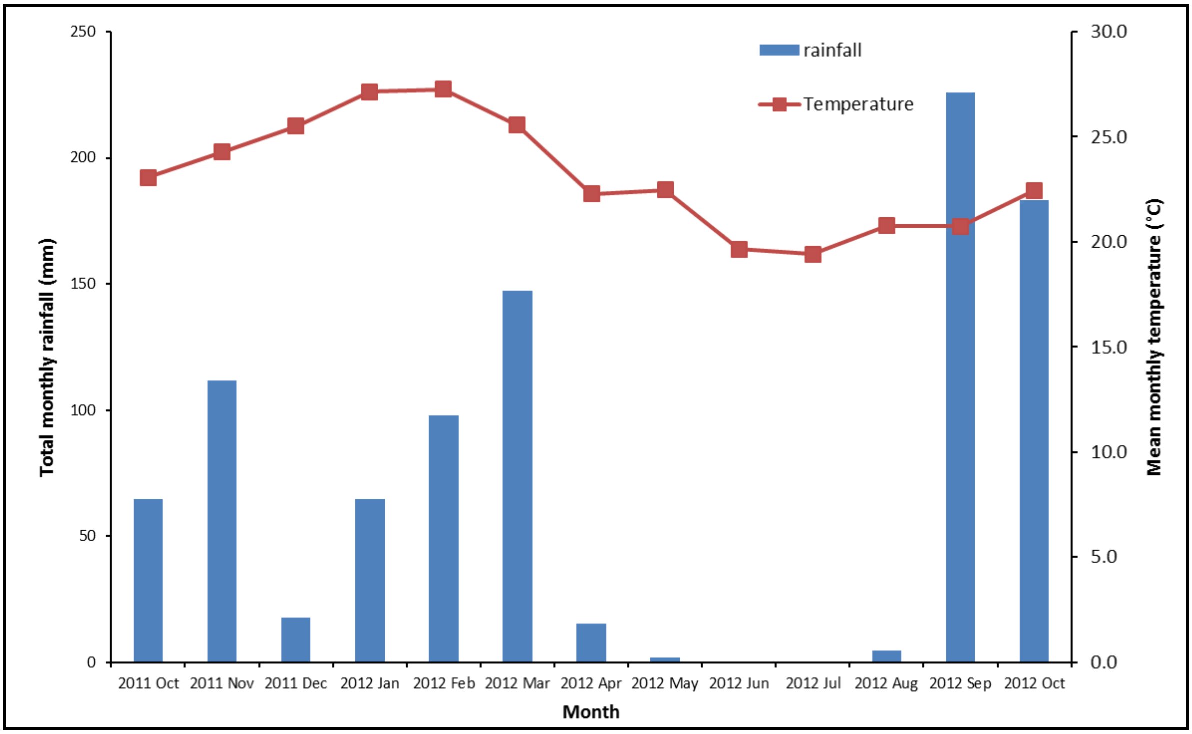


Figure 5.2 Mean monthly temperature and total monthly rainfall for the area during the study period (end of October 2011 to October 2012).

5.3 MATERIAL AND METHODS

5.3.1 Leaf, flower and seedpod phenology

Thirty six *A. nilotica* trees were randomly selected throughout the study area of the reserve. (For a detailed description of this area refer to Chapter 2.) These trees were chosen to represent the variation of age categories of the trees in the area by choosing plants with various stem circumferences measured at 50 cm above ground level. Each of these trees was marked with a coloured heavy-duty plastic tag and its co-ordinates recorded with a GPS. Leaf, flower and seed phenological scores describing the proportion of the tree that was covered by leaves and the current growth stage of each tree were recorded on a 5-weekly basis from the end of October 2011 to October 2012. Due to logistical difficulties during July 2012, recordings were not done on schedule and were delayed until the first week of August 2012, with a six and a half week interval between recordings. The phenology data was subsequently correlated with the total monthly rainfall, mean monthly photoperiod (Time and Date AS 2013) and temperature for those months.

Following Janecke and Smit (2011), the leaf carriage scores that were used, are presented in Table 5.1.

Table 5.1 Categories used to estimate the proportion of the tree that was covered in leaf over the seasons (with the mean for the class given in brackets)

Code	Score
0	No leaves
1	1 - 15% (8%)
2	16 - 40% (28%)
3	41 - 70% (56%)
4	71 - 90% (81%)
5	91 - 100% (96%)

Leaves were classified into four phenophase categories as described by Dekker & Smit (1996) and Janecke & Smit (2011) (Table 5.2).

Table 5.2 Leaf phenophase categories and abbreviations that were used to describe the leaf change during the different seasons.

Code	Description
BL	Budding leaves
IL	Immature leaves
ML	Mature leaves
OL	Old leaves

Classification into these categories was subjective. Budding leaves (BL) were defined as the small closed leaves and leaf buds found on the tree (Figure 5.3a). These are light green in colour. Leaves that had opened fully and were light green in colour and soft to the touch were classed as immature leaves (IL) (Figure 5.3b). Mature leaves (ML) were identified as leaves that had turned a darker shade of green and had become harder to the touch (Figure 5.3c). Old leaves (OL) were classified as those leaves that were visibly in the senescing stage (Figure 5.3d) and the leaves were either turning brown or had gone a yellow/brown colour and were close to falling off.

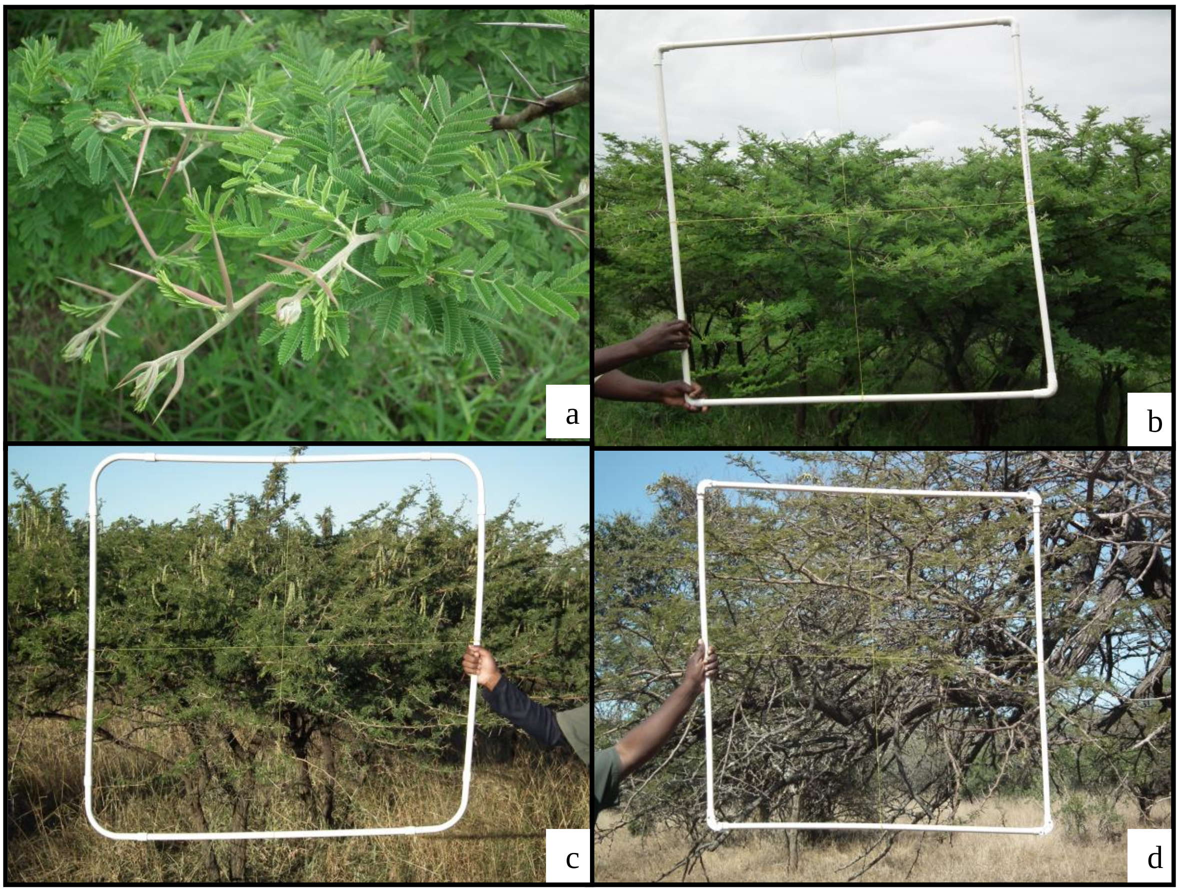
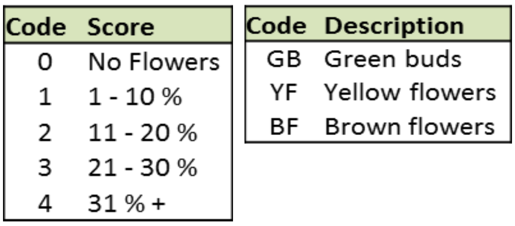


Figure 5.3 A photographic illustration of different leaf phenophase categories: a) Budding leaves (BL), b) Immature leaves (IL), c) Mature leaves (ML) and d) Old leaves (OL). Dimensions of quadrat used in photographs are 1 m x1 m.

The presence of flowers was categorized into 3 categories. A description of these categories is presented in Table 5.3. These categories are described as: GB - the stage of the flowers when they first appear on the tree and are in the form of small green globes (Figure 5.4a). YF - once the flower buds turned yellow, they were classified as yellow flowers (Figure 5.4b). This is a more open globose yellow flower, where it is in its mature reproductive stage. BF - describes the stage where the flowers have passed their mature reproductive stage and have turned brown and are about to fall off the tree (Figure 5.4c). The estimate of flower abundance was allocated a code from 0 to 4. The description of each number is shown in Table 5.3.

Table 5.3 Scoring system for flower estimation and description of each flower category



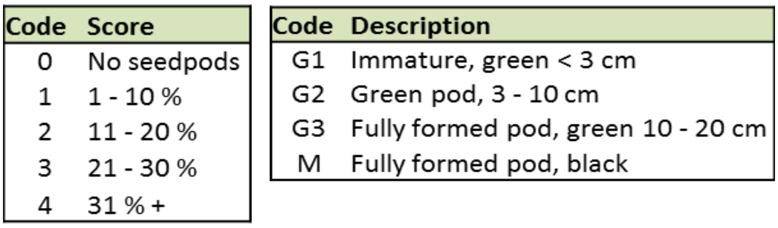
Code	Score
0	No Flowers
1	1 - 10 %
2	11 - 20 %
3	21 - 30 %
4	31 % +

Code	Description
GB	Green buds
YF	Yellow flowers
BF	Brown flowers

Figure 5.4 Flower phenophase categories: a) Green buds (GB), b) Yellow flowers (YF), c) Brown flowers (BF) and d) a combination of all 3 phenophases (green buds, yellow flowers and old brown flowers)

The presence of seedpods was categorized into 4 categories. Table 5.3 summarizes the description of each category. Three categories were allocated to the green pods. The G1 category was represented by undeveloped pods, less than 3 cm in length and green in colour (Figure 5.5a). The G2 category represented pods that were green, 3 – 10 cm in length and the seeds starting to be visible from the outside of the pod (Figure 5.5b). By the time the pods were in the G3 stage, the pods were generally 10 to 20 cm in length and the seeds almost fully developed (Figure 5.5c). These pods also had a very strong, sweet scent to them. Once the pods turn black and harden, they were classified as mature (M) (Figure 5.5d). At this stage the seedpods have a characteristic sweet smell from which the common name (scented pod) is derived.

Table 5.4 Scoring system used for the estimation of seedpods and the description of each seedpod category



Code	Score
0	No seedpods
1	1 - 10 %
2	11 - 20 %
3	21 - 30 %
4	31 % +

Code	Description
G1	Immature, green < 3 cm
G2	Green pod, 3 - 10 cm
G3	Fully formed pod, green 10 - 20 cm
M	Fully formed pod, black

Seedpods and flowers were both grouped with the same phenological scoring system. In consultation with Janecke[1] (Pers. comm, 2013), it was discussed that a tree could not have a 100% flower or pod cover and therefore required a different scoring system to that of the leaves. These categories were more biased towards the lower range and had a limit of 4. The scores used to classify the proportion of the tree that was covered in flowers or seedpods are described in Table 5.4.

For the cover estimations to be as accurate as possible, a 1 m^2 quadrat was used to regulate the area of these estimations. The frame was subdivided halfway across each side to dissect the quadrat and make 4 x 0.25 m^2 squares within the grid. At every recording interval, this quadrat was held up to each tree and a photograph was taken at the time the estimation was done. Photographs were taken in approximately the same position and at the same scale during each observation. These photographs were used to verify the field scores to ensure the consistency of scoring. Since fire affects the growth of a tree quite drastically, any marked trees that were burnt over the study period were excluded.

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[1] B. Janecke, University of the Free State, Department of Animal, Wildlife and Grassland Sciences, South Africa, email: janeckbb@ufs.ac.za

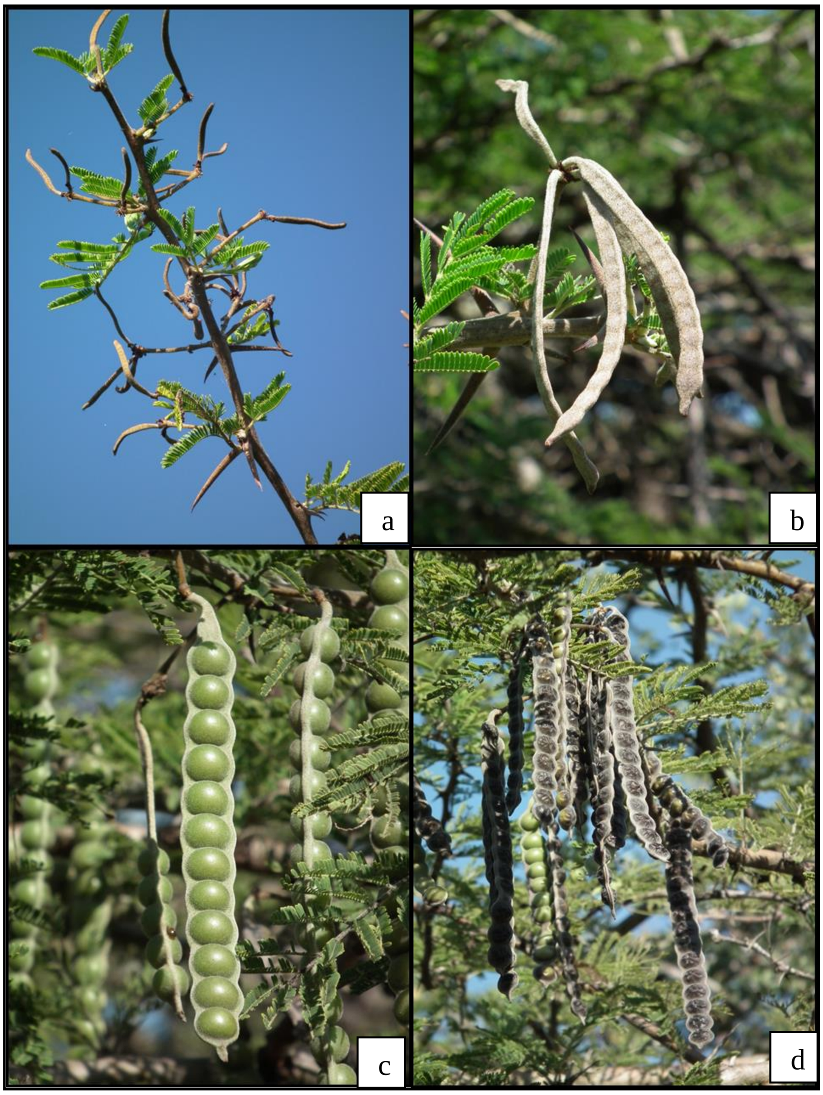

Figure 5.5 Seedpod phenophase categories a) very immature green pods less than 3 cm in length (G1), b) green pods within the 3 to 10 cm length class (G2), c) fully formed green pods, 10 to 20 cm long (G3) and d) fully mature black seed pods (M).

5.3.2 Plant branch growth

Twenty-six trees, with a range (51 to 882 mm) of stem circumferences (measured at 50 cm above ground level) were chosen in the uMkhuze Game Reserve study area. To maintain the environmental variables as constant as possible, all these trees were chosen on soils of strong structure, fairly high clay content (above 20 %) and classified into the Valsrivier soil form (Taylor *et al.* 2013). Each tree was marked with heavy-duty plastic tags and co-ordinates taken for easy location (Figure 5.6). On each tree 4 growing sub-branches, fairly close to the end of the branches were chosen for growth measurements. Each of these branches was marked with a different colour tag for easy identification during the period of repeated sampling

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Figure 5.6 a) Tagged tree branches showing plastic tags marking branches that were monitored. The letter T followed by a number indicates the tree number and B labels the branch number (4 on each tree) on the tree. **b)** A few tags needed replacing after been gnawed off by monkeys, but the cable ties remained on the branches.

The growth of the main tagged branch (M) and its sub-branches (D1, D2 *etc*.) were measured on a five-weekly basis (Figure 5.7). This was done using a tape measure and measurements were taken to the nearest millimetre. Shoots from the main branch that showed any sign of damage (broken or completely browsed off) were discarded from the data set. The phenology of these plants was included in the phenological study. The changes in phenology in the leaves, flowers and seedpods were also recorded in these trees over the study period (October 2011 to October 2012).

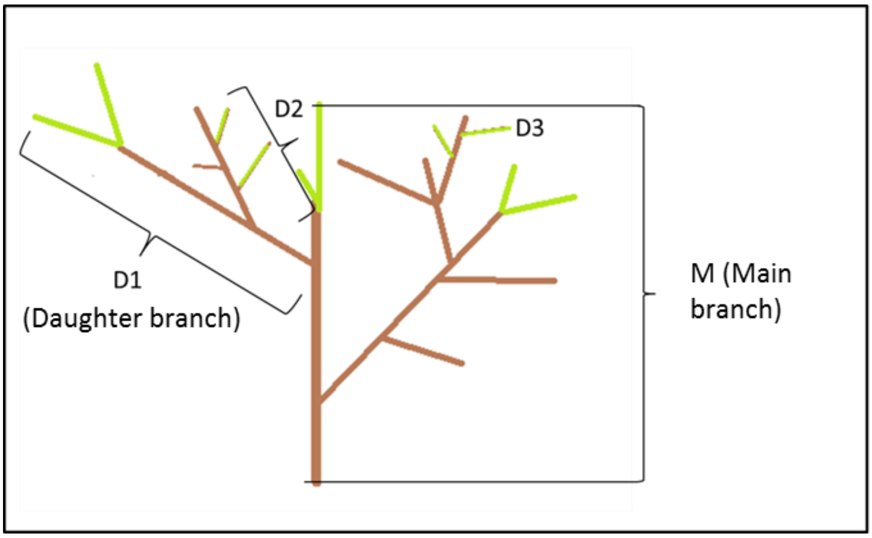


Figure 5.7 A schematic drawing illustrating the demarcation of branches used in the study. Brown branches indicate branches with growth from last season, while light green illustrates new growth. The main branch is identified by the letter "M", while the sub-branches (daughter branches) are identified by the letter "D" followed by a number.

Figure 5.8 Branches were measured on a 5-weekly basis with a tape measure and measured to the nearest millimetre.

5.3.3 Data analysis

Phenology data collected over the months were analysed with descriptive statistics and simple regression analysis using Microsoft Excel (Microsoft 2010) and Statistica 8.0 (Statsoft 2007). Spearman's Rank Correlation (Statsoft 2007) was used to test the relationship between the phenology, growth and the three environmental variables (cumulative monthly rainfall, mean monthly photoperiod and mean monthly temperature) and also to rank the importance of these variable on the phonological change. The analyses were done using Statistica 8.0 (Statsoft 2007).

5.4 RESULTS AND DISCUSSION

5.4.1 Leaf, flower and seedpod phenology

After monitoring the phenological changes in the leaves, flowers and seedpods of *A. nilotica* over 13 months, seasonal patterns were observed for all three aspects of phenology. The development and change of leaf carriage over the study period are illustrated in Figure 5.9.

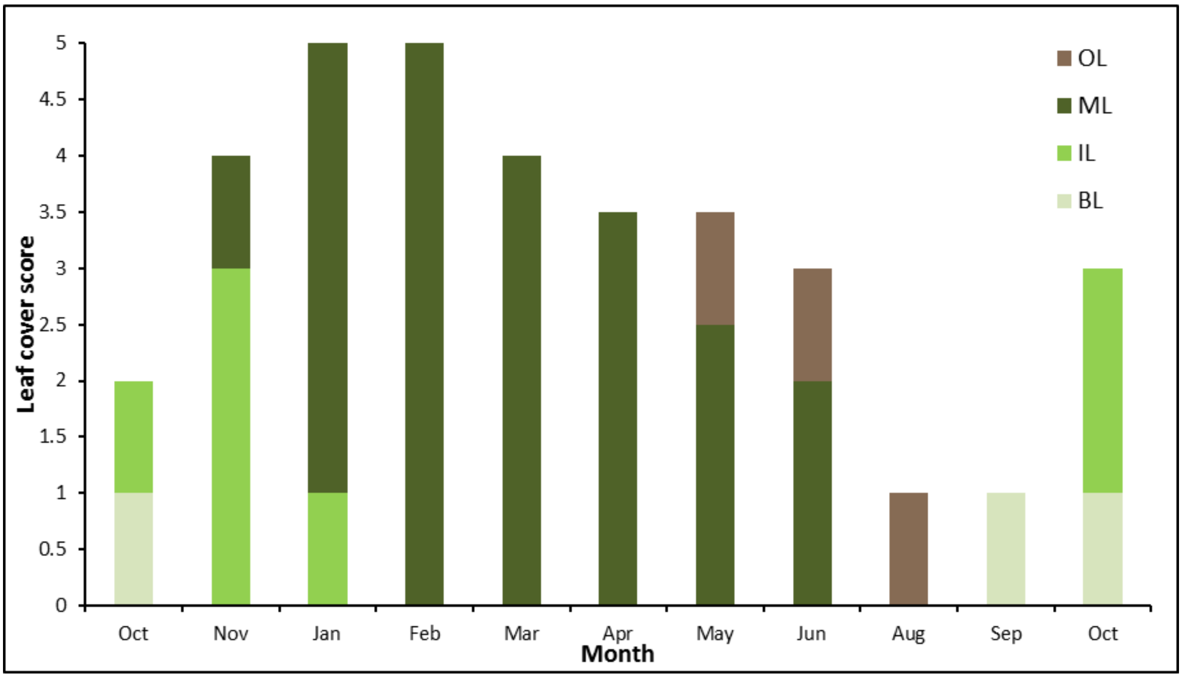


Figure 5.9 Monthly leaf phenology pattern of *A. nilotica* from October 2011 to October 2012. Different leaf stages are illustrated by the different colours shown on the bars. (BL = Budding leaves, IL = Immature leaves, ML = Mature leaves and OL = Old leaves.)

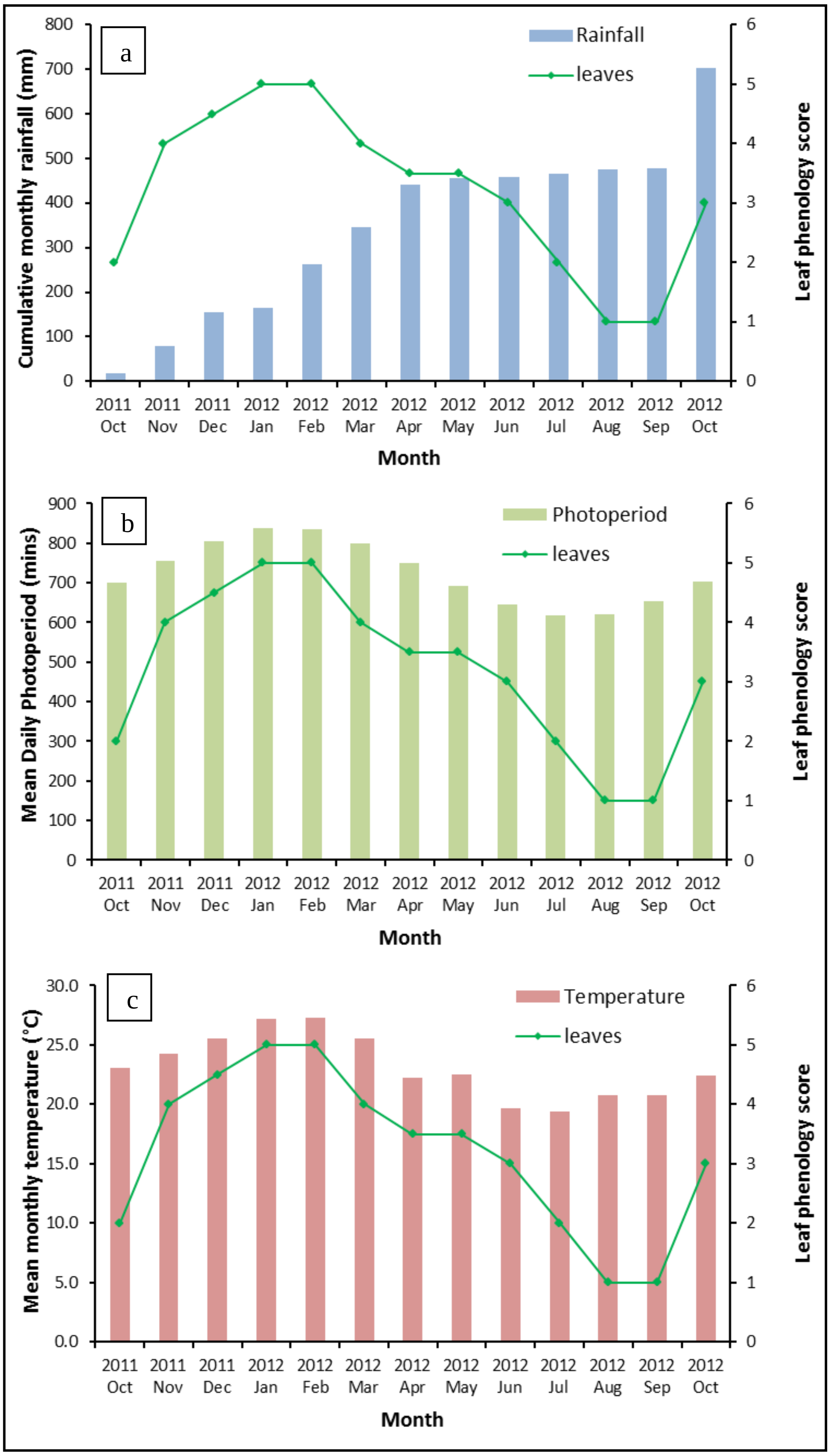


Figure 5.10 The relationship between leaf carriage (phenology) and the climatological variables: **a)** cumulative monthly rainfall, **b**) mean daily photoperiod, and **c)** mean monthly temperature

The leaf phenology of *A. nilotica* shows a distinct seasonal pattern, and like many other plant species, is greatly influenced by-temperature (Higgins *et al.* 2011), photoperiod (Rossatto 2013) and slightly by rainfall (Williams *et al.* 1997, Prior & Bowman 2004) (Figure 5.10). *A nilotica* started the new leafing season with the formation of small leaf buds in early September and continued into October. In South Africa, a similar study conducted on *Colophospermum mopane*, also illustrated a distinct seasonal pattern (Smit 2001). In the latter case, budding started a little later in the season (November/December) and also continued for longer. Leaves developed through the season until they dried out during July to September. During October and November of the next year, trees were mostly bare (Smit 2001). Results of an Australian study on other tree species, shows a similar pattern of deciduous tree phenology that indicates that this is a fairly common phenomenon. This Australian research indicated that the production of new leaves (BL) stopped soon after the start of the wet season (Williams *et al.* 1997). By November, *A nilotica* trees in uMkhuze were showing a large cover of immature leaves (IL) where 41 to 70 % of the tree was recorded with immature leaves and only 1 to 15 % cover with mature leaves (ML) (Figure 5.9). This corresponds well with the increase in photoperiod, an increase in temperature in uMkhuze Game Reserve (Figure 5.10). Immature leaves (IL) were still found on the tree almost halfway into the leafing season, where, by January, the final signs of young leaves were recorded on the trees. January and February are shown to be the months when leafing peaks in the plant, and leaves are covering most of the tree (Figure 5.9). This also happens to be the peak period for both temperature and photoperiod, indicating that there appears to be a correlation between phenology and these two environmental variables. Following these months, leaves start to show signs of senescence, which continued into August, until at the end of the dry winter season when there are few old brown leaves (OL) or no leaves remaining.

The three environmental variables (temperature, rainfall and photoperiod) were correlated against the different phenology stages and the R^2 values were calculated (Table 5.5). A distinct linear relationship was noticed between leaf carriage and temperature ($R^2 = 0.69$, $p < 0.05$), and leaf carriage and photoperiod, ($R^2 = 0.8$, $p < 0.05$) indicating a statistically significant relationship between these factors. A very low R^2 value was determined in the regression analysis between leaf phenology and rainfall. This indicates that rainfall does not greatly influence the seasonal changes of *A. nilotica* leaves in uMkhuze Game Reserve.

At Nylsvley, a study on the phenology of *A. nilotica* also illustrated similar results where the leaves remained on the tree well into the winter months (Milton 1987). Milton (1987) expressed the idea that this will attract herbivores to feed on leaves and the pods thereby dispersing the seeds. Months (May to August) with old or no leaves remaining on the trees have implications for browsing herbivores within the reserve as these old brown leaves are presumed to be far less palatable than the green leaves. A very short turnaround time is needed for the plants to start to bud with new leaves again in October. Since there seems to be a correlation between temperature (R^2 = 0.69) and photoperiod (R^2 = 0.8), and the leaf phenology, it is very difficult to isolate one specific variable. It is therefore concluded that photoperiod, temperature (and even rainfall to a lesser extent) all play an integrated role in the change of phenology in *A. nilotica*.

It is important to take into consideration that all plant species show differences in phenology within different life stages (Augspurger & Bartlett 2003). Recruitment of young trees in the park was not very obvious and therefore it was very difficult to find "young plants" to study. These results only included data from older trees and do not illustrate the effects of these variables have on the phenology of saplings and seedlings. Since seed pods are a direct result of flowering, these two aspects of phenology were combined and the results are presented in Figure 5.11.

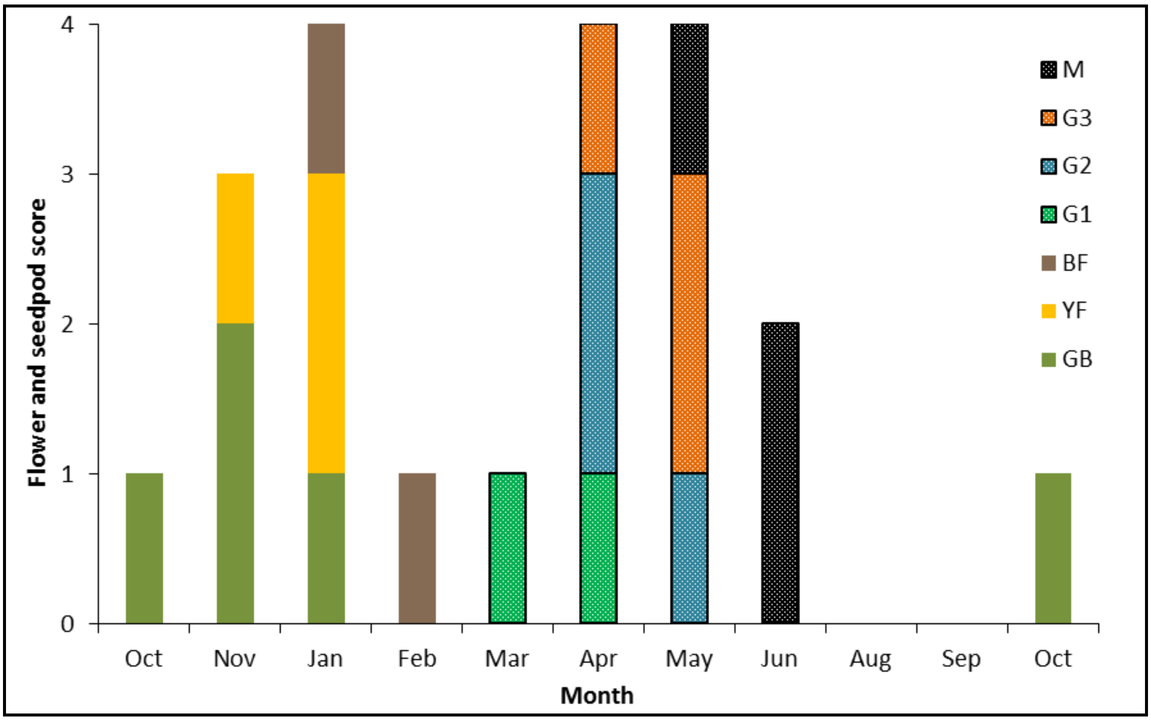


Figure 5.11 Monthly flower and seedpod phenology pattern of *A. nilotica* from October 2011 to October 2012. Different flower and pod stages are illustrated by the different colours shown on the bars. Codes for flowers are defined as: GB = Green buds, YF = Yellow flowers, BF = Brown flowers. Seedpod codes are defined as: very immature green pods less than 3 mm in length (G1), green pods within the 3 to 10 cm length class (G2), fully formed green pods, 10 to 20 cm long (G3) and, fully mature black seed pods (M). (No data were capture for July and hence this month's recordings is absent from the figure.)

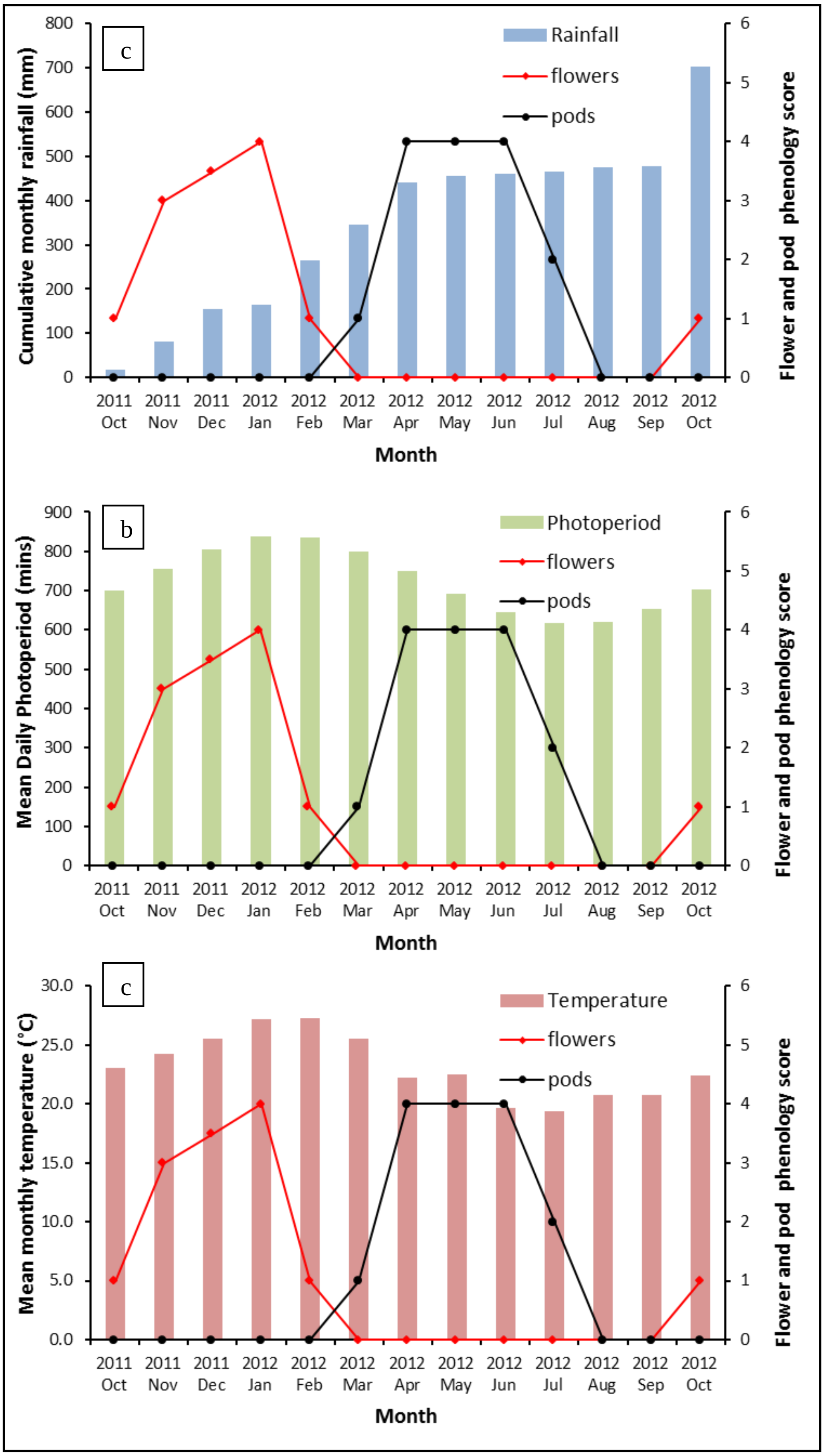
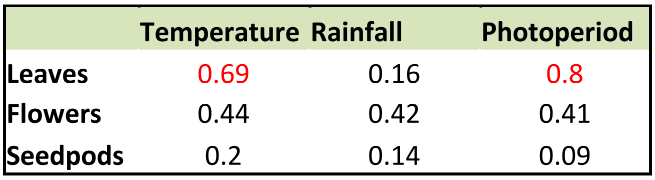


Figure 5.12 The relationship between flower and seedpod phenology and the climatological variables: **a)** Cumulative monthly rainfall, **b**) Mean daily photoperiod, and **c)** Mean monthly temperature.

The results presented in Figure 5.12 and Table 5.5 illustrate very low correlation between rainfall ($R^2 = 0.42$, $p < 0.05$), photoperiod ($R^2 = 0.41$, $p < 0.05$) or temperature ($R^2 = 0.44$, $p < 0.05$) with the development of flowers and an even lower correlation within these variables ($R^2 = 0.14$, 0.09 and 0.2 $p < 0.05$ respectively) for seedpod phenology. No statistical significance and hence no relationship between these environmental factors and phenology was determined.

Table 5.5 Matrix of simple regression analyses showing the R^2 relationships between leaf, flower and seedpod phenology and monthly temperature, photoperiod and cumulative rainfall. Red text indicates significant correlations ($p < 0.5$).



	Temperature	Rainfall	Photoperiod
Leaves	0.69	0.16	0.8
Flowers	0.44	0.42	0.41
Seedpods	0.2	0.14	0.09

Over the year of study, *A. nilotica* started flowering in early October, also at the stage where the first green buds were seen on the tree, and continue through to March, when all that was left on the tree was a small proportion (less than 10%) of old browning flowers. It was noticed that flower development started soon after the leaf budding in October, with new flower buds developing throughout the season. These trees within the reserve were seen to be in their flowering peak during mid-November to early January, overlapping slightly with the peak leafing season (Figure 5.11). At Nylsvley in the Limpopo Province, *A. nilotica* flowered later in the season compared to the plants in uMkhuze and flowers were recorded as being most abundant between December and February (Milton 1987). Since the timing of seasons differs in different regions of the country, it is expected that the beginning and end of the various phenological stages may differ, but the general pattern should remain the same.

In uMkhuze Game Reserve, a slight overlap was noticed in the field where some of the trees were seen to be starting their seeding season while still flowering but this was not a general occurrence and therefore did not have any significant impact on the results presented in Figure 5.12. Due to environmental and possibly genotypical variation, plants in a community will rarely all flower at exactly the same time, although all plants within this population will flower for the same number of days (Elzinga *et al.* 2007). Seed pod formation started in late February/ early March and continued to early May. By June, most of the seedpods had matured, desiccated and had gone dark brown or black in colour. These results correspond in terms of length of flowering to seed ripening with a similar study done at Nylsvley, where these pods ripen during early winter (Milton 1987). By early August, most of the pods with enclosed seeds had either fallen to the ground or had been browsed off the trees and few of the trees had less than 10% black mature seedpods remaining. New seed pods (G1) were produced up until the end of April.

5.4.2 Plant branch growth

After a whole year of monitoring the growth of specifically demarcated branches on each of the marked trees, data were analysed and the results were illustrated in the following figures. During the months of June, July and August 2011, no data were recorded. This was during the winter months and no, or very little, growth was observed on the trees. Hence an extrapolation was performed when the graphs were drawn. Data from the September recordings indicate that there was no growth, and on average a slight decline in growth.

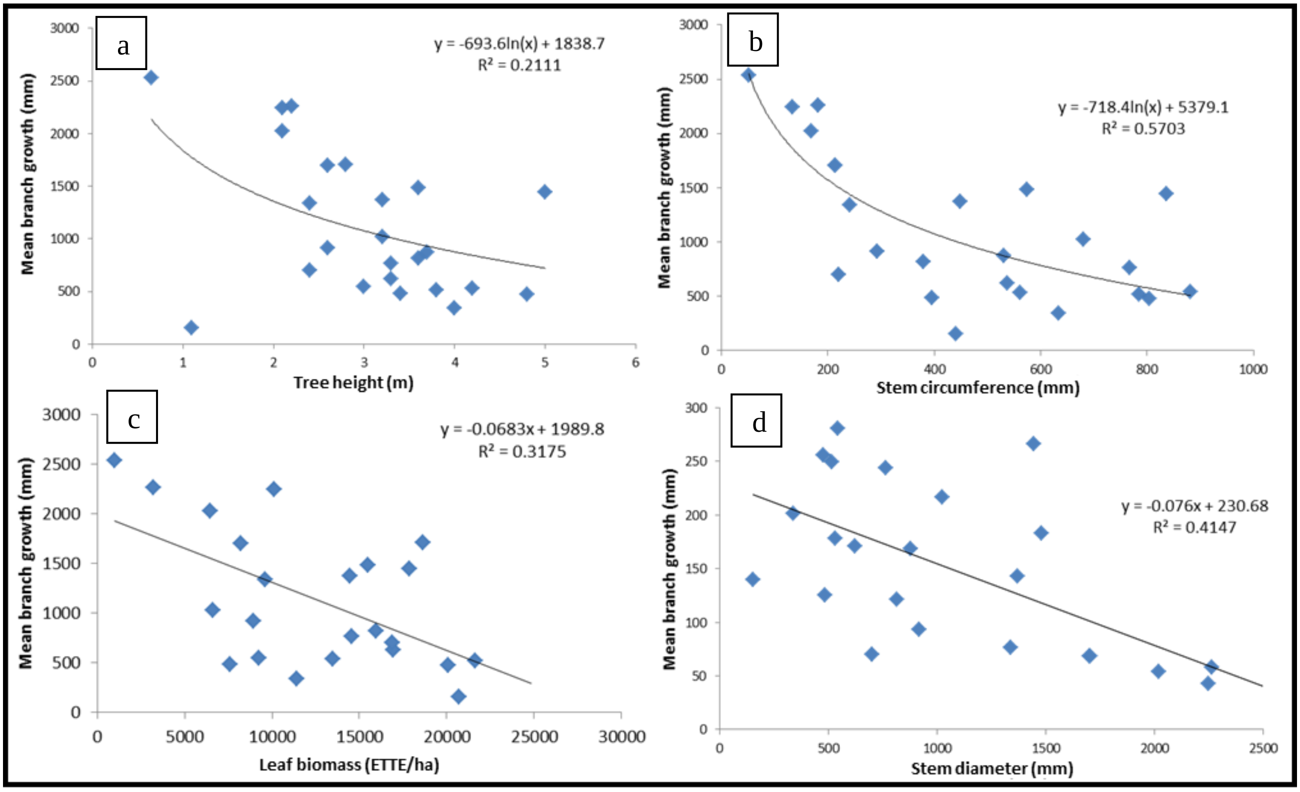


Figure 5.13 Relationship between total mean branch growth and a) tree height, b) tree stem circumference at 50cm from ground level, c) leaf biomass/ha and d) tree stem diameter (at 50 cm from ground level).

A curvi-linear relationship of tree stem circumference and mean total branch growth illustrates a correlation between the two factors ($R^2 = 0.57$, $p < 0.05$). A lower relationship was noted in the correlation between stem diameter and leaf biomass/ ha ($R^2 = 0.4$ and $R^2 = 0.3$, $p < 0.05$) (Figure 5.13). These results illustrate that as the trees increase in size (height, stem circumference and diameter), branch growth declines. This could possibly be due to the fact that there is less of a need for older, larger and well established plants to grow at a fast rate, while a younger plant initially needs to grow at a fast rate to escape potential dangers such as fire and/or browsers. Another reason could be that mature trees invest more energy into reproduction such as flowering and seed production. These trees will have reached maturity and some of them were already starting to show signs of senescence. From personal observation signs of senescence included parts of the tree dying, leaves looking unhealthy and, more often than not, the bark of the stem was covered in lichen. As the density of trees increases the physical space between trees are reduced. Thus, a high tree density does not provide much space for further horizontal growth and lower branches have less light reaching them. This lack of resources is not conducive to plant growth and could explain the negative effect density has on plant sub-branch growth.

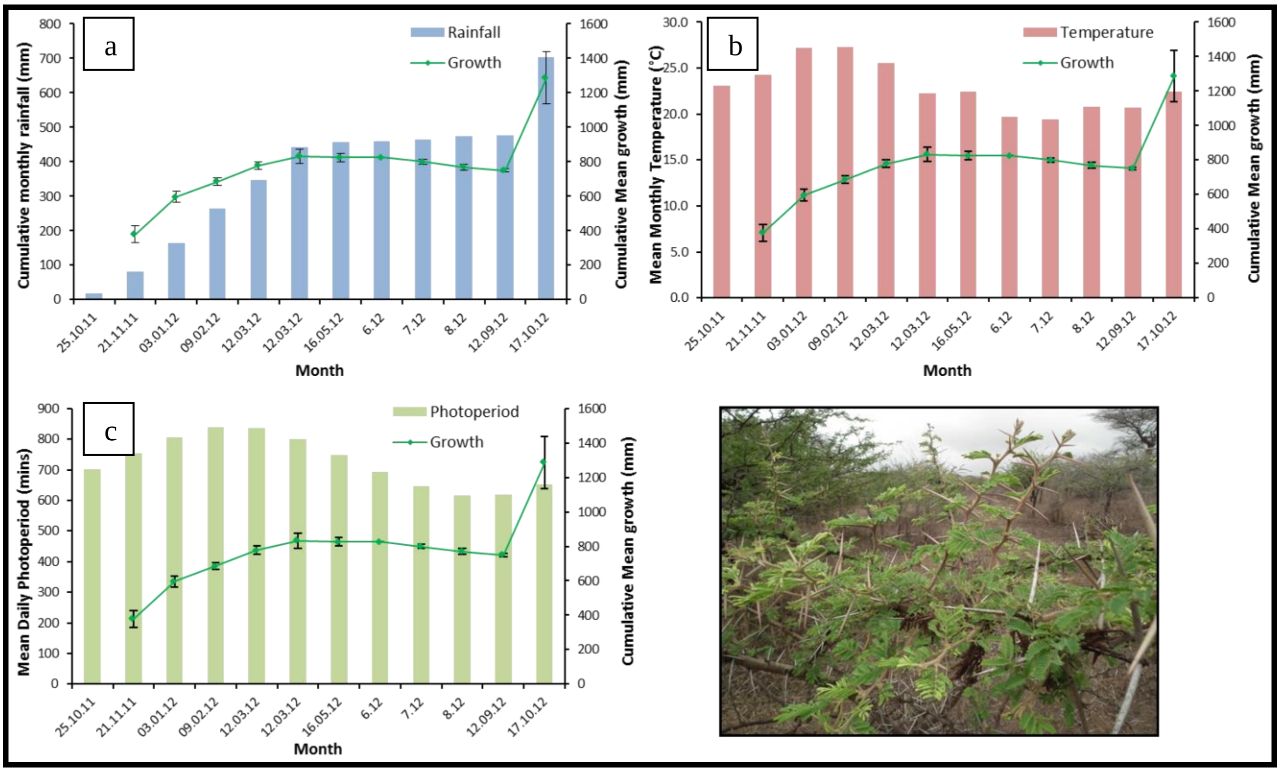


Figure 5.14 The relationship between the cumulated mean growth of the branches and climatological variables: a) cumulative monthly rainfall, b) mean monthly temperature, and c) daylight length. During the winter months (June to August), no growth occurred and measurements were not made between June to August and data was extrapolated for these months

Table 5.6 Matrix of simple regression analyses showing the R^2 relationships between cumulative branch growth and the environmental variables (rainfall, temperature and photoperiod). Text in red indicates significant correlations ($p < 0.05$).

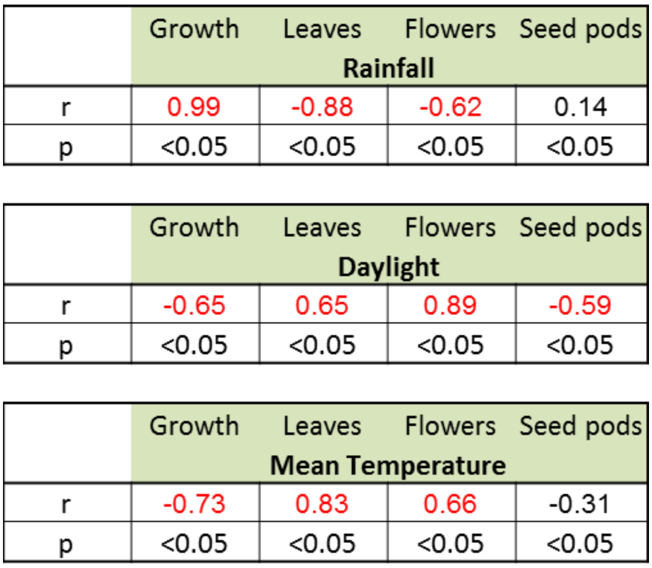
	Rainfall	Temperature	Photoperiod
R²	0.89	0.04	0.56
p	p<0.05	p<0.05	p<0.05

When correlating the environmental variables (rainfall, temperature and photoperiod) with branch growth using a simple linear regression, the regression equation of strongest statistical significance was the relationship of rainfall with branch growth ($R^2 = 0.89$, $p<0.05$) (Table 5.6). This indicates that rainfall plays a very prominent and important role in branch growth. The effect of photoperiod and temperature had very little correlation on branch growth. When the total cumulative growth was plotted against the cumulative rainfall, a distinct trend is at the onset of the wet season when the rainfall increases and the branch growth displayed a corresponding increase in growth. Once the rainfall eases off, the branch growth displayed a corresponding slow down (Figure 5.14). The relation between these two variables indicates that during the wet season (October to April) there is a high average growth rate within these trees. Once the rainy season had subsided, (May to September) very little growth was recorded. In those seasons with a combination of high temperatures, long day lengths and high rainfall (November to April) there is a much higher mean growth than during the winter period when temperatures are just below 20°C (Figure 5.14).

The literature perused has also indicated that growth of many plant species (including *Acacia*) is encouraged by a longer photoperiod (Adams & Langton 1998). These longer daylight hours provide the plant with a longer period to photosynthesise and thus they have a longer daily period for growth. From the data presented in Figure 5.14 it is evident that when the photoperiod (daylight hours) is high the mean growth of these trees are also high. This observation corresponds with similar studies involving *A. karroo* (Janecke & Smit 2011) and *C. mopane* (Smit 2001), where the highest branch growth was measured during November and December (wet summer months) This confirms that over the Spring/Summer period, when rainfall, temperature and photoperiod are at their maximum, conditions for growth are optimal.

The results of the Spearman's Rank Correlation between the mean monthly temperatures, cumulative rainfall, mean monthly photoperiod and cumulative growth, leaf, flower and seed phenology scores are presented in Table 5.7.

Table 5.7 Results of the Rank Correlation Co-efficient analyses between cumulative rainfall, average monthly photoperiod and average monthly temperatures (independent variables) and branch growth, leaf, flower and seed carriage percentages of each plant species (dependent variables) (p <0.5).



	Growth	Leaves	Flowers	Seed pods
	Rainfall			
r	0.99	-0.88	-0.62	0.14
p	<0.05	<0.05	<0.05	<0.05

	Growth	Leaves	Flowers	Seed pods
	Daylight			
r	-0.65	0.65	0.89	-0.59
p	<0.05	<0.05	<0.05	<0.05

	Growth	Leaves	Flowers	Seed pods
	Mean Temperature			
r	-0.73	0.83	0.66	-0.31
p	<0.05	<0.05	<0.05	<0.05

The Spearman's Rank Correlation showed statistically significant (p <0.5) correlations between phenology and branch growth and the three measured environmental variables. They varied from positive (r = 0.99, p <0.5) to negative (r = - 0.7, p <0.5) (Table 5.6). Of these variables rainfall is notable with the highest correlation (r = 0.99) between branch growth and rainfall, confirming a very strong link between the two (Table 5.7). Leaf phenology and rainfall, photoperiod and mean monthly temperature all had a moderate to very strong correlation where they too varied from positive (r = 0.65 to 0.77, p <0.5) to negative (r = - 0.88, p <0.5). The correlations were also moderate to high between the flower phenology score and the three environmental variables (rainfall: r = -0.62, photoperiod: r = 0.89 and mean monthly temperature: r = 0.66, p <0.5). Finally, seedpod phenology did not seem to have much correlation with any of the three variables. No correlation was seen with seedpod phenology and rainfall (r = 0.14, p <0.5) or mean monthly temperature (r = - 0.31, p <0.5), whereas a low correlation was recorded for photoperiod (r = 0.59, p <0.5).

Due to the time limitation of this study (these data has been taken from only one year of recordings), allowances should be made for annual differences. Variability between years, especially for rainfall and temperature, is large and therefore it can be expected that results may differ considerably from year to year. Global climate change is thought to alter the phenology of a plant significantly (Cleland *et al.* 2007). An increase in length of the season, decrease in frost days and an increase in temperature has been shown to be very important for plant growth and, with global change, the possible earlier onset of spring will create a longer growing season as well (Cleland *et al.* 2007). In order to get a greater understanding on how the phenology of the tree would react during different climatic variations, this research would have to be extended for a number of years of varying rainfall (*i.e.* both drought and excessive rainfall, as well as early and rainfall). Similarly years with extremes of temperature variation would have to be studied.

Another challenge to this study was the monthly branch measurements. During intense browsing pressure and during winter months when leaves are limited, browsers are known to utilize shoots to a greater extent than when leaves are in abundance (Van der Waal 2005). Sub-branches were frequently found to have been browsed and had to be excluded from the study. Browsing could have an effect on the plant where more sub-branch growth is encouraged or a flush of out-of-season leaves can occur (du Toit *et al.* 1990) and therefore have a bias towards the growth of the tree. To have overcome this bias, exclusion plots would have to be placed around the trees to prevent any browsing. Although this would not prevent insect herbivory on the trees, it would prevent the bulk of the browsing incidents from occurring.

Notwithstanding these weaknesses, the outcomes of this data can still be very useful in providing a basic understanding of the processes of plant phenology. This knowledge will be useful in managing both the plant and the animals within the reserve. Understanding the flowering process further, could provide information to guide the recommended seasonality of burning. For example, when burning to reduce thickening or prevent bush encroachment, a burn after the plant has expended a lot of energy on flowering and pod production, but before the seeds are ripe (in this study, March/April), is recommended. A burn when a plant has the least accumulated resources ensures that the fewest number of viable seeds are produced. A plant lacking in accumulated resources may also be stunted in its growth, which will prevent its further development towards maturity. A further long-term study on leaf phenology needs to be done in order to validate these results over fluctuating climatic conditions.

A. nilotica provides valuable feed for the browsing herbivores within the reserve. The leaf phenological study has illustrated the seasonality of the leaves and the period of the year, when leaf cover drops significantly. It is now known that the critical period when browsing herbivores rely on *A. nilotica* forage has been identified as from May through to September, when the leaves start to turn to a yellowy brown colour and leaf cover drops almost completely. Although animals are known to feed on fallen litter (leaves and pods) of various plant species (Buys 1990), once the podding season had finished by early August, very few pods remained on the ground. From personal observation, once the leaves have fallen off their stalks, they are tiny and do not last long before they, too, are either consumed or decomposed.

A large proportion of this reserve is well populated with *A. nilotica* and other deciduous plants that are important for browsing animals. In a reserve where the aim is for as little human interference as possible, management would expect the condition of animals to decline over winter. The only other option, which is currently in place in uMkhuze, is to remove surplus animals from the reserve. This can be in the form of relocation or culling and, in the process reduces the stocking rate within the reserve. On game ranches where more human interference occurs, a further option would be to provide the animals with additional feed (in the form of hay, pellets and licks) in order to maintain their condition through the winter and other feed-critical periods (Janecke & Smit 2011).

5.5 CONCLUSION

This study has indicated the importance seasons play in the leaf, flower and seed pod phenology as well as the branch growth. *A. nilotica* is seen to have its peak leafing period during the middle of the wet season and its critical period during the drier winter months. Leaf biomass and tree stem circumference have also shown to have a negative relationship on branch growth. The outcome of this data will be useful for further management of this tree although the seasonality changes over KZN must be taken into account. Although the pattern will remain the same, the dates of change in phenology may differ.

CHAPTER 6

TOWARDS MANAGEMENT GUIDELINES BASED ON THE CONCEPTUAL UNDERSTANDING OF THE *ACACIA NILOTICA* LIFE CYCLE

6.1 INTRODUCTION

The expansion of *A. nilotica* occurs both as an increase in tree density at sites (bush thickening) in which they naturally occur and as encroachment into new areas where they did not previously occur (bush encroachment). This is a threat to the rangelands within the province as this thickening reduces the grazing potential of these areas. To gain an understanding of *A. nilotica* thicket formation, a synthesis of our understanding of the mechanisms and processes of this thickening needs to be developed. This understanding will provide a conceptual framework within which to develop management strategies. With different land use practices ranging from commercial agriculture to conservation, the causes and consequences of an increase in woody plant density are often perceived differently by land managers with their different needs. Within conservation and natural rangelands, such woody plant increase may be accepted as a natural process, involving a succession that is driven by global changes and local land management practices (Wiegand *et al.* 2006). In agricultural areas it is often seen to be a response to some form of artificial disturbance such as land use change, change in fire regime or intensive grazing (Jeltsch *et al.* 2000, Ward 2005a).

Negative effects of an increase of woody plants can include competition with herbaceous vegetation for sunlight, soil water and nutrients. A dense stand of woody plants can have a possible negative effect on fauna and floral biodiversity where shading and allelopathic compounds may prevent other plant species from growing in the same areas as these woody plant species. Dense bush can restrict animal movement; thereby making areas encroached by woody plants unfavourable to herbivores. Competition with herbaceous species for soil water and nutrients is a well-documented impact of woody plants (Scholes & Archer 1997). Since tree roots grow deep into the soil, and into a zone where no herbaceous competition occurs, low growing herbaceous species have very little competitive effect on tree nutrient uptake. The competition impacts of woody plants are generally more detrimental on herbaceous plant species. Trees have a competitive advantage over grasses for soil water and nutrients since they can utilize these resources in the same rooting zone as that of grasses, but also in deeper soil layers (Scholes & Archer 1997).

To control this plant effectively, the most appropriate management intervention needs to be identified. Firstly, is it considered a problem or not in the specific area under study? If it is considered a problem, the exact nature of the problem needs to be identified, as well as the extent of the problem. Management interventions may include the complete removal of all the plants of the species concerned, or selective thinning to a pre-determined density. Alternatively, it may require the prevention of any further increase of the plant. If the thickening or encroachment of woody plants is on the same level as that of alien invasive plants, then an intensive management plan that may involve mechanical removal and the use herbicides could be developed. In a situation where the encroachment is not yet considered a problem, the management plan may incorporate preventative measures such as the use of fire and conservative stocking rates, combined with constant monitoring of the potential problem. Finally, if it is concluded that the plant is not a current or potential threat to the existing land use practice, then the management can be continued without alteration.

Depending on the nature and extent of the problem, the spatial and temporal scale of the management plan must be established. If the area of bush thickening by a specific woody species is considered serious at a provincial level, a provincial strategy on managing the plant needs to be developed and implemented. On the other end of the scale, the problem may be very localized, which will require a smaller-scale management approach. The next step will be the establishment of the decision making process guided by a decision support system that involves the most suitable line of action which may include the use of herbicides, mechanical clearing, prescribed burning and correct grazing management (Zimmerman & Mwazi 2002).

In this chapter mechanisms and processes affecting *A. nilotica* will be identified and used to develop a “tool box” of management options. The fundamental basis to the approach for a solution is that there is no quick and easy solution to the problem and that each situation is unique. It is for this reason that an integrated long-term strategy, based on management objectives and the unique characteristics of each situation, needs to be developed.

This chapter aims to combine knowledge relating to bush thickening by *A. nilotica* in order to develop a management strategy for those areas currently experiencing *A. nilotica* thickening/ encroachment and those areas that have the potential to experience this problem in the future.

6.2 CONCEPTUAL UNDERSTANDING ON *ACACIA NILOTICA* THICKENING

6.2.1 Introduction

A summary of the proposed conceptual model of recruitment and basic life cycle of *A. nilotica* is presented in Figure 7.1 as a number of distinct states and transitions. These states and transitions are subsequently discussed with reference to supporting sources of information.

6.2.1 Life cycle

Primarily there are five distinct states in the life cycle of *A. nilotica*, each one playing a potential role in the process of bush thickening of *A. nilotica*. These five states are: (i) addition of seeds to a seed bank; (ii) seed germination and establishment of the seedling; (iii) growth into a sapling; (iv) mature tree; and (v) senescing tree.

6.2.1.1 Seed bank

The seed bank, a store of viable seeds that are found either on the surface or in the soil (Roberts 1981), is an important part of the life cycle of *A. nilotica*, and plays a big role in seedling recruitment and establishment (Van der Valk & Davis 1978). On a landscape level, *A. nilotica* can have up to 86 000 seeds/ha within its seed bank, of which a mean of 68 to 77% will not have been predated on and are still intact (Witkowski & Garner 2000). Seeds can remain dormant within the soil until conditions are suitable for germination (Finch-Savage & Leubner-Metzger 2006). Following the onset of conditions suitable for germination, seeds are likely to germinate and aggravate the concern of woody plant thickening in the area. Within the context of this research, it is assumed that the physical properties of the soil contribute to the effectiveness of the seed banks. The hardness of the topsoil layer and the extent of the surface capping impact negatively on the effectiveness of the seed bank. A hard surface crusting limits the number of seeds that can get into the soil. The permeability of the soil is another factor affecting seed bank effectiveness. Too wet a soil may drown the seeds, heavy clay soils may create a difficulty when it comes to seedling germination. Another concern for a seed within the seed bank is seed predation. Small seed predators such as rodents are known to dig seeds up and consume them as they are a valuable food source. Antelope, rodents and insects will also consume *A. nilotica* seeds once they have fallen to the ground. Other larger herbivores (giraffe, kudu and elephant) often assist in seed germination by passing the seed unharmed through the digestive system, scarifying them in the process and transporting them to another area. In this way, dispersal of the plant occurs and woody plant expansion is encouraged (Miller 1996). Other forms of physical scarification include erosion from soil, wind and fire.

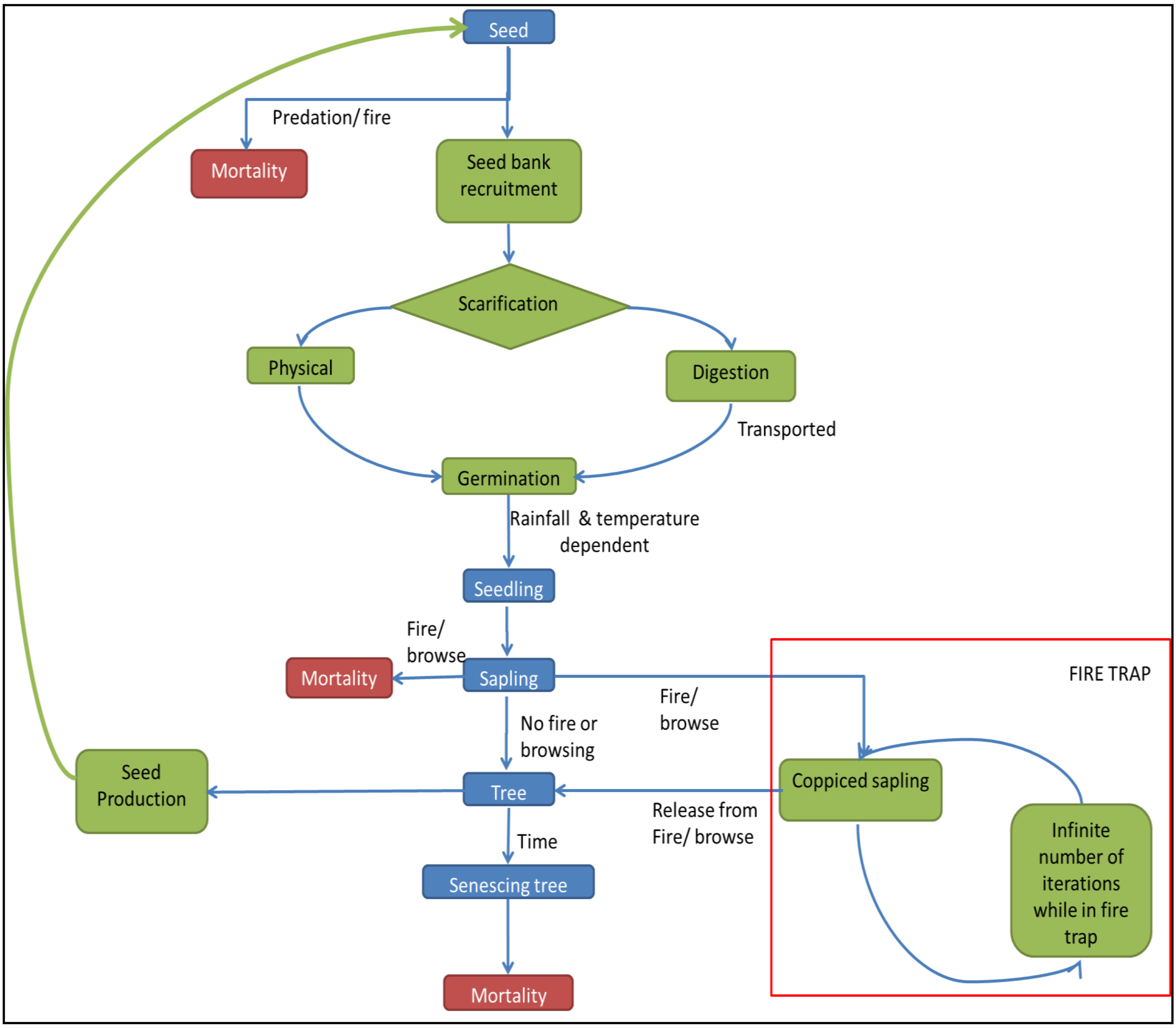


Figure 6.1 Conceptual sequence of the life cycle of A. *nilotica* from seed production to mortality as a number of distinct states and transitions. The blue blocks represent the 5 different states the plant will go through in its life span while the green blocks illustrate the processes the plant goes through to the next state.

Once the seeds are in the seed bank and suitable climatic conditions are met, germination is likely to take place. Successful germination of *A. nilotica* seeds depends on a variety of environmental factors. If soil capping is too extreme, seedlings will battle to crack through the soil surface to continue their growth. Hoof action, for this reason, is a vital component of this process as it breaks the crust, allowing for infiltration of rainfall and assisting in plant germination. One of the ideal conditions for *A. nilotica* seedling germination includes the time after a fire. Fire promotes scarification and burns away any herbaceous biomass thus leaving open areas with no shade competition (Walters *et al.*

2004). Rainfall and warm temperatures are also known to encourage germination events and stimulate seedling growth (Choinski & Tuohy 1991, Wilson & Witkowski 1998).

6.2.1.2 Recruitment

The recruitment for new individual *A. nilotica* plants is through seed growth. If no seeds are produced then no recruitment occurs. After recruitment the plants can be held in the fire trap for decades without being noticed or having any detrimental effect on the surrounding environment. If mature/adult plants are evident within a site, they will be a seed source. On the other hand, if there are no mature plants there will be no seed production. This is an important factor to take into consideration when managing *A. nilotica* – if a mature plant can be restricted at its flowering/pod production stage, recruitment can be curtailed. Another aspect that encourages successful recruitment is the transport of the seed within animals. If it is conceptually accepted that different animal species move different distances, then seeds can be deposited at a variety of distances from the parent tree. Since animals that are highly territorial do not move large distances, the seeds they carry will not be moved far. It is assumed that other animals that are less territorial (*e.g.* impala have territories on average of 66 000 m^2 (Vincent 1979)) and will drop seeds within an estimated 1 or 2 km from the tree, while animals such as elephants, that have very little to no territorial behaviour (Smithers 1983) can walk larger distances (10 – 20 km per day) (Ipavec *et al.* 2007) and have the potential to establish a new stand of trees in areas that were previously free of potentially encroaching plants (like *A. nilotica*).

Within the seed bank, three conditions (hoof action, fire and low herbaceous cover) also affect seed longevity. A possible mechanism for *A. nilotica* thickening is disturbance due to overgrazing. Overgrazing leads to a low herbaceous biomass that lowers the shade, nutrient and other resource competition. Through overgrazing, the fuel load is reduced and hot fires cannot be implemented and therefore seedlings won’t be killed. Stocking an area heavily and promoting overgrazing also leads to trampling. As previously mentioned, this hoof action breaks up soil clods and discourages soil crusting which affects seed longevity and germination. When managing a property, it should be taken into consideration that apart from affecting the condition of the veld composition, overgrazing also encourages woody plant thickening. Too much grazing reduces the fire fuel load (Bachelet *et al.* 2000, Joubert *et al.* 2008). This makes effective burning difficult and infrequent, thereby supporting the growth of young plants to get to the stage where they are no longer burnt down by fire

6.2.1.3 Seedling stage

A seedling is defined as a newly germinated, single herbaceous-stemmed plant with a single apical meristem. This is one of the most vulnerable stages in the life history of the plant. This stage is highly vulnerable to herbivory – either in the form of incidental grazing, where it is grazed unintentionally by a bulk grazer, or where a herbivore focuses on it specifically and selectively browses the seedling. Once the apical meristem is removed from a seedling plant, mortality is likely to occur. Fire has a similar effect to herbivory where the delicate apical meristems are burnt, or the whole plant, is damaged by fire. Finally a possible allelopathic chemical affect could influence and affect the growth of these seedlings. Throughout the period of this study, very few young *A. nilotica* seedlings were found to be growing under the adult trees in the Mkhuze Game Reserve study site. Whether this was due to shading or allelopathy is beyond the scope of this study, although these factors must not be discarded.

6.2.1.4 The sapling stage

Once the plant matures past its seedling stage, it develops into a sapling which can be defined as a 'young' tree (Oxford Dictionaries 2014), In this context, it is taken to be a plant small enough to be burnt down, but less vulnerable to browsing and fire than a seedling. If a sapling gets burnt down, it has the ability to coppice and re-grow.

A feature of *A. nilotica* plants is that they are able to coppice. From observations in uMkhuze, depending on the management, not all plants coppice. The coppicing plant is more often than not, multi-stemmed and its size is determined by the fire trap (approximately 2 m high) due to the fire sensitivity of these plants (Trollope 1974). Since coppicing trees use any excess carbohydrate storage for coppice growth, the plants at this stage rarely produce any flowers or seedpods. If a fire burns through a cohort of coppicing trees on a regular basis, these plants may remain trapped in this stage for long period of time. A few years without fire in an area of coppicing plants will result in these plants escaping the firetrap and entering the mature tree stage of their life history.

Through personal observations in uMkhuze, one way that some woody species (such as *A. nilotica*) can increase in plant biomass, is through coppicing from the base and assuming a multi-stemmed format with increased volume, biomass and height. Coppicing is mostly management induced and can be caused by fire, browsing, clearing and harvesting of trees. Mature plants seem to be less likely to coppice than young plants.

- **Mechanisms of coppicing**

Once an *A nilotica* plant has been burnt, browsed or harvested, it is stimulated to coppice. In *A. nilotica* this occurs from the base of the stem, unlike other coppicing plants (e.g. *Dichrostachys cinerea*) which can coppice from the roots thereby promoting additional small trees coppiced within a radius of the parent tree.

With global change and the increase in CO_2, the rate of photosynthesis has increased in woody plants, this increase promotes more photosynthesis which in turn increases the amount of carbohydrates produced and stored. The high production of carbohydrates increases the root biomass and hence the ability of the plant to coppice (Bond & Midgley 2000).

6.2.1.5 Mature tree stage

Once an *A. nilotica* plant is mature and has reached the tree phase, it is at a stage where it is most resilient to fire and herbivory. It is also at this stage where it is at its most influential in increasing biomass and promoting thickening. These mature plants flower on a regular basis which then leads to fertilization, seed pod formation and development. Since the volume of leaf mass on these adult trees is far greater than that of the trees in any other life stages, it has been noticed during this study (Chapter 5) that these trees are also subjected to year-round herbivory, peaking in the late winter when, generally, there is limited browse available. At first leaf bud break, the new leaves are soft and nutritious and selective feeding takes place when new leaves and young branches are browsed first. During the seeding season, seedpods with seeds provide valuable fodder for many herbivores and are predated on by insects and rodents as well.

6.2.1.6 Senescing tree stage

The final stage occurs when the tree starts to senesce. *A. nilotica* trees are said to live for between 25 and 60 years (Kriticos *et al.* 1999), this senescing stage covers the final years of the tree's life. A question that remains unanswered is, does the life of these trees get lengthened if they are coppiced earlier in their life history? Or is their lifespan similar to that of a tree that has never coppiced? From personal observations during this research, at this senescing stage, branches begin to droop downwards, patches of branches die and, in uMkhuze Reserve, the bark of these old trees are seen to be covered in lichen. Lichen is known to favour the decaying wood of other senescing trees and it is not uncommon to find lichen on older trees of other plant species (Kalwij *et al.* 2005). It can therefore be deduced that similar results happen in aging *A. nilotica* trees.

6.2.2 Site selectivity

Within KZN (on a regional scale), *A. nilotica* is very site specific as to where the species is likely to grow. From the predictive species distribution model developed in Chapter 3 (using the Maxent model) it is determined that this species has the potential to occur over much of KZN but is more prevalent in areas at lower altitudes and with higher rainfall. Within a landscape scale, *A. nilotica* seems to prefer landforms where there are soils with a high clay content. The position in the landscape in which these trees generally occur is on the flat-bottomed areas of a catena. Thickening of *A. nilotica* seems to be increasing in density where there has been a disturbance often created by management, whether this is managed commercially, communally or for conservation, the result does not differ greatly (Wigley *et al.* 2009).

6.2.3 Plant sociology

Woody plant species in general, and *A. nilotica* is no exception, prevent the growth of other plant species either by shading, intense competition for soil nutrients and moisture, or by producing allelopathic chemicals that restrict the growth of other plants (El-Khawas & Shehata 2005). In uMkhuze Game Reserve, a few grasses and *E. divinorum* were the only plant species that were seen to resist this.

Although *A. nilotica* is perceived by many land managers to have unfavourable effects on the ecosystem, it is imperative to remember that it is still an important component of the ecosystem. It, like many other floral components, contributes to natural succession pathways in the ecosystem. A conceptualized successional cycle of *A. nilotica* begins with the colonization by this plant of a grassland/open savanna ecosystem, where the first signs of this woody plant are noticed. Over a period of time, under correct conditions (both natural and managerial), this initial cohort matures, flowers, produces seed and new plants germinate, creating a dense stand or thicket of *A. nilotica*. From what is seen to have happened at uMkhuze Game Reserve, once this cohort matures and thins out a bit, *E. divinorum* and sometimes other *Acacia (*such as *Acacia luederitzii)* species will grow in the *A. nilotica* stand and this becomes more like a low forest as defined by Edwards (1983). A similar secondary successional shift has been documented in Hluhluwe Game Reserve where *A. nilotica* savannas have been seen to be being replaced by certain broadleaved plant species, in particular *Euclea* species (Skowno *et al.* 1999). It was also found that *Acacia karroo* seedlings were more commonly found under adult plants than were *A. nilotica* seedlings (Skowno *et al.* 1999). These are all obvious signs of secondary succession. In other areas of uMkhuze Game Reserve, these *A. nilotica* cohorts have all reached a senescing stage at the same time. Since these stands are all of similar age, these groups of *A. nilotica* are dying out at much the same time. This results in a return to a more open savanna scenario once again. This will remain as such until favourable conditions and a cohort of seeds in the seed bank germinate and the successional cycle is initiated again. This succession takes place over the lifespan of the plant (*i.e.* up to 60 years). Within the uMkhuze context, many areas are noted to be in the senescing stage, where a few trees within the group have already died and it is just a matter of time before the other trees die, opening up an area for the successional cycle to continue its pattern. As mentioned before, *E. divinorum* is seen to have some relation with *A. nilotica* in that they seem to be one of the few woody plants to establish and grow within dense stands of *A. nilotica* trees. The competition and dynamics between these two species was already noticed in 1987 (Smith & Goodman 1987) and very little further has been recorded on the relationship between the two species. The above is a conceptual model that needs further investigation. Informal observations indicate that this sequence does occur but there may be complexities to this model as other trees grow in places where *A. nilotica* creates suitable conditions for their recruitment.

6.3 MANAGEMENT AND CONTROL

6.3.1 Introduction

This section takes into account the life history characteristics of *A nilotica* described in Section 7.2 and uses this information to develop strategies that may guide management actions given different scenarios. A variety of management actions are available within this “toolkit” of management actions and range from natural, fairly unobtrusive methods (*e.g.* browsing) to extremely intrusive and resource intensive (*e.g.* bulldozers).

6.3.2 Prevention of infestation

In managing an increase in *A. nilotica*, both in terms of the area encroached and of density, the first objective that every landowner should consider is to prevent the establishment of this species in areas where there are currently no plants. In doing this, a lot of time, money and other resources can be saved. Through keeping herbivore movement under control, the movement and spread of *A. nilotica* seeds can be drastically reduced in intensively managed areas (such as commercial livestock farms). Understandably, in areas that are less intensively managed, this solution is more difficult to achieve. The best form of management in a thicket-free area is to continue with the existing land management and prevent any disturbances. Management should be implemented to make sure that seeds do not get into an area that is prone to infestation. If woody plants are noticed, action must be implemented to prevent further growth of these seedlings.

6.3.3 Management decision toolbox

Tool 1: FIRE

Fire is a natural component of the KZN landscape and can be harnessed as a management tool at different stages of the *A nilotica* life history.

1a Fire and seeds

A hot, high intensity fire created by a large fuel load will kill seeds on the surface and in the topsoil. However, low intensity fire can also stimulate seed germination.

1b Fire and seedlings

Fire can be a very effective tool in reducing seedling survival. When burning to control or remove seedlings, the best time to do this is when the grass fuel load is high so that a high intensity fire can be run through an area, killing all the young seedlings. The phenology study in Chapter 5 indicates that seeds are available for germination after May. After this, with the appropriate rainfall, germination will occur. If there is a large seed germination event, a fire should be considered within a few months after germination.

While the plant is a seedling (It is not known how long it remains in this stage as it is likely to be variable depending on rainfall), it will be killed by fire. As a management tool, fire is used when the plant is still in its seedling stage.

1c Fire and coppice plants

Regular burning is able to maintain a coppice plant within the fire trap. The benefit of this is that while the plant is coppicing, no flowers or seeds are produced. It is important to maintain coppicing plants at a low height and within the firetrap, thereby keeping them at an available browse level that is most convenient for the majority of browsers. To achieve this, a regular, high intensity burn is needed. With the increase in CO_2, plants are now able to escape from the fire trap more easily and hence need to be managed with great care (Bond & Midgley 2000).

1d Fire and mature trees

While mature plants have generally escaped the firetrap and coppicing is not a concern, a fierce, high intensity fire will result in some top kill. What is then of concern is the number of seed these plants produce. The best way to control further establishment is to burn the trees once they have maximized energy use through flower and seed production. Burning once the tree has set seed (at small green seedpod stage) is suggested to remove seed and, in this way to deplete reserves. Achieving this is particularly difficult since a high fuel load is needed to carry the fire throughout the stand. To achieve the necessary grass load under these trees is not always possible. Many of these plants will survive but through burning these trees, seed production will be curtailed. In this way the recruitment of new trees is slowed down and seed dispersal by animals to *A. nilotica*-free zones is also reduced.

Senescing trees are least on a land manager's list of concern. Seed production is expected to be lower as these plants are in the process of dying and do not contribute greatly to the recruitment of new plants.

Tool 2: ANIMALS

2a Browsing

The main impact of browsing as a management tool is that it reduces tree biomass. Another impact of browsing is that it promotes coppicing. Due to animals of differing heights, browsing at different heights coppicing and re-sprouting under these circumstances will occur at different levels and thereby change the dimensions of the tree. Depending on the browser, the extent of the browsing impact can vary. Bulk browsers (such as black rhino and elephant) create a far more significant impact on a tree than that of a selective browser (such as suni or nyala). Although coppicing and resprouting are different processes and plants respond differently, browsing stimulates branch growth and coppicing in a way similar to fire. If a plant is browsed close to the surface, coppicing will occur, while animals browsing branch tips will result in resprouting. Browsers also assist in seed control by biting off and consuming seedpods during the seeding season.

2b High intensity browsing

According to Trollope (1974), the ecological role of fire in the control of bush encroachment is to maintain the woody plants at an available height for browsers. A high intensity fire successfully top kills woody plants to an approximate level of 2 m. It has been shown that putting a very high density of browsers (such as goats) into an area, following a burn, successfully reduces bush thickness and is a highly successful tool in reducing tree density. The research of Sweet & Mphinyane (1986) illustrated that over 3 years, bush density decreased by 52% using high density browsing in a camp system in Botswana, in an area dominated by *Combretum apiculatum* and *Acacia nigrescens*. Another study of post burn, high density browsing by goats showed that, over a five year time period, there was a 90% reduction in bush density (Trollope 1974).

2c Timing and seasonality of browse

The timing of certain browse actions are essential. In controlling seed spread, very heavy browsing in the early season of growth, during flowering and until the early stages of pod development should be allowed. However, in a controlled environment, before the seeds are at the ripe stage, the browsers need to be removed so they do not spread the seeds. Allowing animals to browse after a fire kills the coppice. This reduces the plant size and its vigour.

2d Grazing:

Grazing is an effective management tool if used correctly. A low grazing stocking density allows the grass biomass to build up creating a larger fire fuel load which thus produces hotter and more frequent fires, killing seeds, seedlings, saplings and coppice. Bulk grazers will also graze seedlings in their non-selective foraging. Too many selective grazers will encourage seedling growth as they selectively leave seedlings during their grazing and these will grow into saplings.

To assist with the management of *A. nilotica,* holistic strategies involving the stock currently in place, should be used. In the agricultural system, a strategy can be developed in managing livestock within camps. For example, by concentrating the stock in a camp when the plant is at its most vulnerable, that is the seedling stage, so that as many small seedlings as is possible have their meristems removed or are damaged**.** In using animals to work strategically with managing this plant, livestock must be removed from a camp with *A. nilotica* when seeds are close to mature and are ready to be transported. This way seeds are not moved and don't infect other areas. Working with game is far more challenging since they cannot be as easily moved. One of the few actions that can be encouraged is the browsing of the plant. This can be achieved in conjunction with fire. After a fire has been run through an area, new coppice is imminent. When animals browse these new sprouts, it is assumed that more carbohydrates held in storage are used for re-sprouting and hence less carbohydrates will be available for later growth and hence fewer flowers and seeds are produced.

2e Animal stocking numbers and ratios

The correct stocking intensity and ratio of animals is another management action that could be applied to manage the increase in *A. nilotica* (and other woody plant) density. Browsing animals can either be selective or bulk browsers and, depending on their height, browse at different levels above the ground. This factor needs to be considered since a lack of animals in one level and overstocking in another level could become an issue especially over the late winter season when levels of available browse are low.

In areas prone to bush encroachment, land users need to make sure areas are not over-stocked with grazers. Too many grazers intensify competition for resources (sunlight, nutrient, space) and present conditions for woody seedlings to grow. Furthermore, as a result of overgrazing, the grass fuel load is reduced thereby lowering the frequency and intensity at which a fire can burn through an area.

Tool 3: HERBICIDES

Herbicides that kill the adult or coppicing plants can be used very effectively in managing the plant. These chemicals are often used in combination with other management techniques (*e.g.* mechanical control or fire). This integrated management approach is often more effective than using just one form of control.

Tool 4: MECHANICAL CONTROL

4a Chopping

Chopping trees can reduce plant volume and coppice re-growth. The perception is that, although mature trees have greater root storage than plants within the firetrap, they do not coppice as easily as do saplings. Cutting saplings down at the base without treating the stump with herbicide may promote further coppicing – which may effectively revert the plant to being caught in the 'fire-trap'. Clearing an area in its entirety of trees such as *A. nilotica* trees can create severe negative consequences within the ecosystem. Multi-stem branches coppice up more thickly than before thus creating a shaded area that prevents other plant species from growing. Competition for resources also increases under these circumstances. Harvesting of large mature trees for fence posts or firewood provides access to resources (nutrients, sunlight etc.) that were not previously available, thereby creating suitable conditions for the smaller trees to rapidly grow and occupy as much of these resources as physically possible.

4b Bulldozers

The use of bulldozers is the most intensive form of woody plant management. Large areas of land are selected where the trees are to be flattened completely. Although this is a very harsh and very expensive method, it is highly effective when the land is being transformed to pastures or palatable-species enriched rangeland.

Tool 5: WHERE TO FOCUS

After the decision has been made to reduce or eradicate *A. nilotica* encroachment, an implementation strategy is needed – one component of this is where to focus the management effort. Since there are similarities in dealing with an invasive indigenous plant and with an invasive alien species, it helps to visit the strategies developed for alien invasive management such as those developed by Williams and West (2000) for weed management in New Zealand.

Example – for *A. nilotica* control and prevention of further infestation:

Stage 1: Ideally, the first place to focus on would be those areas without *A. nilotica* and particularly those that are prone to infestation, but have not yet been invaded. These areas are identified using predictive habitat techniques, as has been done in Chapter 3 using the Maxent model. This will guide agricultural organizations such as the Department of Agriculture and Environmental Affairs where to where to focus extension efforts and to allocate resources to assist landowners. In these areas, correct plans need to be implemented to prevent *A. nilotica* from infesting and becoming a problem.

Stage 2: The next point of focus should be any plants that are found on hill crests and slopes. Here the fairly small numbers of trees can be relatively easily controlled (browsing, fire, mechanical chopping and herbicides) to remove the adult trees that act as seed sources. Although *A. nilotica* populations may be lower in number on these slopes, their seeds, through the action of water and wind, are more likely to travel down-slope than those on the flatter areas. In focusing on this, the seed point sources are removed.

Stage 3: In the case of *A. nilotica*, the focus area would be on the heavy clayed bottomlands where *A. nilotica* is often densely congregated. By attempting to control seed production of these trees, the chances of the seeds being deposited and infesting another area, are lower. Where there are fenced camps, seed spread should be controlled by allowing very heavy browsing in the early-season stages of growth, during flowering and in early stages of pod development. To prevent further spreading in a livestock situation, animals can then be removed completely once the seeds start to mature. This process may be mimicked in unfenced areas by using fire and water availability to manipulate animal densities in the affected sites

Control strategies can also be focused in the different parts of the landscape when applying mechanical or chemical management. Since the intention in managing *A. nilotica* is often to control and not eradicate the plant completely, mechanical clearing must be done in a way that does not negatively impact on the availability of browse for the browsing herbivores within the area. Mechanical chopping should not be done without the simultaneous use of herbicides.

6.4 CONCLUSION

The philosophy of this chapter is that an understanding of the ecology of *A nilotica* is needed to develop a suite of tools which can be used by the land manager under different situations to develop an integrated strategy for the management of *A nilotica.*

This philosophy includes combinations of these methods mentioned. To create a greater understanding of how the system that is under study functions, ecological processes in the system are worked with to control the plant.

A nilotica is not always a problem. Where it is, there are different management options (*e.g.* eradication or control). Each management situation is different so a unique approach needs to be developed for each area. There are a number of tools available and these should be combined to have an integrated management approach. However, successful experience and thus the confidence to achieve substantial control, unless very intensive management is applied, is still lacking.

ABSTRACT

THE POPULATION DYNAMICS OF *ACACIA NILOTICA* SUBSP. *KRAUSSIANA* IN NORTHERN KWAZULU-NATAL

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Globally the thickening of woody plants is on the increase, creating many issues within these areas of encroachment. Within KwaZulu-Natal, one such species, *Acacia nilotica,* is part of this phenomenon. *A. nilotica* is currently creating an issue over a large portion of the province. An increase in tree density lowers the amount of available grazing which reduces the stocking numbers of grazing herbivores. A better understanding of the drivers, phenology and growth of this plant will assist in providing information to control the establishment and increase of tree density of this plant species. Focussing on a smaller area in KwaZulu-Natal, uMkhuze Game Reserve, in the northern region of the province, was chosen as the study area. This reserve was chosen as the study area as it is currently experiencing an increase in *A. nilotica* density as well as having good historical management records and imagery.

The Maxent species distribution model was used to determine the extent and potential distribution of *A. nilotica* within KwaZulu-Natal. For this study *A. nilotica* presence data, collected from surveys done by the KZN Department of Agriculture and Environmental Affairs, along with environmental variable data (rainfall, altitude, geology and mean minimum temperature) were used to model the potential distribution of the plant. Results indicate that a large portion of the province has the potential for *A. nilotica* occurrence. This distribution map has created an awareness of this plant for land users within the province. It also illustrates that a possible increase in temperature and rainfall from global change may provide more areas within KwaZulu-Natal with the potential to inhabit *A. nilotica*.

Within uMkhuze Game Reserve, the plant communities were surveyed, described, classified and mapped. From this the approximate areas and tree density of *A. nilotica* were estimated. Seventy

sites were surveyed with the 5 measurements for the BECVOL procedure. Site data were run through the BECVOL 3-model and grouped into one of the 12 identified vegetation communities. Of these 12 communities, *A. nilotica* were found to be in 8 of them. This is a possible 73% of the park that has the potential to contain *A. nilotica*. Tree density for these vegetation classes ranges from an estimated 950 to almost 7 000 plants/ha, while tree volume ranged from 5 200 to approximately 15 900 ETTE/ha. These results provide good baseline data for the vegetation of the reserve and illustrate the variety that an area can have. Different vegetation communities require different management practices and therefore this vegetation map illustrates these rough boundaries.

An assessment of the monthly plant phenology was undertaken to gain insight into the inter-seasonal changes of *A. nilotica*. Browsing herbivores rely on the available browse of deciduous plants like *A. nilotica*, where forage becomes limited during the winter season. This understanding also provides insight into the biology of the plant for easier control. Thirty-two trees were marked and monthly leaf, flower and seedpod phenology was recorded on a qualitative scoring basis. Four branches within each of these trees were marked and repeat monthly growth measurements were taken. The leaf phenology had a seasonal pattern that seemed to be linked largely to temperature and photoperiod. New leaves budded in late September to October and leaves started to senesce by June. *A. nilotica* produces summer (October to February) flowers and seeds followed thereafter (March to June). The major plant growth was also found to be in the warm, high rainfall season. A distinct link was noted between tree stem circumference (age) and tree branch growth. These phenological seasons are useful in guiding management decisions for both the stocking of game in the reserve and for the control of *A. nilotica*.

Finally, all the knowledge gained from this study and other literature sources were pulled together to develop a conceptual understanding on how best to aid in the control of this plant species. This conceptual understanding provides detailed information into the different life stages of the plant and a ‘tool kit’ of suggestions into the management and control of this plant. Through this research, an integrated management plan using a combination of holistic management measures is regarded as the recommended form of control for this plant species.

Keywords: BECVOL-model, Bush thickening, Phenology, Plant recruitment, Species distribution, Vegetation communities, Woody plants

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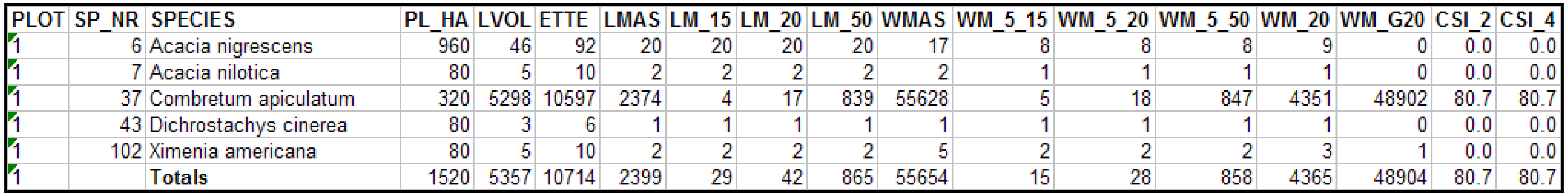
APPENDIX A

Field names used by the BECVOL program and their units are given in parenthesis:

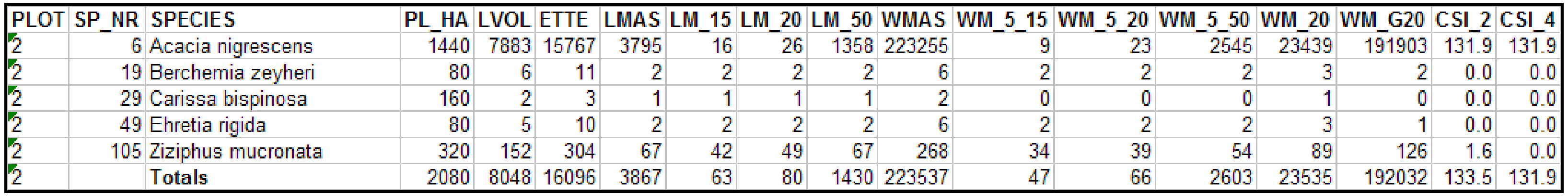
PLOT - Experimental plot
SP_NR - Number of species according to tree list
SPECIES - Tree species
PL_HA - Plants/ha
LVOL - Leaf volume (m^3)/ha
ETTE - Evapotranspiration Tree Equivalents/ha
LMAS - Leaf Dry Mass/ha (kg DM/ha)
LM_15 - Leaf Dry Mass/ha below a browsing height of 1.5 m (kg DM/ha)
LM_20 - Leaf Dry Mass/ha below a browsing height of 2.0 m (kg DM/ha)
LM_50 - Leaf Dry Mass/ha below a browsing height of 5.0 m (kg DM/ha)
WMAS - Total wood dry mass/ha (all fractions) (kg DM/ha)
WM_5_15 - Total shoots dry mass/ha of shoots <0.5 cm and below 1.5 m (kg DM/ha)
WM_5_20 - Total shoots dry mass/ha of shoots <0.5 cm and below 2.0 m (kg DM/ha)
WM_5_50 - Total shoots dry mass/ha of shoots <0.5 cm and below 5.0 m (kg DM/ha)
WM_20 - Total stem dry mass/ha of stems >0.5-20 cm in diameter (kg DM/ha)
WM_G20 - Total wood dry mass/ha of wood >20 cm in diameter (kg DM/ha)
CSI_2 - Canopied Subhabitat Index based on trees with a minimum height of 2 m
CSI_4 - Canopied Subhabitat Index based on trees with a minimum height of 4 m

Appendix A1: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 1 during the 2011/2012 season.



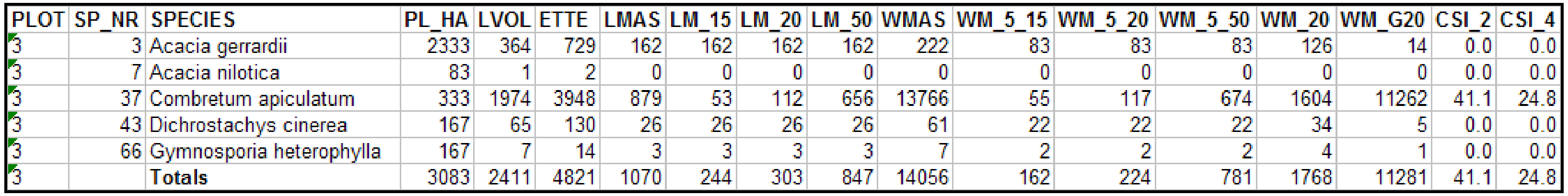
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
1	6	Acacia nigrescens	960	46	92	20	20	20	20	17	8	8	8	9	0	0.0	0.0
1	7	Acacia nilotica	80	5	10	2	2	2	2	2	1	1	1	1	0	0.0	0.0
1	37	Combretum apiculatum	320	5298	10597	2374	4	17	839	55628	5	18	847	4351	48902	80.7	80.7
1	43	Dichrostachys cinerea	80	3	6	1	1	1	1	1	1	1	1	1	0	0.0	0.0
1	102	Ximenia americana	80	5	10	2	2	2	2	5	2	2	2	3	1	0.0	0.0
1		**Totals**	1520	5357	10714	2399	29	42	865	55654	15	28	858	4365	48904	80.7	80.7

Appendix A2: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 2 during the 2011/2012 season.



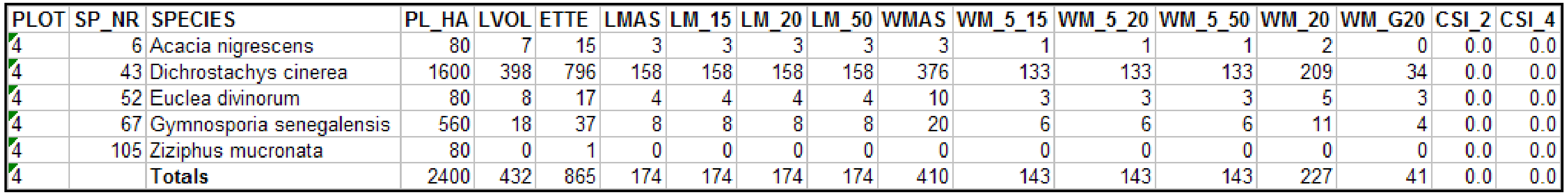
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
2	6	Acacia nigrescens	1440	7883	15767	3795	16	26	1358	223255	9	23	2545	23439	191903	131.9	131.9
2	19	Berchemia zeyheri	80	6	11	2	2	2	2	6	2	2	2	3	2	0.0	0.0
2	29	Carissa bispinosa	160	2	3	1	1	1	1	2	0	0	0	1	0	0.0	0.0
2	49	Ehretia rigida	80	5	10	2	2	2	2	6	2	2	2	3	1	0.0	0.0
2	105	Ziziphus mucronata	320	152	304	67	42	49	67	268	34	39	54	89	126	1.6	0.0
2		**Totals**	2080	8048	16096	3867	63	80	1430	223537	47	66	2603	23535	192032	133.5	131.9

Appendix A3: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 3 during the 2011/2012 season.



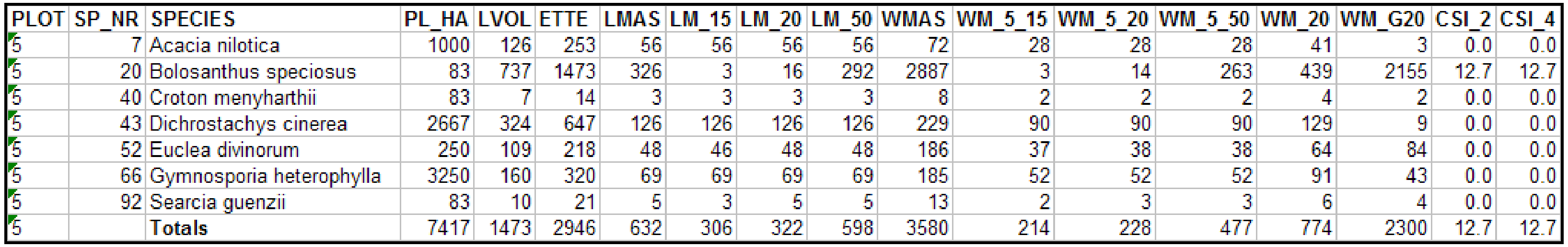
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
3	3	Acacia gerrardii	2333	364	729	162	162	162	162	222	83	83	83	126	14	0.0	0.0
3	7	Acacia nilotica	83	1	2	0	0	0	0	0	0	0	0	0	0	0.0	0.0
3	37	Combretum apiculatum	333	1974	3948	879	53	112	656	13766	55	117	674	1604	11262	41.1	24.8
3	43	Dichrostachys cinerea	167	65	130	26	26	26	26	61	22	22	22	34	5	0.0	0.0
3	66	Gymnosporia heterophylla	167	7	14	3	3	3	3	7	2	2	2	4	1	0.0	0.0
3		**Totals**	3083	2411	4821	1070	244	303	847	14056	162	224	781	1768	11281	41.1	24.8

Appendix A4: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 4 during the 2011/2012 season.



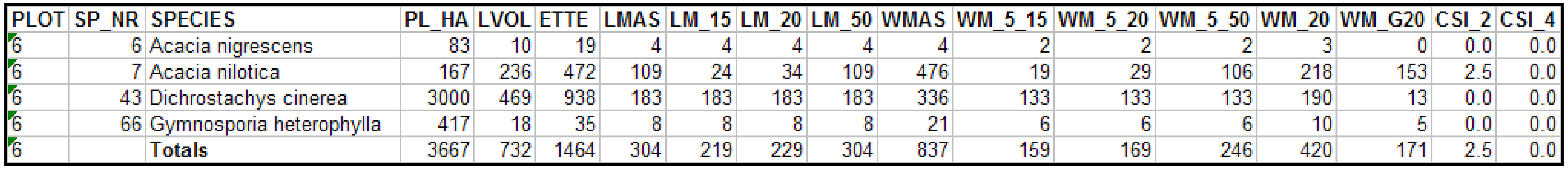
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
4	6	Acacia nigrescens	80	7	15	3	3	3	3	3	1	1	1	2	0	0.0	0.0
4	43	Dichrostachys cinerea	1600	398	796	158	158	158	158	376	133	133	133	209	34	0.0	0.0
4	52	Euclea divinorum	80	8	17	4	4	4	4	10	3	3	3	5	3	0.0	0.0
4	67	Gymnosporia senegalensis	560	18	37	8	8	8	8	20	6	6	6	11	4	0.0	0.0
4	105	Ziziphus mucronata	80	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
4		**Totals**	2400	432	865	174	174	174	174	410	143	143	143	227	41	0.0	0.0

AppendixA5: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 5 during the 2011/2012 season.



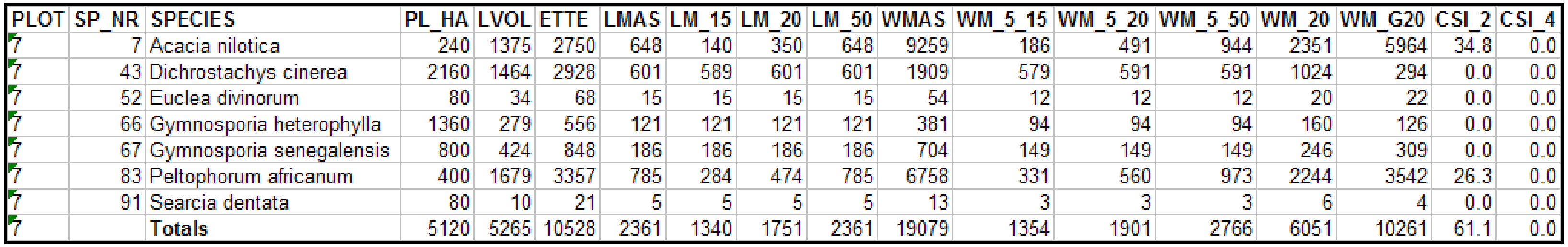
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
5	7	Acacia nilotica	1000	126	253	56	56	56	56	72	28	28	28	41	3	0.0	0.0
5	20	Bolosanthus speciosus	83	737	1473	326	3	16	292	2887	3	14	263	439	2155	12.7	12.7
5	40	Croton menyharthii	83	7	14	3	3	3	3	8	2	2	2	4	2	0.0	0.0
5	43	Dichrostachys cinerea	2667	324	647	126	126	126	126	229	90	90	90	129	9	0.0	0.0
5	52	Euclea divinorum	250	109	218	48	46	48	48	186	37	38	38	64	84	0.0	0.0
5	66	Gymnosporia heterophylla	3250	160	320	69	69	69	69	185	52	52	52	91	43	0.0	0.0
5	92	Searcia guenzii	83	10	21	5	3	5	5	13	2	3	3	6	4	0.0	0.0
5		**Totals**	7417	1473	2946	632	306	322	598	3580	214	228	477	774	2300	12.7	12.7

Appendix A6: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 6 during the 2011/2012 season.



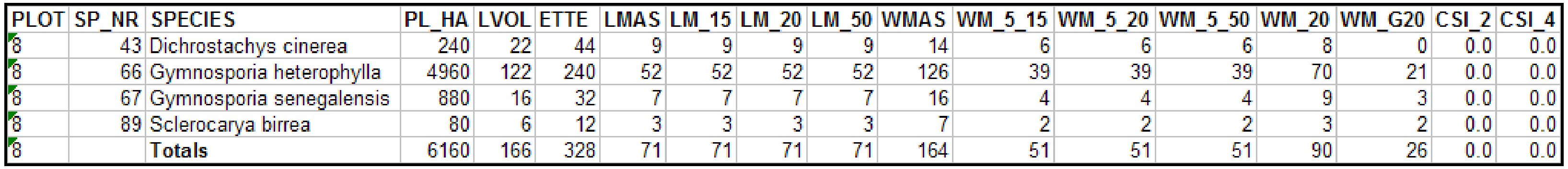
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
6	6	Acacia nigrescens	83	10	19	4	4	4	4	4	2	2	2	3	0	0.0	0.0
6	7	Acacia nilotica	167	236	472	109	24	34	109	476	19	29	106	218	153	2.5	0.0
6	43	Dichrostachys cinerea	3000	469	938	183	183	183	183	336	133	133	133	190	13	0.0	0.0
6	66	Gymnosporia heterophylla	417	18	35	8	8	8	8	21	6	6	6	10	5	0.0	0.0
6		**Totals**	3667	732	1464	304	219	229	304	837	159	169	246	420	171	2.5	0.0

Appendix A7: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 7 during the 2011/2012 season.



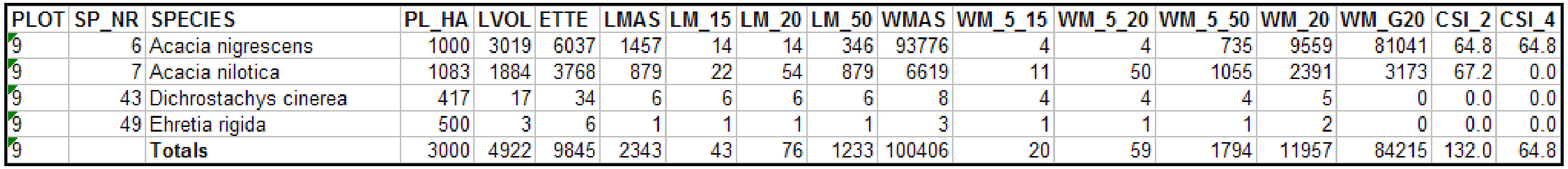
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
7	7	Acacia nilotica	240	1375	2750	648	140	350	648	9259	186	491	944	2351	5964	34.8	0.0
7	43	Dichrostachys cinerea	2160	1464	2928	601	589	601	601	1909	579	591	591	1024	294	0.0	0.0
7	52	Euclea divinorum	80	34	68	15	15	15	15	54	12	12	12	20	22	0.0	0.0
7	66	Gymnosporia heterophylla	1360	279	556	121	121	121	121	381	94	94	94	160	126	0.0	0.0
7	67	Gymnosporia senegalensis	800	424	848	186	186	186	186	704	149	149	149	246	309	0.0	0.0
7	83	Peltophorum africanum	400	1679	3357	785	284	474	785	6758	331	560	973	2244	3542	26.3	0.0
7	91	Searcia dentata	80	10	21	5	5	5	5	13	3	3	3	6	4	0.0	0.0
7		**Totals**	5120	5265	10528	2361	1340	1751	2361	19079	1354	1901	2766	6051	10261	61.1	0.0

Appendix A8: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 8 during the 2011/2012 season.



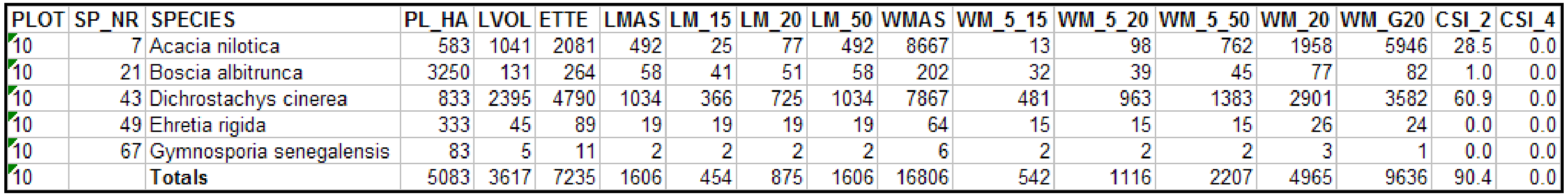
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
8	43	Dichrostachys cinerea	240	22	44	9	9	9	9	14	6	6	6	8	0	0.0	0.0
8	66	Gymnosporia heterophylla	4960	122	240	52	52	52	52	126	39	39	39	70	21	0.0	0.0
8	67	Gymnosporia senegalensis	880	16	32	7	7	7	7	16	4	4	4	9	3	0.0	0.0
8	89	Sclerocarya birrea	80	6	12	3	3	3	3	7	2	2	2	3	2	0.0	0.0
8		**Totals**	6160	166	328	71	71	71	71	164	51	51	51	90	26	0.0	0.0

Appendix A9: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 9 during the 2011/2012 season.



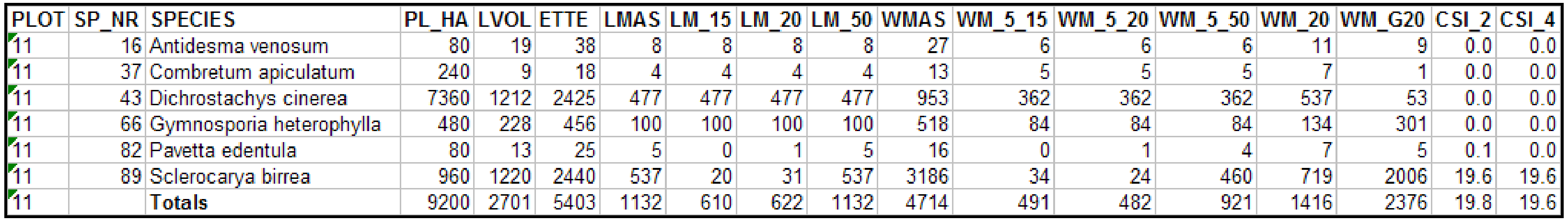
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
9	6	Acacia nigrescens	1000	3019	6037	1457	14	14	346	93776	4	4	735	9559	81041	64.8	64.8
9	7	Acacia nilotica	1083	1884	3768	879	22	54	879	6619	11	50	1055	2391	3173	67.2	0.0
9	43	Dichrostachys cinerea	417	17	34	6	6	6	6	8	4	4	4	5	0	0.0	0.0
9	49	Ehretia rigida	500	3	6	1	1	1	1	3	1	1	1	2	0	0.0	0.0
9		**Totals**	3000	4922	9845	2343	43	76	1233	100406	20	59	1794	11957	84215	132.0	64.8

Appendix A10: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 10 during the 2011/2012 season.



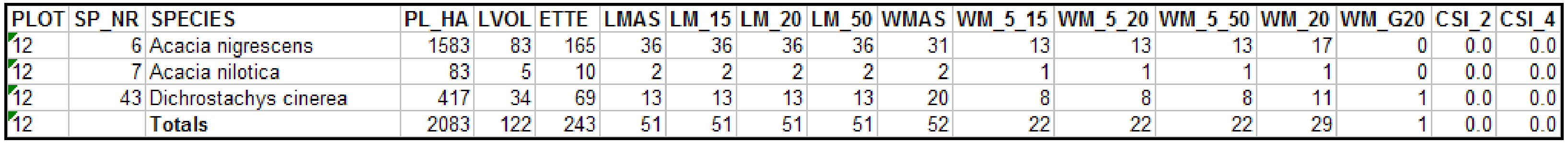
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
10	7	Acacia nilotica	583	1041	2081	492	25	77	492	8667	13	98	762	1958	5946	28.5	0.0
10	21	Boscia albitrunca	3250	131	264	58	41	51	58	202	32	39	45	77	82	1.0	0.0
10	43	Dichrostachys cinerea	833	2395	4790	1034	366	725	1034	7867	481	963	1383	2901	3582	60.9	0.0
10	49	Ehretia rigida	333	45	89	19	19	19	19	64	15	15	15	26	24	0.0	0.0
10	67	Gymnosporia senegalensis	83	5	11	2	2	2	2	6	2	2	2	3	1	0.0	0.0
10		**Totals**	5083	3617	7235	1606	454	875	1606	16806	542	1116	2207	4965	9636	90.4	0.0

Appendix A11: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 11 during the 2011/2012 season.



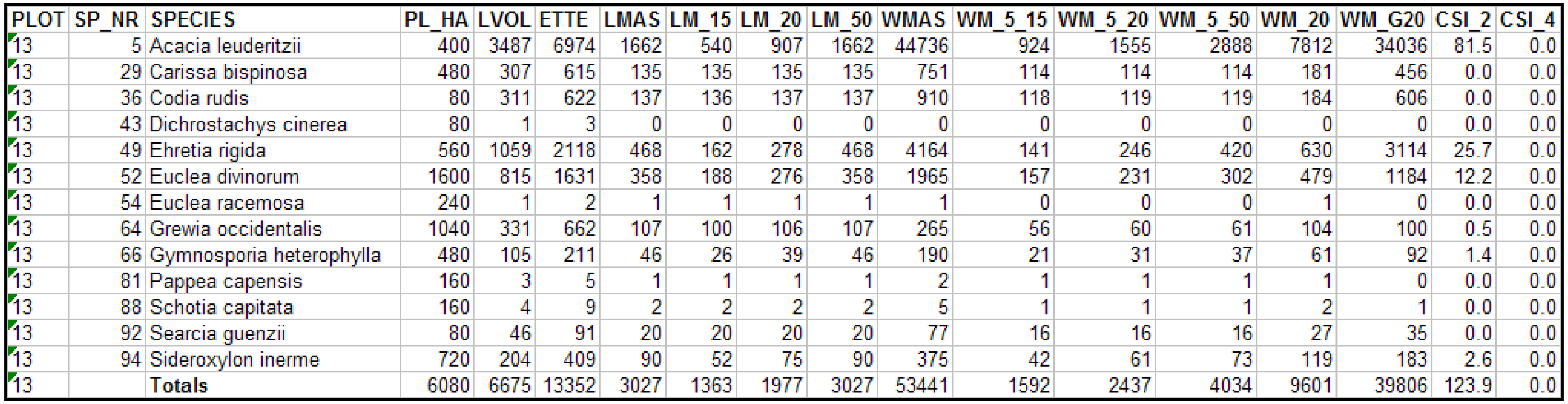
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
11	16	Antidesma venosum	80	19	38	8	8	8	8	27	6	6	6	11	9	0.0	0.0
11	37	Combretum apiculatum	240	9	18	4	4	4	4	13	5	5	5	7	1	0.0	0.0
11	43	Dichrostachys cinerea	7360	1212	2425	477	477	477	477	953	362	362	362	537	53	0.0	0.0
11	66	Gymnosporia heterophylla	480	228	456	100	100	100	100	518	84	84	84	134	301	0.0	0.0
11	82	Pavetta edentula	80	13	25	5	0	1	5	16	0	1	4	7	5	0.1	0.0
11	89	Sclerocarya birrea	960	1220	2440	537	20	31	537	3186	34	24	460	719	2006	19.6	19.6
11		**Totals**	9200	2701	5403	1132	610	622	1132	4714	491	482	921	1416	2376	19.8	19.6

Appendix A12: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 12 during the 2011/2012 season.



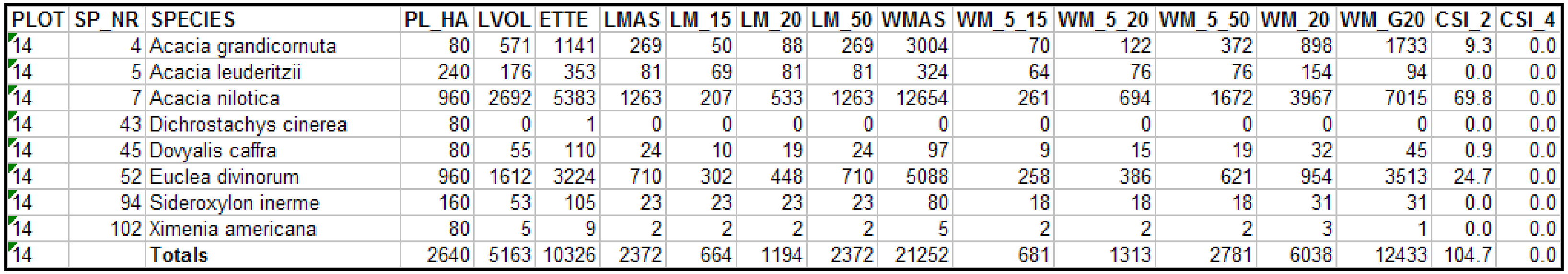
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
12	6	Acacia nigrescens	1583	83	165	36	36	36	36	31	13	13	13	17	0	0.0	0.0
12	7	Acacia nilotica	83	5	10	2	2	2	2	2	1	1	1	1	0	0.0	0.0
12	43	Dichrostachys cinerea	417	34	69	13	13	13	13	20	8	8	8	11	1	0.0	0.0
12		**Totals**	2083	122	243	51	51	51	51	52	22	22	22	29	1	0.0	0.0

Appendix A13: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 13 during the 2011/2012 season.



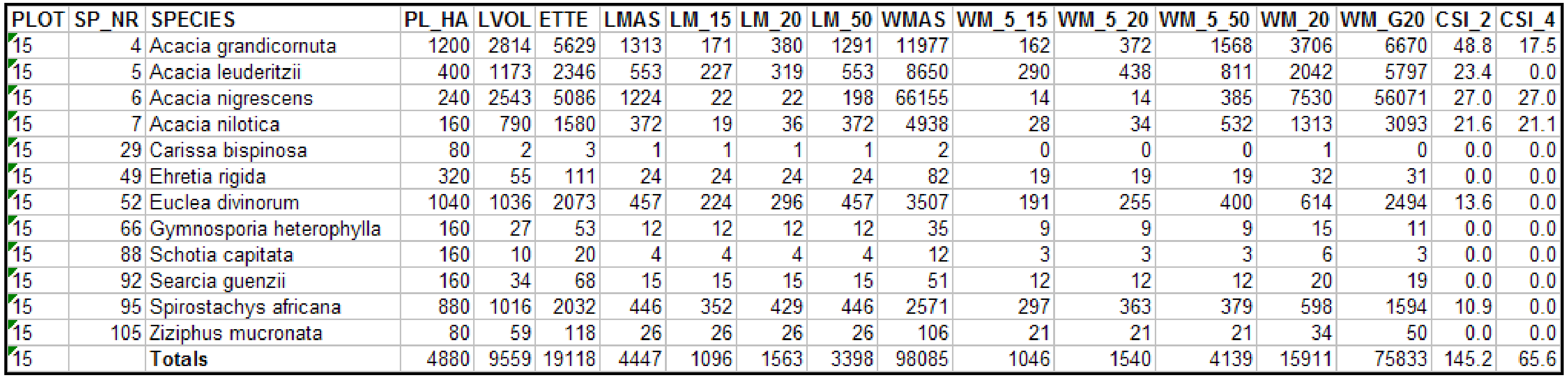
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
13	5	Acacia leuderitzii	400	3487	6974	1662	540	907	1662	44736	924	1555	2888	7812	34036	81.5	0.0
13	29	Carissa bispinosa	480	307	615	135	135	135	135	751	114	114	114	181	456	0.0	0.0
13	36	Codia rudis	80	311	622	137	136	137	137	910	118	119	119	184	606	0.0	0.0
13	43	Dichrostachys cinerea	80	1	3	0	0	0	0	0	0	0	0	0	0	0.0	0.0
13	49	Ehretia rigida	560	1059	2118	468	162	278	468	4164	141	246	420	630	3114	25.7	0.0
13	52	Euclea divinorum	1600	815	1631	358	188	276	358	1965	157	231	302	479	1184	12.2	0.0
13	54	Euclea racemosa	240	1	2	1	1	1	1	1	0	0	0	1	0	0.0	0.0
13	64	Grewia occidentalis	1040	331	662	107	100	106	107	265	56	60	61	104	100	0.5	0.0
13	66	Gymnosporia heterophylla	480	105	211	46	26	39	46	190	21	31	37	61	92	1.4	0.0
13	81	Pappea capensis	160	3	5	1	1	1	1	2	1	1	1	1	0	0.0	0.0
13	88	Schotia capitata	160	4	9	2	2	2	2	5	1	1	1	2	1	0.0	0.0
13	92	Searcia guenzii	80	46	91	20	20	20	20	77	16	16	16	27	35	0.0	0.0
13	94	Sideroxylon inerme	720	204	409	90	52	75	90	375	42	61	73	119	183	2.6	0.0
13		**Totals**	6080	6675	13352	3027	1363	1977	3027	53441	1592	2437	4034	9601	39806	123.9	0.0

AppendixA14: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 14 during the 2011/2012 season.



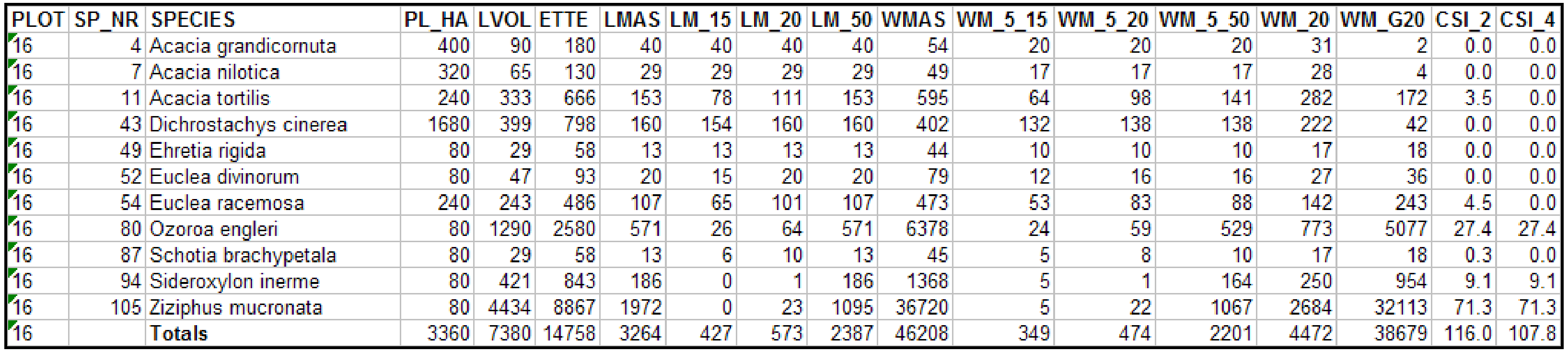
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
14	4	Acacia grandicornuta	80	571	1141	269	50	88	269	3004	70	122	372	898	1733	9.3	0.0
14	5	Acacia leuderitzii	240	176	353	81	69	81	81	324	64	76	76	154	94	0.0	0.0
14	7	Acacia nilotica	960	2692	5383	1263	207	533	1263	12654	261	694	1672	3967	7015	69.8	0.0
14	43	Dichrostachys cinerea	80	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
14	45	Dovyalis caffra	80	55	110	24	10	19	24	97	9	15	19	32	45	0.9	0.0
14	52	Euclea divinorum	960	1612	3224	710	302	448	710	5088	258	386	621	954	3513	24.7	0.0
14	94	Sideroxylon inerme	160	53	105	23	23	23	23	80	18	18	18	31	31	0.0	0.0
14	102	Ximenia americana	80	5	9	2	2	2	2	5	2	2	2	3	1	0.0	0.0
14		**Totals**	2640	5163	10326	2372	664	1194	2372	21252	681	1313	2781	6038	12433	104.7	0.0

Appendix A15: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 15 during the 2011/2012 season.



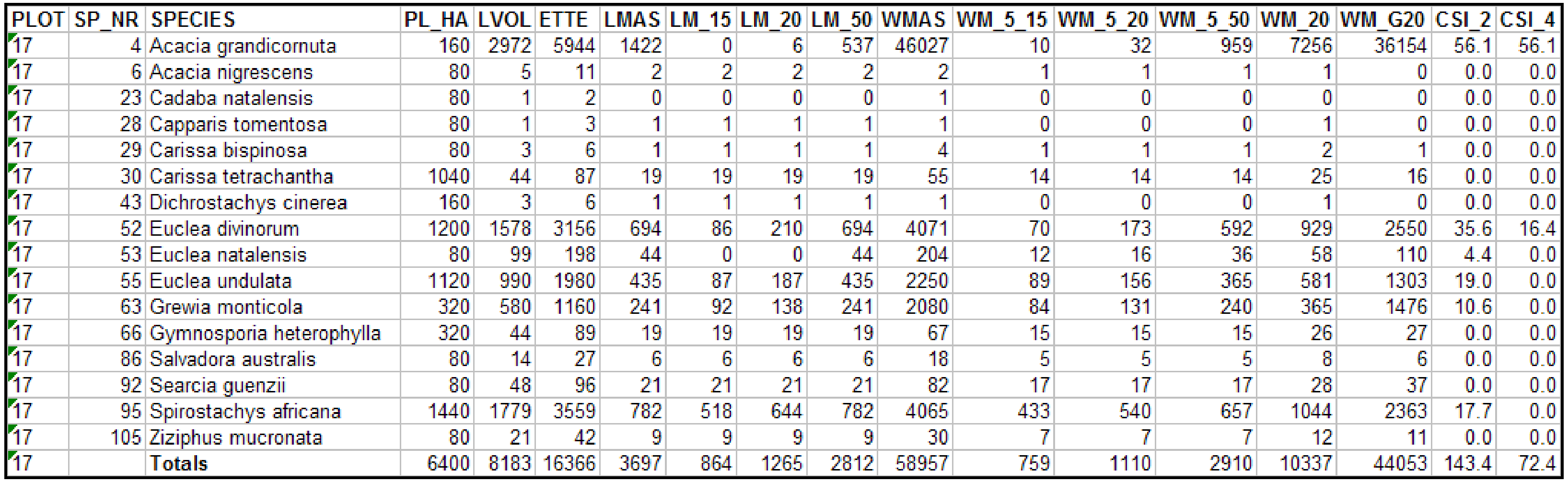
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
15	4	Acacia grandicornuta	1200	2814	5629	1313	171	380	1291	11977	162	372	1568	3706	6670	48.8	17.5
15	5	Acacia leuderitzii	400	1173	2346	553	227	319	553	8650	290	438	811	2042	5797	23.4	0.0
15	6	Acacia nigrescens	240	2543	5086	1224	22	22	198	66155	14	14	385	7530	56071	27.0	27.0
15	7	Acacia nilotica	160	790	1580	372	19	36	372	4938	28	34	532	1313	3093	21.6	21.1
15	29	Carissa bispinosa	80	2	3	1	1	1	1	2	0	0	0	1	0	0.0	0.0
15	49	Ehretia rigida	320	55	111	24	24	24	24	82	19	19	19	32	31	0.0	0.0
15	52	Euclea divinorum	1040	1036	2073	457	224	296	457	3507	191	255	400	614	2494	13.6	0.0
15	66	Gymnosporia heterophylla	160	27	53	12	12	12	12	35	9	9	9	15	11	0.0	0.0
15	88	Schotia capitata	160	10	20	4	4	4	4	12	3	3	3	6	3	0.0	0.0
15	92	Searcia guenzii	160	34	68	15	15	15	15	51	12	12	12	20	19	0.0	0.0
15	95	Spirostachys africana	880	1016	2032	446	352	429	446	2571	297	363	379	598	1594	10.9	0.0
15	105	Ziziphus mucronata	80	59	118	26	26	26	26	106	21	21	21	34	50	0.0	0.0
15		**Totals**	4880	9559	19118	4447	1096	1563	3398	98085	1046	1540	4139	15911	75833	145.2	65.6

Appendix A16: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 16 during the 2011/2012 season.



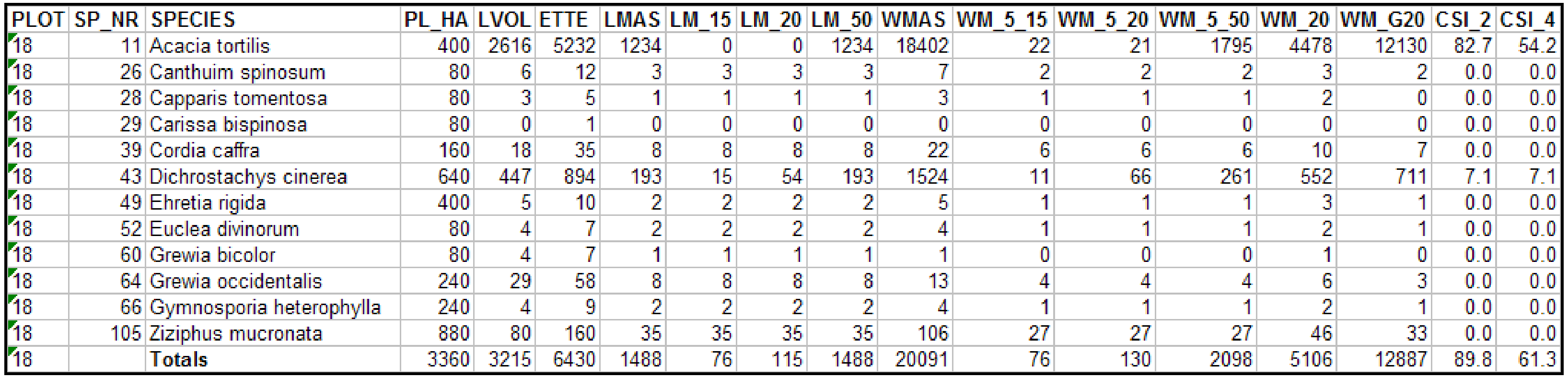
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
16	4	Acacia grandicornuta	400	90	180	40	40	40	40	54	20	20	20	31	2	0.0	0.0
16	7	Acacia nilotica	320	65	130	29	29	29	29	49	17	17	17	28	4	0.0	0.0
16	11	Acacia tortilis	240	333	666	153	78	111	153	595	64	98	141	282	172	3.5	0.0
16	43	Dichrostachys cinerea	1680	399	798	160	154	160	160	402	132	138	138	222	42	0.0	0.0
16	49	Ehretia rigida	80	29	58	13	13	13	13	44	10	10	10	17	18	0.0	0.0
16	52	Euclea divinorum	80	47	93	20	15	20	20	79	12	16	16	27	36	0.0	0.0
16	54	Euclea racemosa	240	243	486	107	65	101	107	473	53	83	88	142	243	4.5	0.0
16	80	Ozoroa engleri	80	1290	2580	571	26	64	571	6378	24	59	529	773	5077	27.4	27.4
16	87	Schotia brachypetala	80	29	58	13	6	10	13	45	5	8	10	17	18	0.3	0.0
16	94	Sideroxylon inerme	80	421	843	186	0	1	186	1368	5	1	164	250	954	9.1	9.1
16	105	Ziziphus mucronata	80	4434	8867	1972	0	23	1095	36720	5	22	1067	2684	32113	71.3	71.3
16		**Totals**	3360	7380	14758	3264	427	573	2387	46208	349	474	2201	4472	38679	116.0	107.8

Appendix A17: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 17 during the 2011/2012 season.



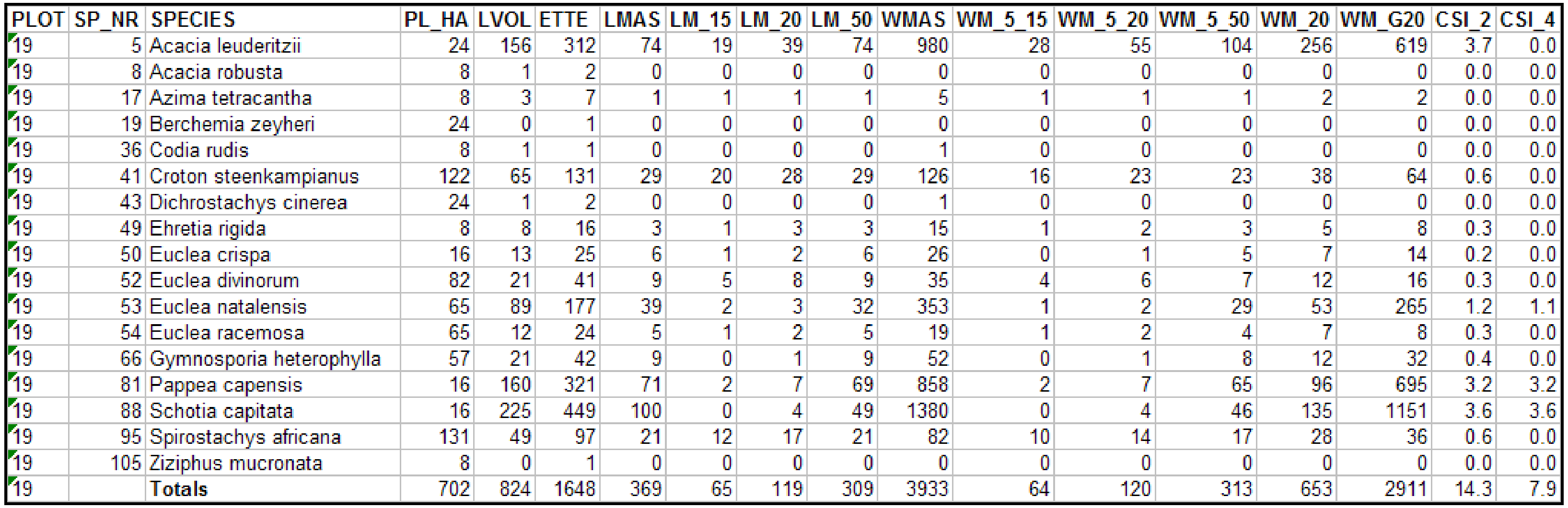
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
17	4	Acacia grandicornuta	160	2972	5944	1422	0	6	537	46027	10	32	959	7256	36154	56.1	56.1
17	6	Acacia nigrescens	80	5	11	2	2	2	2	2	1	1	1	1	0	0.0	0.0
17	23	Cadaba natalensis	80	1	2	0	0	0	0	1	0	0	0	0	0	0.0	0.0
17	28	Capparis tomentosa	80	1	3	1	1	1	1	1	0	0	0	1	0	0.0	0.0
17	29	Carissa bispinosa	80	3	6	1	1	1	1	4	1	1	1	2	1	0.0	0.0
17	30	Carissa tetrachantha	1040	44	87	19	19	19	19	55	14	14	14	25	16	0.0	0.0
17	43	Dichrostachys cinerea	160	3	6	1	1	1	1	1	0	0	0	1	0	0.0	0.0
17	52	Euclea divinorum	1200	1578	3156	694	86	210	694	4071	70	173	592	929	2550	35.6	16.4
17	53	Euclea natalensis	80	99	198	44	0	0	44	204	12	16	36	58	110	4.4	0.0
17	55	Euclea undulata	1120	990	1980	435	87	187	435	2250	89	156	365	581	1303	19.0	0.0
17	63	Grewia monticola	320	580	1160	241	92	138	241	2080	84	131	240	365	1476	10.6	0.0
17	66	Gymnosporia heterophylla	320	44	89	19	19	19	19	67	15	15	15	26	27	0.0	0.0
17	86	Salvadora australis	80	14	27	6	6	6	6	18	5	5	5	8	6	0.0	0.0
17	92	Searcia guenzii	80	48	96	21	21	21	21	82	17	17	17	28	37	0.0	0.0
17	95	Spirostachys africana	1440	1779	3559	782	518	644	782	4065	433	540	657	1044	2363	17.7	0.0
17	105	Ziziphus mucronata	80	21	42	9	9	9	9	30	7	7	7	12	11	0.0	0.0
17		**Totals**	6400	8183	16366	3697	864	1265	2812	58957	759	1110	2910	10337	44053	143.4	72.4

Appendix A18: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 18 during the 2011/2012 season.



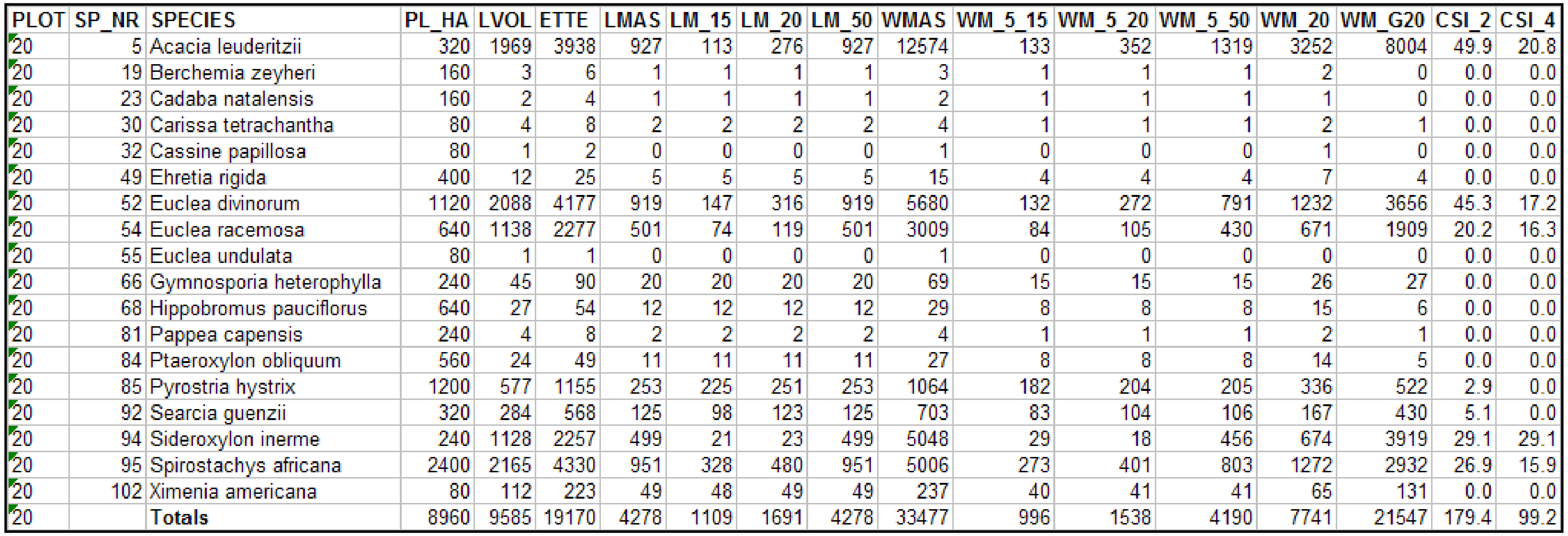
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
18	11	Acacia tortilis	400	2616	5232	1234	0	0	1234	18402	22	21	1795	4478	12130	82.7	54.2
18	26	Canthuim spinosum	80	6	12	3	3	3	3	7	2	2	2	3	2	0.0	0.0
18	28	Capparis tomentosa	80	3	5	1	1	1	1	3	1	1	1	2	0	0.0	0.0
18	29	Carissa bispinosa	80	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
18	39	Cordia caffra	160	18	35	8	8	8	8	22	6	6	6	10	7	0.0	0.0
18	43	Dichrostachys cinerea	640	447	894	193	15	54	193	1524	11	66	261	552	711	7.1	7.1
18	49	Ehretia rigida	400	5	10	2	2	2	2	5	1	1	1	3	1	0.0	0.0
18	52	Euclea divinorum	80	4	7	2	2	2	2	4	1	1	1	2	1	0.0	0.0
18	60	Grewia bicolor	80	4	7	1	1	1	1	1	0	0	0	1	0	0.0	0.0
18	64	Grewia occidentalis	240	29	58	8	8	8	8	13	4	4	4	6	3	0.0	0.0
18	66	Gymnosporia heterophylla	240	4	9	2	2	2	2	4	1	1	1	2	1	0.0	0.0
18	105	Ziziphus mucronata	880	80	160	35	35	35	35	106	27	27	27	46	33	0.0	0.0
18		**Totals**	3360	3215	6430	1488	76	115	1488	20091	76	130	2098	5106	12887	89.8	61.3

Appendix A19: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 19 during the 2011/2012 season.



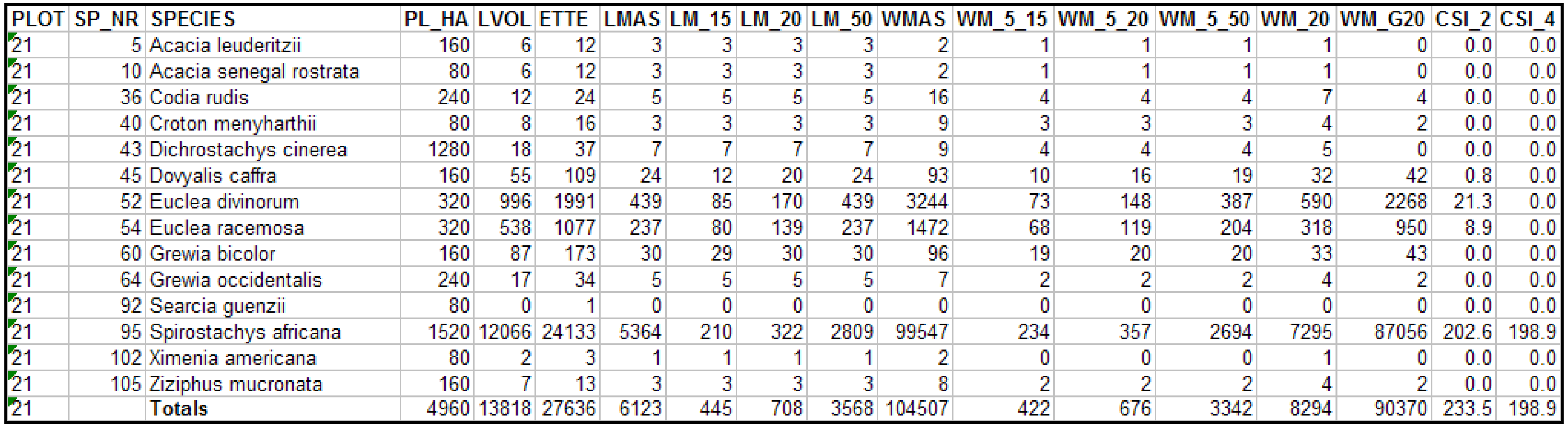
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
19	5	Acacia leuderitzii	24	156	312	74	19	39	74	980	28	55	104	256	619	3.7	0.0
19	8	Acacia robusta	8	1	2	0	0	0	0	0	0	0	0	0	0	0.0	0.0
19	17	Azima tetracantha	8	3	7	1	1	1	1	5	1	1	1	2	2	0.0	0.0
19	19	Berchemia zeyheri	24	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
19	36	Codia rudis	8	1	1	0	0	0	0	1	0	0	0	0	0	0.0	0.0
19	41	Croton steenkampianus	122	65	131	29	20	28	29	126	16	23	23	38	64	0.6	0.0
19	43	Dichrostachys cinerea	24	1	2	0	0	0	0	1	0	0	0	0	0	0.0	0.0
19	49	Ehretia rigida	8	8	16	3	1	3	3	15	1	2	3	5	8	0.3	0.0
19	50	Euclea crispa	16	13	25	6	1	2	6	26	0	1	5	7	14	0.2	0.0
19	52	Euclea divinorum	82	21	41	9	5	8	9	35	4	6	7	12	16	0.3	0.0
19	53	Euclea natalensis	65	89	177	39	2	3	32	353	1	2	29	53	265	1.2	1.1
19	54	Euclea racemosa	65	12	24	5	1	2	5	19	1	2	4	7	8	0.3	0.0
19	66	Gymnosporia heterophylla	57	21	42	9	0	1	9	52	0	1	8	12	32	0.4	0.0
19	81	Pappea capensis	16	160	321	71	2	7	69	858	2	7	65	96	695	3.2	3.2
19	88	Schotia capitata	16	225	449	100	0	4	49	1380	0	4	46	135	1151	3.6	3.6
19	95	Spirostachys africana	131	49	97	21	12	17	21	82	10	14	17	28	36	0.6	0.0
19	105	Ziziphus mucronata	8	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
19		**Totals**	702	824	1648	369	65	119	309	3933	64	120	313	653	2911	14.3	7.9

Appendix A20: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 20 during the 2011/2012 season.



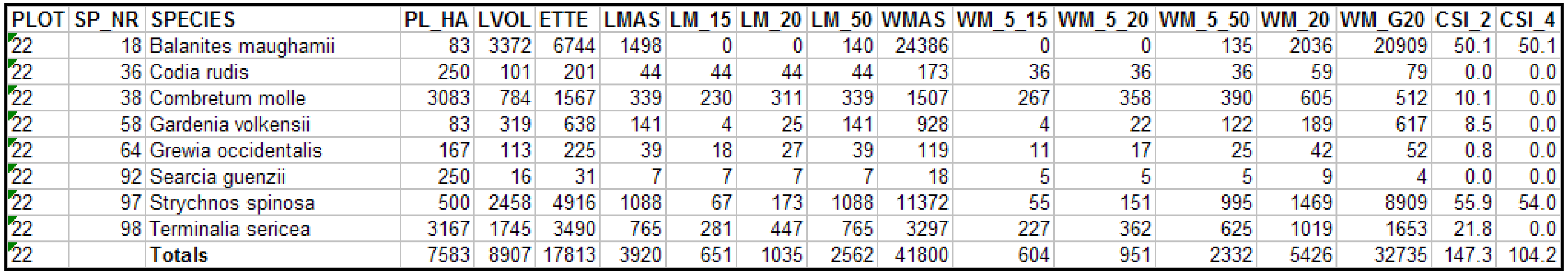
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
20	5	Acacia leuderitzii	320	1969	3938	927	113	276	927	12574	133	352	1319	3252	8004	49.9	20.8
20	19	Berchemia zeyheri	160	3	6	1	1	1	1	3	1	1	1	2	0	0.0	0.0
20	23	Cadaba natalensis	160	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
20	30	Carissa tetrachantha	80	4	8	2	2	2	2	4	1	1	1	2	1	0.0	0.0
20	32	Cassine papillosa	80	1	2	0	0	0	0	1	0	0	0	1	0	0.0	0.0
20	49	Ehretia rigida	400	12	25	5	5	5	5	15	4	4	4	7	4	0.0	0.0
20	52	Euclea divinorum	1120	2088	4177	919	147	316	919	5680	132	272	791	1232	3656	45.3	17.2
20	54	Euclea racemosa	640	1138	2277	501	74	119	501	3009	84	105	430	671	1909	20.2	16.3
20	55	Euclea undulata	80	1	1	0	0	0	0	1	0	0	0	0	0	0.0	0.0
20	66	Gymnosporia heterophylla	240	45	90	20	20	20	20	69	15	15	15	26	27	0.0	0.0
20	68	Hippobromus pauciflorus	640	27	54	12	12	12	12	29	8	8	8	15	6	0.0	0.0
20	81	Pappea capensis	240	4	8	2	2	2	2	4	1	1	1	2	1	0.0	0.0
20	84	Ptaeroxylon obliquum	560	24	49	11	11	11	11	27	8	8	8	14	5	0.0	0.0
20	85	Pyrostria hystrix	1200	577	1155	253	225	251	253	1064	182	204	205	336	522	2.9	0.0
20	92	Searcia guenzii	320	284	568	125	98	123	125	703	83	104	106	167	430	5.1	0.0
20	94	Sideroxylon inerme	240	1128	2257	499	21	23	499	5048	29	18	456	674	3919	29.1	29.1
20	95	Spirostachys africana	2400	2165	4330	951	328	480	951	5006	273	401	803	1272	2932	26.9	15.9
20	102	Ximenia americana	80	112	223	49	48	49	49	237	40	41	41	65	131	0.0	0.0
20		**Totals**	8960	9585	19170	4278	1109	1691	4278	33477	996	1538	4190	7741	21547	179.4	99.2

Appendix A21: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 21 during the 2011/2012 season.



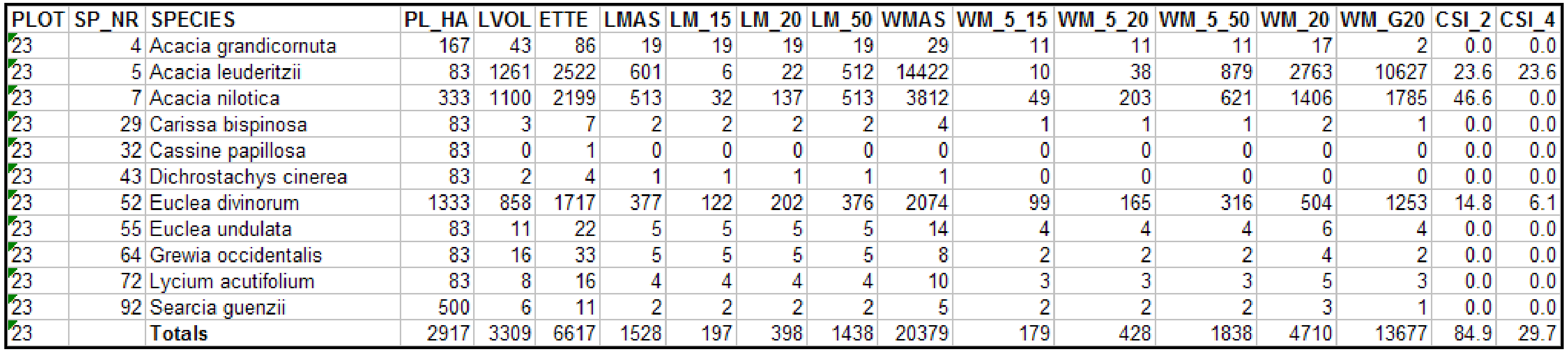
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
21	5	Acacia leuderitzii	160	6	12	3	3	3	3	2	1	1	1	1	0	0.0	0.0
21	10	Acacia senegal rostrata	80	6	12	3	3	3	3	2	1	1	1	1	0	0.0	0.0
21	36	Codia rudis	240	12	24	5	5	5	5	16	4	4	4	7	4	0.0	0.0
21	40	Croton menyharthii	80	8	16	3	3	3	3	9	3	3	3	4	2	0.0	0.0
21	43	Dichrostachys cinerea	1280	18	37	7	7	7	7	9	4	4	4	5	0	0.0	0.0
21	45	Dovyalis caffra	160	55	109	24	12	20	24	93	10	16	19	32	42	0.8	0.0
21	52	Euclea divinorum	320	996	1991	439	85	170	439	3244	73	148	387	590	2268	21.3	0.0
21	54	Euclea racemosa	320	538	1077	237	80	139	237	1472	68	119	204	318	950	8.9	0.0
21	60	Grewia bicolor	160	87	173	30	29	30	30	96	19	20	20	33	43	0.0	0.0
21	64	Grewia occidentalis	240	17	34	5	5	5	5	7	2	2	2	4	2	0.0	0.0
21	92	Searcia guenzii	80	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
21	95	Spirostachys africana	1520	12066	24133	5364	210	322	2809	99547	234	357	2694	7295	87056	202.6	198.9
21	102	Ximenia americana	80	2	3	1	1	1	1	2	0	0	0	1	0	0.0	0.0
21	105	Ziziphus mucronata	160	7	13	3	3	3	3	8	2	2	2	4	2	0.0	0.0
21		**Totals**	4960	13818	27636	6123	445	708	3568	104507	422	676	3342	8294	90370	233.5	198.9

Appendix A22: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 22 during the 2011/2012 season.



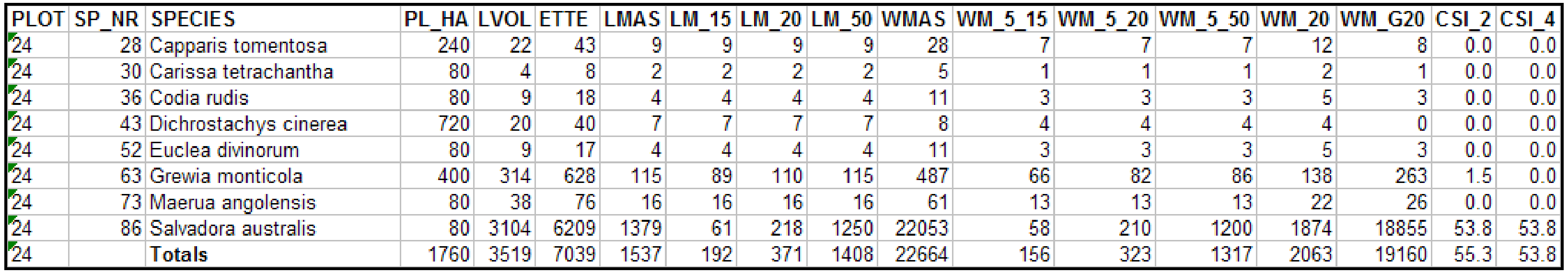
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
22	18	Balanites maughamii	83	3372	6744	1498	0	0	140	24386	0	0	135	2036	20909	50.1	50.1
22	36	Codia rudis	250	101	201	44	44	44	44	173	36	36	36	59	79	0.0	0.0
22	38	Combretum molle	3083	784	1567	339	230	311	339	1507	267	358	390	605	512	10.1	0.0
22	58	Gardenia volkensii	83	319	638	141	4	25	141	928	4	22	122	189	617	8.5	0.0
22	64	Grewia occidentalis	167	113	225	39	18	27	39	119	11	17	25	42	52	0.8	0.0
22	92	Searcia guenzii	250	16	31	7	7	7	7	18	5	5	5	9	4	0.0	0.0
22	97	Strychnos spinosa	500	2458	4916	1088	67	173	1088	11372	55	151	995	1469	8909	55.9	54.0
22	98	Terminalia sericea	3167	1745	3490	765	281	447	765	3297	227	362	625	1019	1653	21.8	0.0
22		**Totals**	7583	8907	17813	3920	651	1035	2562	41800	604	951	2332	5426	32735	147.3	104.2

Appendix A23: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 23 during the 2011/2012 season.



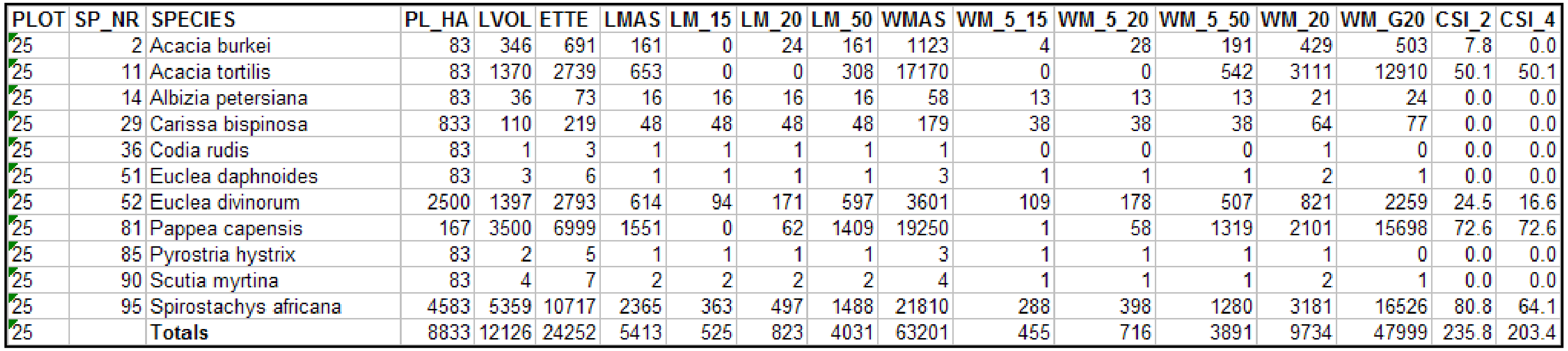
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
23	4	Acacia grandicornuta	167	43	86	19	19	19	19	29	11	11	11	17	2	0.0	0.0
23	5	Acacia leuderitzii	83	1261	2522	601	6	22	512	14422	10	38	879	2763	10627	23.6	23.6
23	7	Acacia nilotica	333	1100	2199	513	32	137	513	3812	49	203	621	1406	1785	46.6	0.0
23	29	Carissa bispinosa	83	3	7	2	2	2	2	4	1	1	1	2	1	0.0	0.0
23	32	Cassine papillosa	83	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
23	43	Dichrostachys cinerea	83	2	4	1	1	1	1	1	0	0	0	0	0	0.0	0.0
23	52	Euclea divinorum	1333	858	1717	377	122	202	376	2074	99	165	316	504	1253	14.8	6.1
23	55	Euclea undulata	83	11	22	5	5	5	5	14	4	4	4	6	4	0.0	0.0
23	64	Grewia occidentalis	83	16	33	5	5	5	5	8	2	2	2	4	2	0.0	0.0
23	72	Lycium acutifolium	83	8	16	4	4	4	4	10	3	3	3	5	3	0.0	0.0
23	92	Searcia guenzii	500	6	11	2	2	2	2	5	2	2	2	3	1	0.0	0.0
23		**Totals**	2917	3309	6617	1528	197	398	1438	20379	179	428	1838	4710	13677	84.9	29.7

Appendix A24: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 24 during the 2011/2012 season.



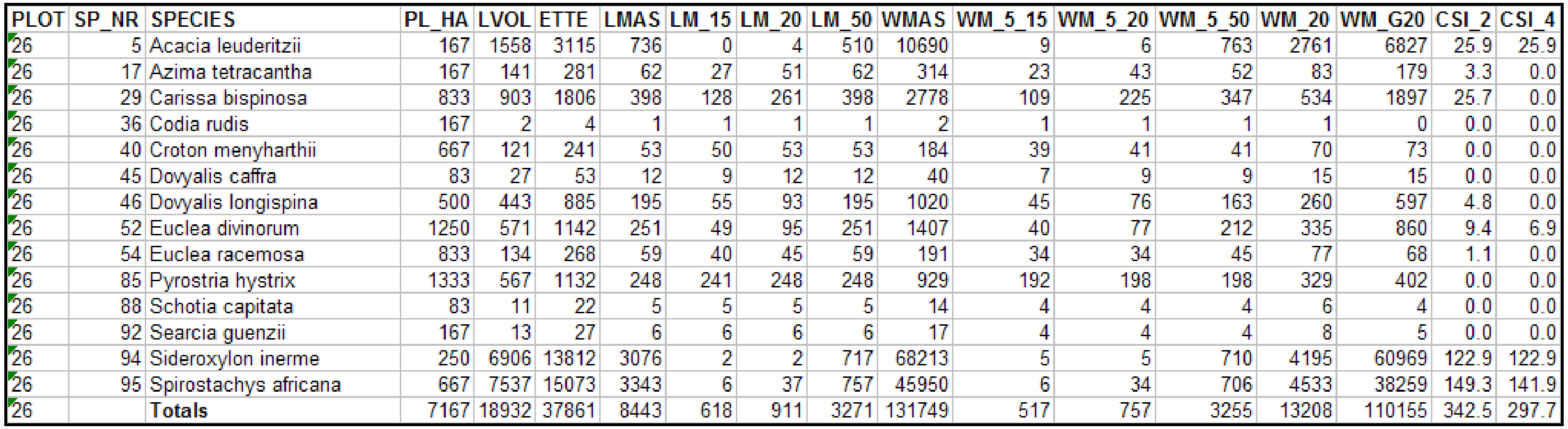
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
24	28	Capparis tomentosa	240	22	43	9	9	9	9	28	7	7	7	12	8	0.0	0.0
24	30	Carissa tetrachantha	80	4	8	2	2	2	2	5	1	1	1	2	1	0.0	0.0
24	36	Codia rudis	80	9	18	4	4	4	4	11	3	3	3	5	3	0.0	0.0
24	43	Dichrostachys cinerea	720	20	40	7	7	7	7	8	4	4	4	4	0	0.0	0.0
24	52	Euclea divinorum	80	9	17	4	4	4	4	11	3	3	3	5	3	0.0	0.0
24	63	Grewia monticola	400	314	628	115	89	110	115	487	66	82	86	138	263	1.5	0.0
24	73	Maerua angolensis	80	38	76	16	16	16	16	61	13	13	13	22	26	0.0	0.0
24	86	Salvadora australis	80	3104	6209	1379	61	218	1250	22053	58	210	1200	1874	18855	53.8	53.8
24		**Totals**	1760	3519	7039	1537	192	371	1408	22664	156	323	1317	2063	19160	55.3	53.8

Appendix A25: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 25 during the 2011/2012 season.



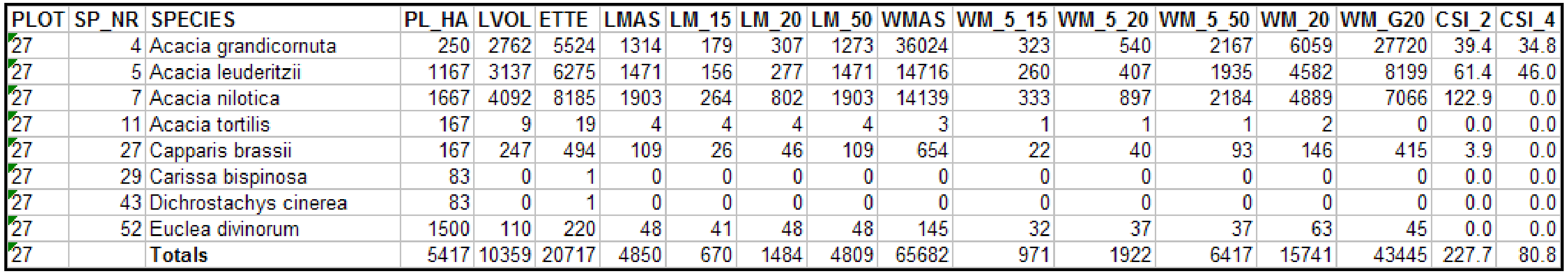
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
25	2	Acacia burkei	83	346	691	161	0	24	161	1123	4	28	191	429	503	7.8	0.0
25	11	Acacia tortilis	83	1370	2739	653	0	0	308	17170	0	0	542	3111	12910	50.1	50.1
25	14	Albizia petersiana	83	36	73	16	16	16	16	58	13	13	13	21	24	0.0	0.0
25	29	Carissa bispinosa	833	110	219	48	48	48	48	179	38	38	38	64	77	0.0	0.0
25	36	Codia rudis	83	1	3	1	1	1	1	1	0	0	0	1	0	0.0	0.0
25	51	Euclea daphnoides	83	3	6	1	1	1	1	3	1	1	1	2	1	0.0	0.0
25	52	Euclea divinorum	2500	1397	2793	614	94	171	597	3601	109	178	507	821	2259	24.5	16.6
25	81	Pappea capensis	167	3500	6999	1551	0	62	1409	19250	1	58	1319	2101	15698	72.6	72.6
25	85	Pyrostria hystrix	83	2	5	1	1	1	1	3	1	1	1	1	0	0.0	0.0
25	90	Scutia myrtina	83	4	7	2	2	2	2	4	1	1	1	2	1	0.0	0.0
25	95	Spirostachys africana	4583	5359	10717	2365	363	497	1488	21810	288	398	1280	3181	16526	80.8	64.1
25		**Totals**	8833	12126	24252	5413	525	823	4031	63201	455	716	3891	9734	47999	235.8	203.4

Appendix A26: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 26 during the 2011/2012 season.



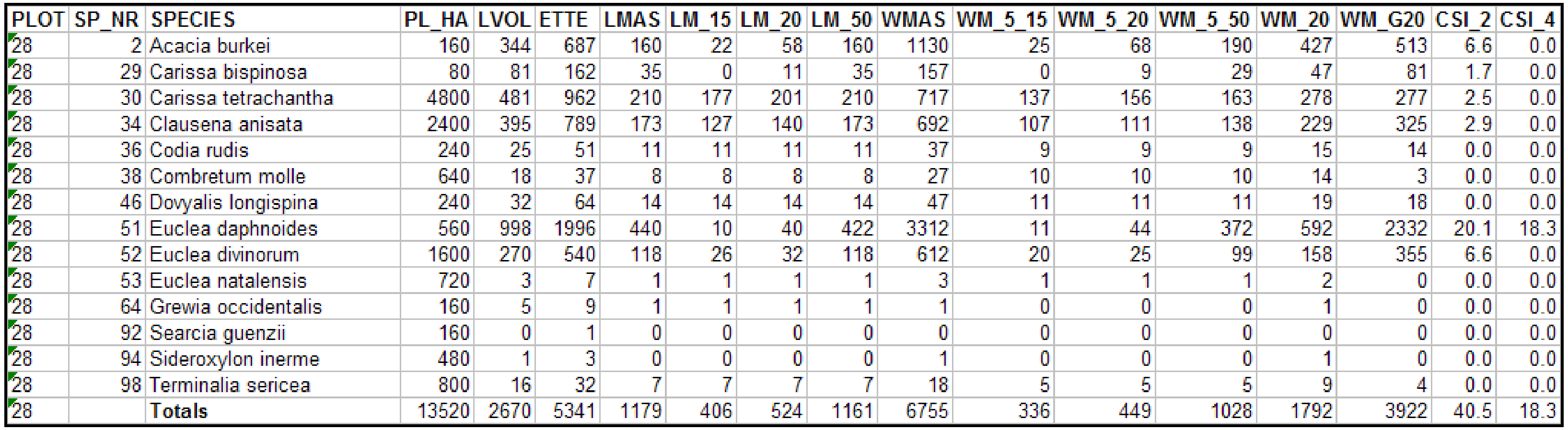
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
26	5	Acacia leuderitzii	167	1558	3115	736	0	4	510	10690	9	6	763	2761	6827	25.9	25.9
26	17	Azima tetracantha	167	141	281	62	27	51	62	314	23	43	52	83	179	3.3	0.0
26	29	Carissa bispinosa	833	903	1806	398	128	261	398	2778	109	225	347	534	1897	25.7	0.0
26	36	Codia rudis	167	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
26	40	Croton menyharthii	667	121	241	53	50	53	53	184	39	41	41	70	73	0.0	0.0
26	45	Dovyalis caffra	83	27	53	12	9	12	12	40	7	9	9	15	15	0.0	0.0
26	46	Dovyalis longispina	500	443	885	195	55	93	195	1020	45	76	163	260	597	4.8	0.0
26	52	Euclea divinorum	1250	571	1142	251	49	95	251	1407	40	77	212	335	860	9.4	6.9
26	54	Euclea racemosa	833	134	268	59	40	45	59	191	34	34	45	77	68	1.1	0.0
26	85	Pyrostria hystrix	1333	567	1132	248	241	248	248	929	192	198	198	329	402	0.0	0.0
26	88	Schotia capitata	83	11	22	5	5	5	5	14	4	4	4	6	4	0.0	0.0
26	92	Searcia guenzii	167	13	27	6	6	6	6	17	4	4	4	8	5	0.0	0.0
26	94	Sideroxylon inerme	250	6906	13812	3076	2	2	717	68213	5	5	710	4195	60969	122.9	122.9
26	95	Spirostachys africana	667	7537	15073	3343	6	37	757	45950	6	34	706	4533	38259	149.3	141.9
26		**Totals**	7167	18932	37861	8443	618	911	3271	131749	517	757	3255	13208	110155	342.5	297.7

Appendix A27: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 27 during the 2011/2012 season.



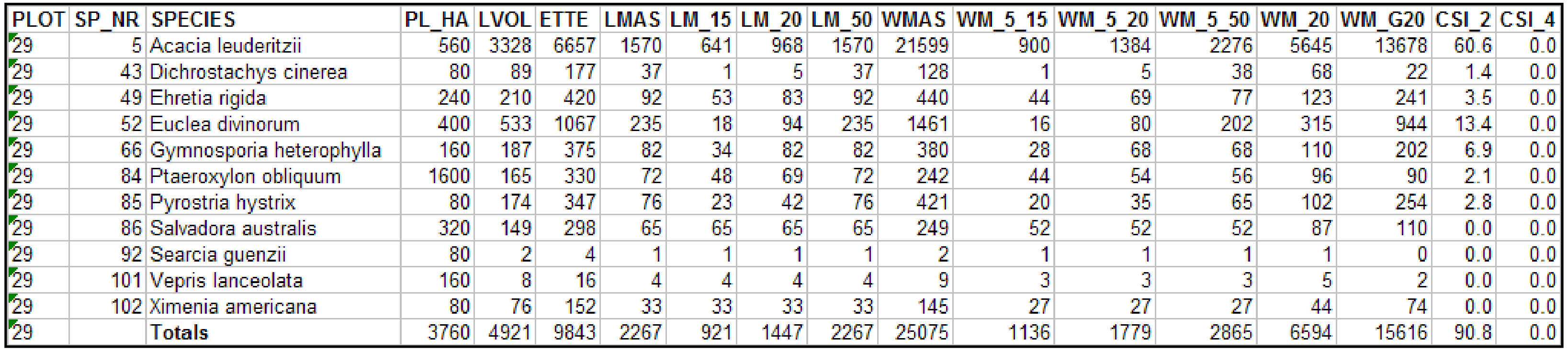
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
27	4	Acacia grandicornuta	250	2762	5524	1314	179	307	1273	36024	323	540	2167	6059	27720	39.4	34.8
27	5	Acacia leuderitzii	1167	3137	6275	1471	156	277	1471	14716	260	407	1935	4582	8199	61.4	46.0
27	7	Acacia nilotica	1667	4092	8185	1903	264	802	1903	14139	333	897	2184	4889	7066	122.9	0.0
27	11	Acacia tortilis	167	9	19	4	4	4	4	3	1	1	1	2	0	0.0	0.0
27	27	Capparis brassii	167	247	494	109	26	46	109	654	22	40	93	146	415	3.9	0.0
27	29	Carissa bispinosa	83	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
27	43	Dichrostachys cinerea	83	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
27	52	Euclea divinorum	1500	110	220	48	41	48	48	145	32	37	37	63	45	0.0	0.0
27		**Totals**	5417	10359	20717	4850	670	1484	4809	65682	971	1922	6417	15741	43445	227.7	80.8

Appendix A28: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 28 during the 2011/2012 season.



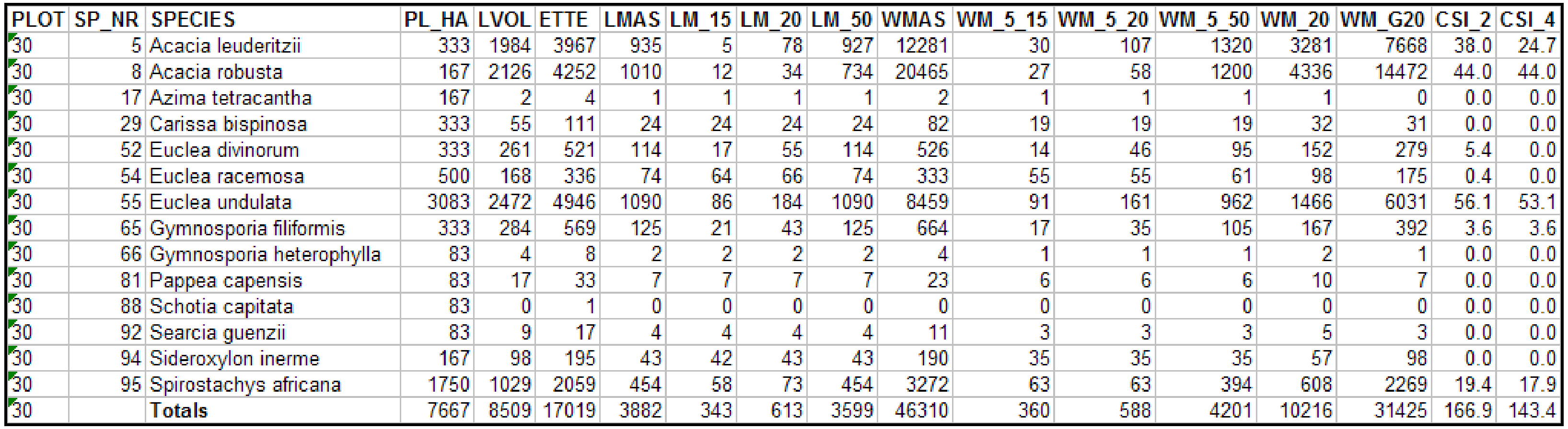
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
28	2	Acacia burkei	160	344	687	160	22	58	160	1130	25	68	190	427	513	6.6	0.0
28	29	Carissa bispinosa	80	81	162	35	0	11	35	157	0	9	29	47	81	1.7	0.0
28	30	Carissa tetrachantha	4800	481	962	210	177	201	210	717	137	156	163	278	277	2.5	0.0
28	34	Clausena anisata	2400	395	789	173	127	140	173	692	107	111	138	229	325	2.9	0.0
28	36	Codia rudis	240	25	51	11	11	11	11	37	9	9	9	15	14	0.0	0.0
28	38	Combretum molle	640	18	37	8	8	8	8	27	10	10	10	14	3	0.0	0.0
28	46	Dovyalis longispina	240	32	64	14	14	14	14	47	11	11	11	19	18	0.0	0.0
28	51	Euclea daphnoides	560	998	1996	440	10	40	422	3312	11	44	372	592	2332	20.1	18.3
28	52	Euclea divinorum	1600	270	540	118	26	32	118	612	20	25	99	158	355	6.6	0.0
28	53	Euclea natalensis	720	3	7	1	1	1	1	3	1	1	1	2	0	0.0	0.0
28	64	Grewia occidentalis	160	5	9	1	1	1	1	1	0	0	0	1	0	0.0	0.0
28	92	Searcia guenzii	160	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
28	94	Sideroxylon inerme	480	1	3	0	0	0	0	1	0	0	0	1	0	0.0	0.0
28	98	Terminalia sericea	800	16	32	7	7	7	7	18	5	5	5	9	4	0.0	0.0
28		**Totals**	13520	2670	5341	1179	406	524	1161	6755	336	449	1028	1792	3922	40.5	18.3

Appendix A29: Data obtained from the secondary calculations of the BECVOL- computer programme for Site 29 during the 2011/2012 season.



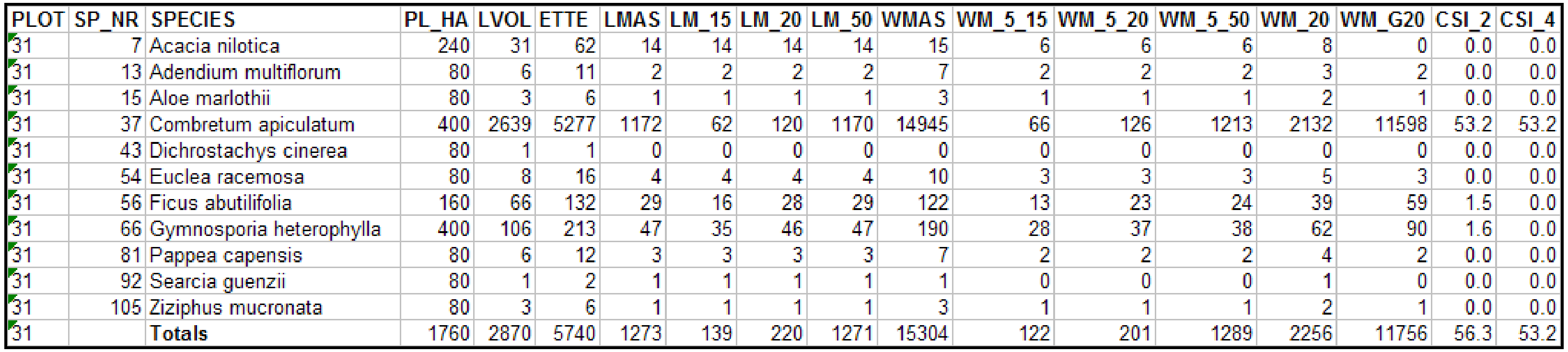
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
29	5	Acacia leuderitzii	560	3328	6657	1570	641	968	1570	21599	900	1384	2276	5645	13678	60.6	0.0
29	43	Dichrostachys cinerea	80	89	177	37	1	5	37	128	1	5	38	68	22	1.4	0.0
29	49	Ehretia rigida	240	210	420	92	53	83	92	440	44	69	77	123	241	3.5	0.0
29	52	Euclea divinorum	400	533	1067	235	18	94	235	1461	16	80	202	315	944	13.4	0.0
29	66	Gymnosporia heterophylla	160	187	375	82	34	82	82	380	28	68	68	110	202	6.9	0.0
29	84	Ptaeroxylon obliquum	1600	165	330	72	48	69	72	242	44	54	56	96	90	2.1	0.0
29	85	Pyrostria hystrix	80	174	347	76	23	42	76	421	20	35	65	102	254	2.8	0.0
29	86	Salvadora australis	320	149	298	65	65	65	65	249	52	52	52	87	110	0.0	0.0
29	92	Searcia guenzii	80	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
29	101	Vepris lanceolata	160	8	16	4	4	4	4	9	3	3	3	5	2	0.0	0.0
29	102	Ximenia americana	80	76	152	33	33	33	33	145	27	27	27	44	74	0.0	0.0
29		**Totals**	3760	4921	9843	2267	921	1447	2267	25075	1136	1779	2865	6594	15616	90.8	0.0

Appendix A30: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 30 during the 2011/2012 season.



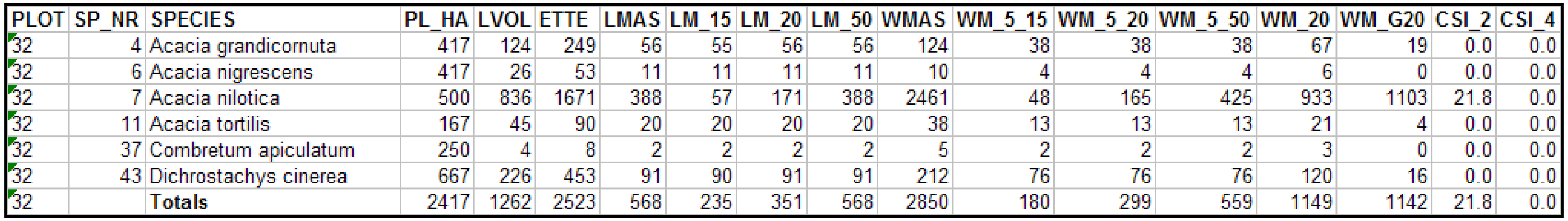
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
30	5	Acacia leuderitzii	333	1984	3967	935	5	78	927	12281	30	107	1320	3281	7668	38.0	24.7
30	8	Acacia robusta	167	2126	4252	1010	12	34	734	20465	27	58	1200	4336	14472	44.0	44.0
30	17	Azima tetracantha	167	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
30	29	Carissa bispinosa	333	55	111	24	24	24	24	82	19	19	19	32	31	0.0	0.0
30	52	Euclea divinorum	333	261	521	114	17	55	114	526	14	46	95	152	279	5.4	0.0
30	54	Euclea racemosa	500	168	336	74	64	66	74	333	55	55	61	98	175	0.4	0.0
30	55	Euclea undulata	3083	2472	4946	1090	86	184	1090	8459	91	161	962	1466	6031	56.1	53.1
30	65	Gymnosporia filiformis	333	284	569	125	21	43	125	664	17	35	105	167	392	3.6	3.6
30	66	Gymnosporia heterophylla	83	4	8	2	2	2	2	4	1	1	1	2	1	0.0	0.0
30	81	Pappea capensis	83	17	33	7	7	7	7	23	6	6	6	10	7	0.0	0.0
30	88	Schotia capitata	83	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
30	92	Searcia guenzii	83	9	17	4	4	4	4	11	3	3	3	5	3	0.0	0.0
30	94	Sideroxylon inerme	167	98	195	43	42	43	43	190	35	35	35	57	98	0.0	0.0
30	95	Spirostachys africana	1750	1029	2059	454	58	73	454	3272	63	63	394	608	2269	19.4	17.9
30		**Totals**	7667	8509	17019	3882	343	613	3599	46310	360	588	4201	10216	31425	166.9	143.4

Appendix A31: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 31 during the 2011/2012 season.



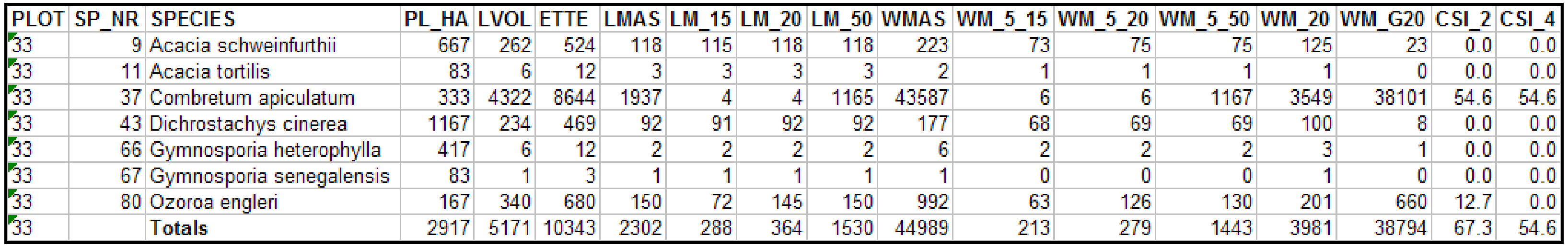
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
31	7	Acacia nilotica	240	31	62	14	14	14	14	15	6	6	6	8	0	0.0	0.0
31	13	Adendium multiflorum	80	6	11	2	2	2	2	7	2	2	2	3	2	0.0	0.0
31	15	Aloe marlothii	80	3	6	1	1	1	1	3	1	1	1	2	1	0.0	0.0
31	37	Combretum apiculatum	400	2639	5277	1172	62	120	1170	14945	66	126	1213	2132	11598	53.2	53.2
31	43	Dichrostachys cinerea	80	1	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
31	54	Euclea racemosa	80	8	16	4	4	4	4	10	3	3	3	5	3	0.0	0.0
31	56	Ficus abutilifolia	160	66	132	29	16	28	29	122	13	23	24	39	59	1.5	0.0
31	66	Gymnosporia heterophylla	400	106	213	47	35	46	47	190	28	37	38	62	90	1.6	0.0
31	81	Pappea capensis	80	6	12	3	3	3	3	7	2	2	2	4	2	0.0	0.0
31	92	Searcia guenzii	80	1	2	1	1	1	1	1	0	0	0	1	0	0.0	0.0
31	105	Ziziphus mucronata	80	3	6	1	1	1	1	3	1	1	1	2	1	0.0	0.0
31		**Totals**	1760	2870	5740	1273	139	220	1271	15304	122	201	1289	2256	11756	56.3	53.2

Appendix A32: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 32 during the 2011/2012 season.



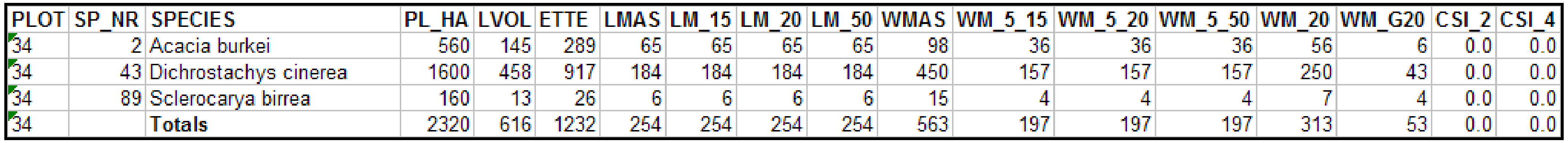
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
32	4	Acacia grandicornuta	417	124	249	56	55	56	56	124	38	38	38	67	19	0.0	0.0
32	6	Acacia nigrescens	417	26	53	11	11	11	11	10	4	4	4	6	0	0.0	0.0
32	7	Acacia nilotica	500	836	1671	388	57	171	388	2461	48	165	425	933	1103	21.8	0.0
32	11	Acacia tortilis	167	45	90	20	20	20	20	38	13	13	13	21	4	0.0	0.0
32	37	Combretum apiculatum	250	4	8	2	2	2	2	5	2	2	2	3	0	0.0	0.0
32	43	Dichrostachys cinerea	667	226	453	91	90	91	91	212	76	76	76	120	16	0.0	0.0
32		**Totals**	2417	1262	2523	568	235	351	568	2850	180	299	559	1149	1142	21.8	0.0

Appendix A33: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 33 during the 2011/2012 season.



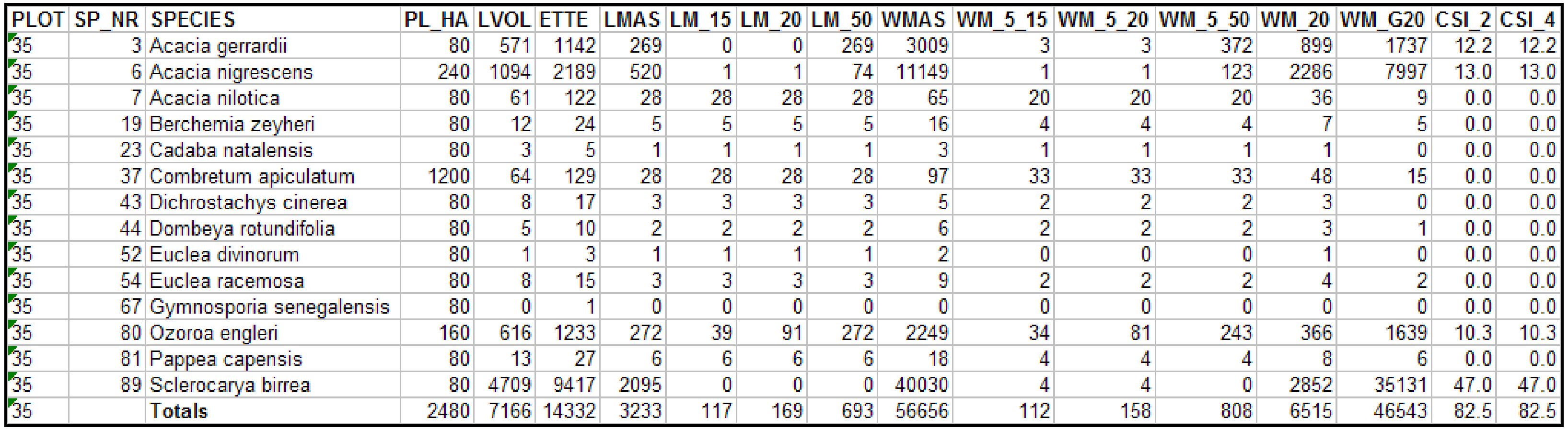
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
33	9	Acacia schweinfurthii	667	262	524	118	115	118	118	223	73	75	75	125	23	0.0	0.0
33	11	Acacia tortilis	83	6	12	3	3	3	3	2	1	1	1	1	0	0.0	0.0
33	37	Combretum apiculatum	333	4322	8644	1937	4	4	1165	43587	6	6	1167	3549	38101	54.6	54.6
33	43	Dichrostachys cinerea	1167	234	469	92	91	92	92	177	68	69	69	100	8	0.0	0.0
33	66	Gymnosporia heterophylla	417	6	12	2	2	2	2	6	2	2	2	3	1	0.0	0.0
33	67	Gymnosporia senegalensis	83	1	3	1	1	1	1	1	0	0	0	1	0	0.0	0.0
33	80	Ozoroa engleri	167	340	680	150	72	145	150	992	63	126	130	201	660	12.7	0.0
33		**Totals**	2917	5171	10343	2302	288	364	1530	44989	213	279	1443	3981	38794	67.3	54.6

Appendix A34: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 34 during the 2011/2012 season.



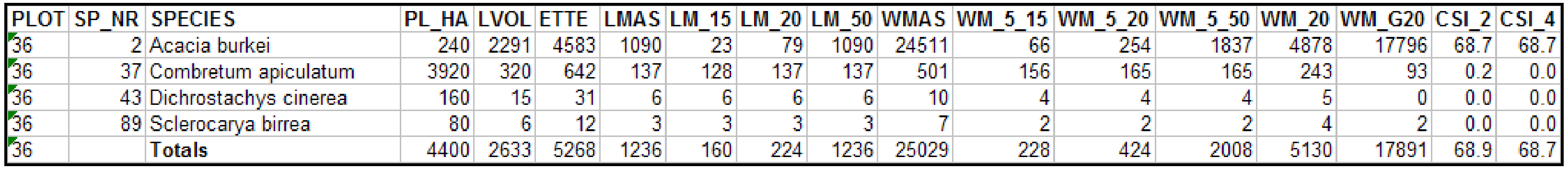
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
34	2	Acacia burkei	560	145	289	65	65	65	65	98	36	36	36	56	6	0.0	0.0
34	43	Dichrostachys cinerea	1600	458	917	184	184	184	184	450	157	157	157	250	43	0.0	0.0
34	89	Sclerocarya birrea	160	13	26	6	6	6	6	15	4	4	4	7	4	0.0	0.0
34		**Totals**	2320	616	1232	254	254	254	254	563	197	197	197	313	53	0.0	0.0

Appendix A35: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 35 during the 2011/2012 season.



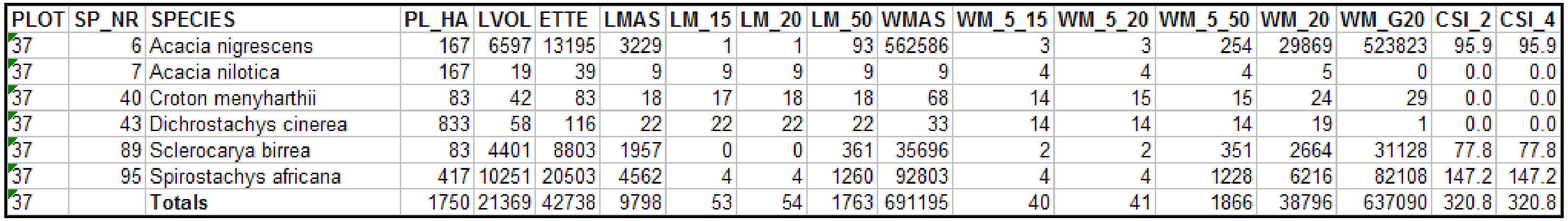
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
35	3	Acacia gerrardii	80	571	1142	269	0	0	269	3009	3	3	372	899	1737	12.2	12.2
35	6	Acacia nigrescens	240	1094	2189	520	1	1	74	11149	1	1	123	2286	7997	13.0	13.0
35	7	Acacia nilotica	80	61	122	28	28	28	28	65	20	20	20	36	9	0.0	0.0
35	19	Berchemia zeyheri	80	12	24	5	5	5	5	16	4	4	4	7	5	0.0	0.0
35	23	Cadaba natalensis	80	3	5	1	1	1	1	3	1	1	1	1	0	0.0	0.0
35	37	Combretum apiculatum	1200	64	129	28	28	28	28	97	33	33	33	48	15	0.0	0.0
35	43	Dichrostachys cinerea	80	8	17	3	3	3	3	5	2	2	2	3	0	0.0	0.0
35	44	Dombeya rotundifolia	80	5	10	2	2	2	2	6	2	2	2	3	1	0.0	0.0
35	52	Euclea divinorum	80	1	3	1	1	1	1	2	0	0	0	1	0	0.0	0.0
35	54	Euclea racemosa	80	8	15	3	3	3	3	9	2	2	2	4	2	0.0	0.0
35	67	Gymnosporia senegalensis	80	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
35	80	Ozoroa engleri	160	616	1233	272	39	91	272	2249	34	81	243	366	1639	10.3	10.3
35	81	Pappea capensis	80	13	27	6	6	6	6	18	4	4	4	8	6	0.0	0.0
35	89	Sclerocarya birrea	80	4709	9417	2095	0	0	0	40030	4	4	0	2852	35131	47.0	47.0
35		**Totals**	2480	7166	14332	3233	117	169	693	56656	112	158	808	6515	46543	82.5	82.5

Appendix A36: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 36 during the 2011/2012 season.



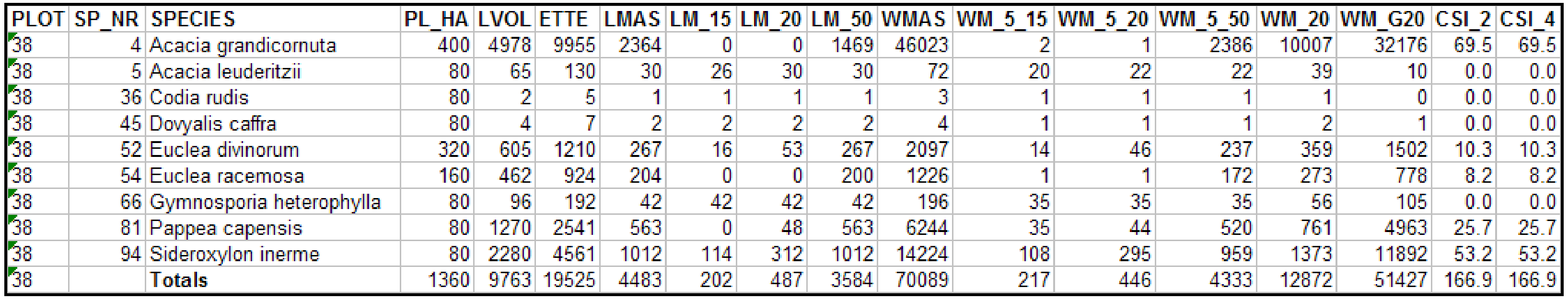
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
36	2	Acacia burkei	240	2291	4583	1090	23	79	1090	24511	66	254	1837	4878	17796	68.7	68.7
36	37	Combretum apiculatum	3920	320	642	137	128	137	137	501	156	165	165	243	93	0.2	0.0
36	43	Dichrostachys cinerea	160	15	31	6	6	6	6	10	4	4	4	5	0	0.0	0.0
36	89	Sclerocarya birrea	80	6	12	3	3	3	3	7	2	2	2	4	2	0.0	0.0
36		**Totals**	4400	2633	5268	1236	160	224	1236	25029	228	424	2008	5130	17891	68.9	68.7

Appendix A37: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 37 during the 2011/2012 season.



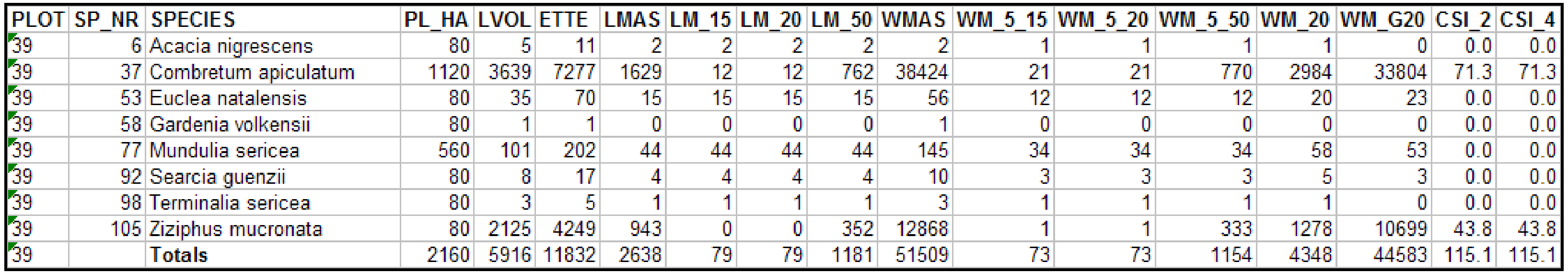
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
37	6	Acacia nigrescens	167	6597	13195	3229	1	1	93	562586	3	3	254	29869	523823	95.9	95.9
37	7	Acacia nilotica	167	19	39	9	9	9	9	9	4	4	4	5	0	0.0	0.0
37	40	Croton menyharthii	83	42	83	18	17	18	18	68	14	15	15	24	29	0.0	0.0
37	43	Dichrostachys cinerea	833	58	116	22	22	22	22	33	14	14	14	19	1	0.0	0.0
37	89	Sclerocarya birrea	83	4401	8803	1957	0	0	361	35696	2	2	351	2664	31128	77.8	77.8
37	95	Spirostachys africana	417	10251	20503	4562	4	4	1260	92803	4	4	1228	6216	82108	147.2	147.2
37		**Totals**	1750	21369	42738	9798	53	54	1763	691195	40	41	1866	38796	637090	320.8	320.8

Appendix A38: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 38 during the 2011/2012 season.



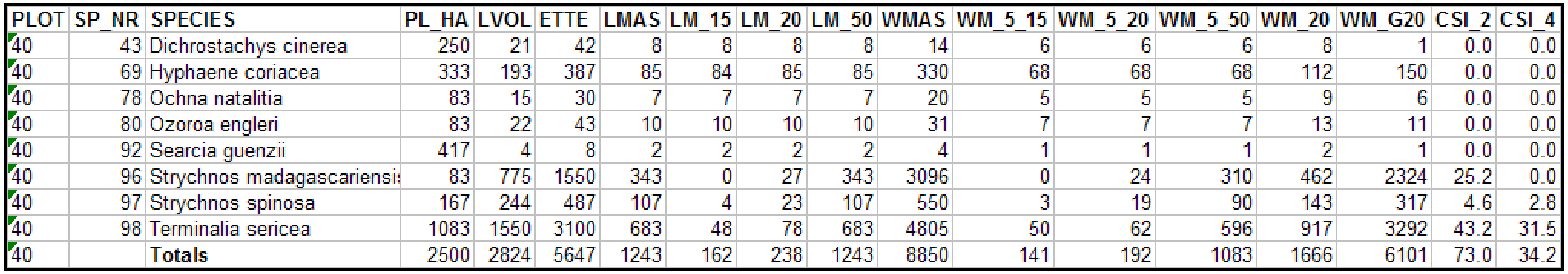
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
38	4	Acacia grandicornuta	400	4978	9955	2364	0	0	1469	46023	2	1	2386	10007	32176	69.5	69.5
38	5	Acacia leuderitzii	80	65	130	30	26	30	30	72	20	22	22	39	10	0.0	0.0
38	36	Codia rudis	80	2	5	1	1	1	1	3	1	1	1	1	0	0.0	0.0
38	45	Dovyalis caffra	80	4	7	2	2	2	2	4	1	1	1	2	1	0.0	0.0
38	52	Euclea divinorum	320	605	1210	267	16	53	267	2097	14	46	237	359	1502	10.3	10.3
38	54	Euclea racemosa	160	462	924	204	0	0	200	1226	1	1	172	273	778	8.2	8.2
38	66	Gymnosporia heterophylla	80	96	192	42	42	42	42	196	35	35	35	56	105	0.0	0.0
38	81	Pappea capensis	80	1270	2541	563	0	48	563	6244	35	44	520	761	4963	25.7	25.7
38	94	Sideroxylon inerme	80	2280	4561	1012	114	312	1012	14224	108	295	959	1373	11892	53.2	53.2
38		**Totals**	1360	9763	19525	4483	202	487	3584	70089	217	446	4333	12872	51427	166.9	166.9

Appendix A39: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 39 during the 2011/2012 season.



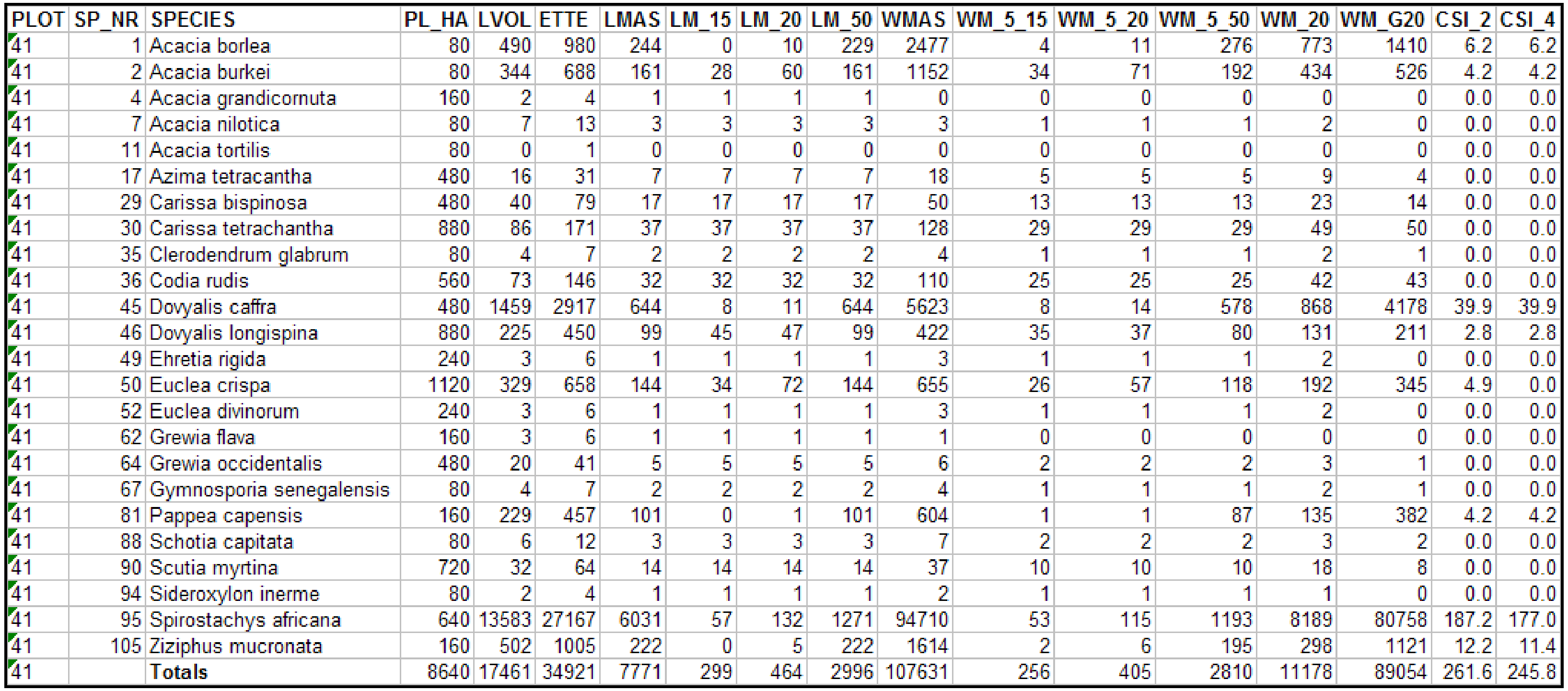
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
39	6	Acacia nigrescens	80	5	11	2	2	2	2	2	1	1	1	1	0	0.0	0.0
39	37	Combretum apiculatum	1120	3639	7277	1629	12	12	762	38424	21	21	770	2984	33804	71.3	71.3
39	53	Euclea natalensis	80	35	70	15	15	15	15	56	12	12	12	20	23	0.0	0.0
39	58	Gardenia volkensii	80	1	1	0	0	0	0	1	0	0	0	0	0	0.0	0.0
39	77	Mundulia sericea	560	101	202	44	44	44	44	145	34	34	34	58	53	0.0	0.0
39	92	Searcia guenzii	80	8	17	4	4	4	4	10	3	3	3	5	3	0.0	0.0
39	98	Terminalia sericea	80	3	5	1	1	1	1	3	1	1	1	1	0	0.0	0.0
39	105	Ziziphus mucronata	80	2125	4249	943	0	0	352	12868	1	1	333	1278	10699	43.8	43.8
39		**Totals**	2160	5916	11832	2638	79	79	1181	51509	73	73	1154	4348	44583	115.1	115.1

Appendix A40: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 40 during the 2011/2012 season.



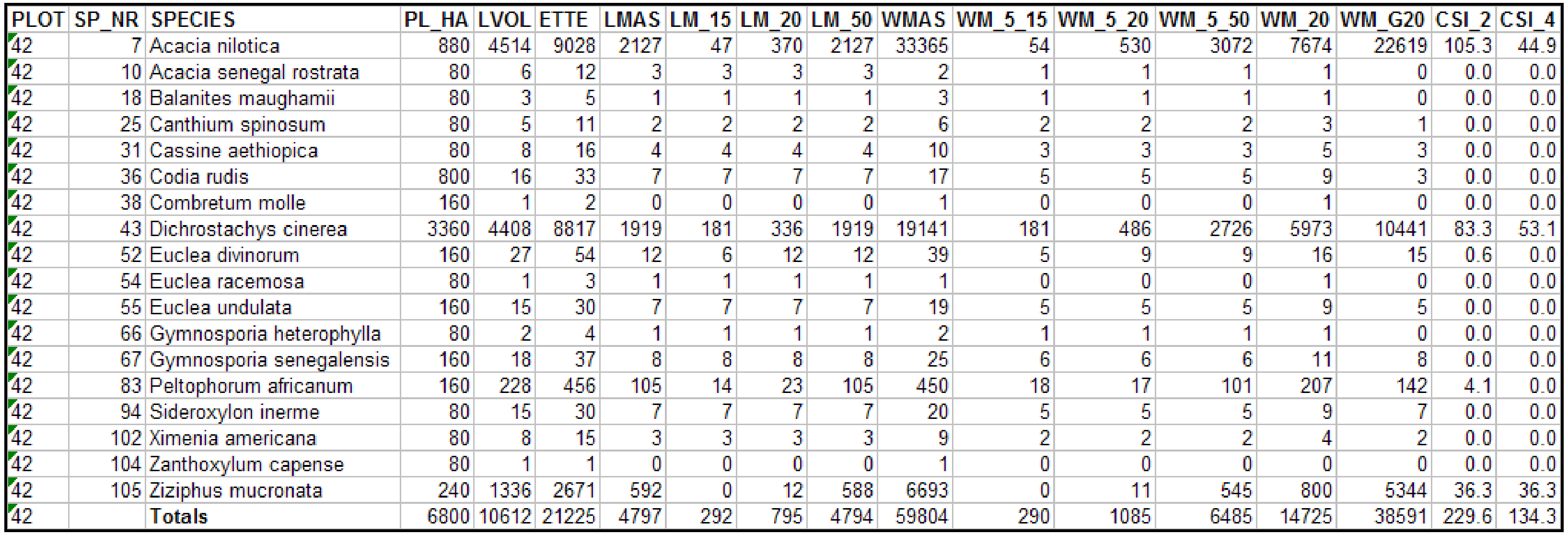
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
40	43	Dichrostachys cinerea	250	21	42	8	8	8	8	14	6	6	6	8	1	0.0	0.0
40	69	Hyphaene coriacea	333	193	387	85	84	85	85	330	68	68	68	112	150	0.0	0.0
40	78	Ochna natalitia	83	15	30	7	7	7	7	20	5	5	5	9	6	0.0	0.0
40	80	Ozoroa engleri	83	22	43	10	10	10	10	31	7	7	7	13	11	0.0	0.0
40	92	Searcia guenzii	417	4	8	2	2	2	2	4	1	1	1	2	1	0.0	0.0
40	96	Strychnos madagascariensi:	83	775	1550	343	0	27	343	3096	0	24	310	462	2324	25.2	0.0
40	97	Strychnos spinosa	167	244	487	107	4	23	107	550	3	19	90	143	317	4.6	2.8
40	98	Terminalia sericea	1083	1550	3100	683	48	78	683	4805	50	62	596	917	3292	43.2	31.5
40		**Totals**	2500	2824	5647	1243	162	238	1243	8850	141	192	1083	1666	6101	73.0	34.2

Appendix A41: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 41 during the 2011/2012 season.



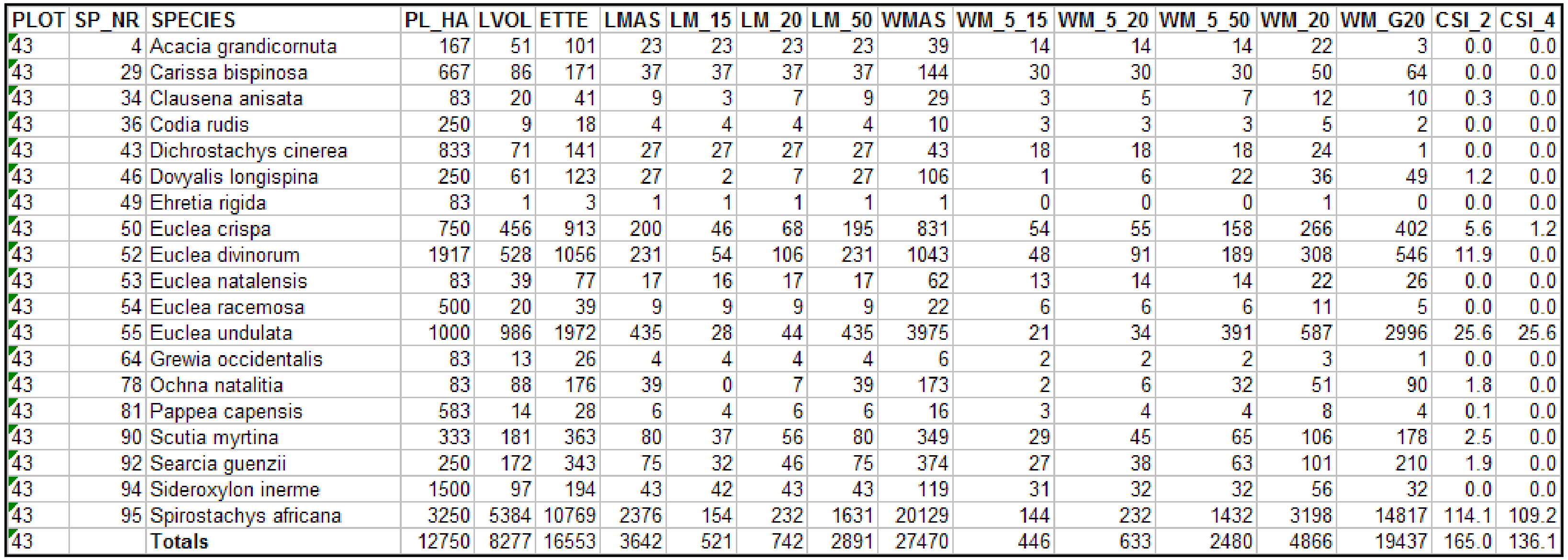
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
41	1	Acacia borlea	80	490	980	244	0	10	229	2477	4	11	276	773	1410	6.2	6.2
41	2	Acacia burkei	80	344	688	161	28	60	161	1152	34	71	192	434	526	4.2	4.2
41	4	Acacia grandicornuta	160	2	4	1	1	1	1	0	0	0	0	0	0	0.0	0.0
41	7	Acacia nilotica	80	7	13	3	3	3	3	3	1	1	1	2	0	0.0	0.0
41	11	Acacia tortilis	80	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
41	17	Azima tetracantha	480	16	31	7	7	7	7	18	5	5	5	9	4	0.0	0.0
41	29	Carissa bispinosa	480	40	79	17	17	17	17	50	13	13	13	23	14	0.0	0.0
41	30	Carissa tetrachantha	880	86	171	37	37	37	37	128	29	29	29	49	50	0.0	0.0
41	35	Clerodendrum glabrum	80	4	7	2	2	2	2	4	1	1	1	2	1	0.0	0.0
41	36	Codia rudis	560	73	146	32	32	32	32	110	25	25	25	42	43	0.0	0.0
41	45	Dovyalis caffra	480	1459	2917	644	8	11	644	5623	8	14	578	868	4178	39.9	39.9
41	46	Dovyalis longispina	880	225	450	99	45	47	99	422	35	37	80	131	211	2.8	2.8
41	49	Ehretia rigida	240	3	6	1	1	1	1	3	1	1	1	2	0	0.0	0.0
41	50	Euclea crispa	1120	329	658	144	34	72	144	655	26	57	118	192	345	4.9	0.0
41	52	Euclea divinorum	240	3	6	1	1	1	1	3	1	1	1	2	0	0.0	0.0
41	62	Grewia flava	160	3	6	1	1	1	1	1	0	0	0	0	0	0.0	0.0
41	64	Grewia occidentalis	480	20	41	5	5	5	5	6	2	2	2	3	1	0.0	0.0
41	67	Gymnosporia senegalensis	80	4	7	2	2	2	2	4	1	1	1	2	1	0.0	0.0
41	81	Pappea capensis	160	229	457	101	0	1	101	604	1	1	87	135	382	4.2	4.2
41	88	Schotia capitata	80	6	12	3	3	3	3	7	2	2	2	3	2	0.0	0.0
41	90	Scutia myrtina	720	32	64	14	14	14	14	37	10	10	10	18	8	0.0	0.0
41	94	Sideroxylon inerme	80	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
41	95	Spirostachys africana	640	13583	27167	6031	57	132	1271	94710	53	115	1193	8189	80758	187.2	177.0
41	105	Ziziphus mucronata	160	502	1005	222	0	5	222	1614	2	6	195	298	1121	12.2	11.4
41		**Totals**	8640	17461	34921	7771	299	464	2996	107631	256	405	2810	11178	89054	261.6	245.8

Appendix A42: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 42 during the 2011/2012 season.



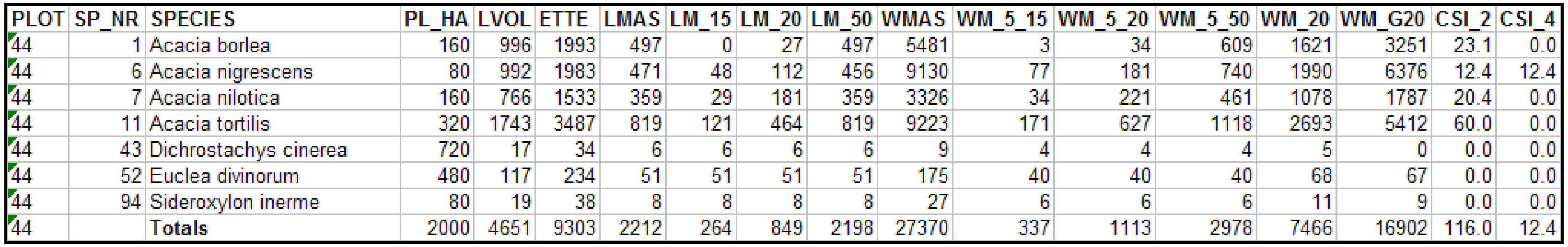
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
42	7	Acacia nilotica	880	4514	9028	2127	47	370	2127	33365	54	530	3072	7674	22619	105.3	44.9
42	10	Acacia senegal rostrata	80	6	12	3	3	3	3	2	1	1	1	1	0	0.0	0.0
42	18	Balanites maughamii	80	3	5	1	1	1	1	3	1	1	1	1	0	0.0	0.0
42	25	Canthium spinosum	80	5	11	2	2	2	2	6	2	2	2	3	1	0.0	0.0
42	31	Cassine aethiopica	80	8	16	4	4	4	4	10	3	3	3	5	3	0.0	0.0
42	36	Codia rudis	800	16	33	7	7	7	7	17	5	5	5	9	3	0.0	0.0
42	38	Combretum molle	160	1	2	0	0	0	0	1	0	0	0	1	0	0.0	0.0
42	43	Dichrostachys cinerea	3360	4408	8817	1919	181	336	1919	19141	181	486	2726	5973	10441	83.3	53.1
42	52	Euclea divinorum	160	27	54	12	6	12	12	39	5	9	9	16	15	0.6	0.0
42	54	Euclea racemosa	80	1	3	1	1	1	1	1	0	0	0	1	0	0.0	0.0
42	55	Euclea undulata	160	15	30	7	7	7	7	19	5	5	5	9	5	0.0	0.0
42	66	Gymnosporia heterophylla	80	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
42	67	Gymnosporia senegalensis	160	18	37	8	8	8	8	25	6	6	6	11	8	0.0	0.0
42	83	Peltophorum africanum	160	228	456	105	14	23	105	450	18	17	101	207	142	4.1	0.0
42	94	Sideroxylon inerme	80	15	30	7	7	7	7	20	5	5	5	9	7	0.0	0.0
42	102	Ximenia americana	80	8	15	3	3	3	3	9	2	2	2	4	2	0.0	0.0
42	104	Zanthoxylum capense	80	1	1	0	0	0	0	1	0	0	0	0	0	0.0	0.0
42	105	Ziziphus mucronata	240	1336	2671	592	0	12	588	6693	0	11	545	800	5344	36.3	36.3
42		**Totals**	6800	10612	21225	4797	292	795	4794	59804	290	1085	6485	14725	38591	229.6	134.3

Appendix A43: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 43 during the 2011/2012 season.



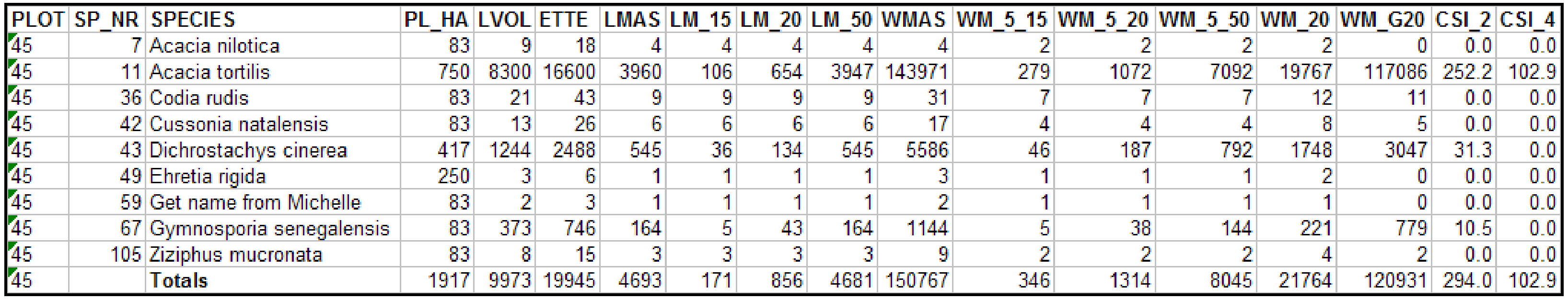
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
43	4	Acacia grandicornuta	167	51	101	23	23	23	23	39	14	14	14	22	3	0.0	0.0
43	29	Carissa bispinosa	667	86	171	37	37	37	37	144	30	30	30	50	64	0.0	0.0
43	34	Clausena anisata	83	20	41	9	3	7	9	29	3	5	7	12	10	0.3	0.0
43	36	Codia rudis	250	9	18	4	4	4	4	10	3	3	3	5	2	0.0	0.0
43	43	Dichrostachys cinerea	833	71	141	27	27	27	27	43	18	18	18	24	1	0.0	0.0
43	46	Dovyalis longispina	250	61	123	27	2	7	27	106	1	6	22	36	49	1.2	0.0
43	49	Ehretia rigida	83	1	3	1	1	1	1	1	0	0	0	1	0	0.0	0.0
43	50	Euclea crispa	750	456	913	200	46	68	195	831	54	55	158	266	402	5.6	1.2
43	52	Euclea divinorum	1917	528	1056	231	54	106	231	1043	48	91	189	308	546	11.9	0.0
43	53	Euclea natalensis	83	39	77	17	16	17	17	62	13	14	14	22	26	0.0	0.0
43	54	Euclea racemosa	500	20	39	9	9	9	9	22	6	6	6	11	5	0.0	0.0
43	55	Euclea undulata	1000	986	1972	435	28	44	435	3975	21	34	391	587	2996	25.6	25.6
43	64	Grewia occidentalis	83	13	26	4	4	4	4	6	2	2	2	3	1	0.0	0.0
43	78	Ochna natalitia	83	88	176	39	0	7	39	173	2	6	32	51	90	1.8	0.0
43	81	Pappea capensis	583	14	28	6	4	6	6	16	3	4	4	8	4	0.1	0.0
43	90	Scutia myrtina	333	181	363	80	37	56	80	349	29	45	65	106	178	2.5	0.0
43	92	Searcia guenzii	250	172	343	75	32	46	75	374	27	38	63	101	210	1.9	0.0
43	94	Sideroxylon inerme	1500	97	194	43	42	43	43	119	31	32	32	56	32	0.0	0.0
43	95	Spirostachys africana	3250	5384	10769	2376	154	232	1631	20129	144	232	1432	3198	14817	114.1	109.2
43		**Totals**	12750	8277	16553	3642	521	742	2891	27470	446	633	2480	4866	19437	165.0	136.1

Appendix A44: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 44 during the 2011/2012 season.



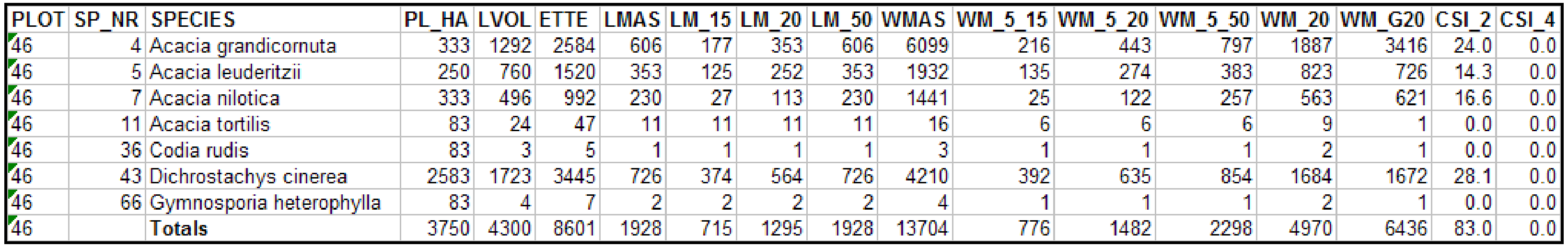
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
44	1	Acacia borlea	160	996	1993	497	0	27	497	5481	3	34	609	1621	3251	23.1	0.0
44	6	Acacia nigrescens	80	992	1983	471	48	112	456	9130	77	181	740	1990	6376	12.4	12.4
44	7	Acacia nilotica	160	766	1533	359	29	181	359	3326	34	221	461	1078	1787	20.4	0.0
44	11	Acacia tortilis	320	1743	3487	819	121	464	819	9223	171	627	1118	2693	5412	60.0	0.0
44	43	Dichrostachys cinerea	720	17	34	6	6	6	6	9	4	4	4	5	0	0.0	0.0
44	52	Euclea divinorum	480	117	234	51	51	51	51	175	40	40	40	68	67	0.0	0.0
44	94	Sideroxylon inerme	80	19	38	8	8	8	8	27	6	6	6	11	9	0.0	0.0
44		**Totals**	2000	4651	9303	2212	264	849	2198	27370	337	1113	2978	7466	16902	116.0	12.4

Appendix A45: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 45 during the 2011/2012 season.



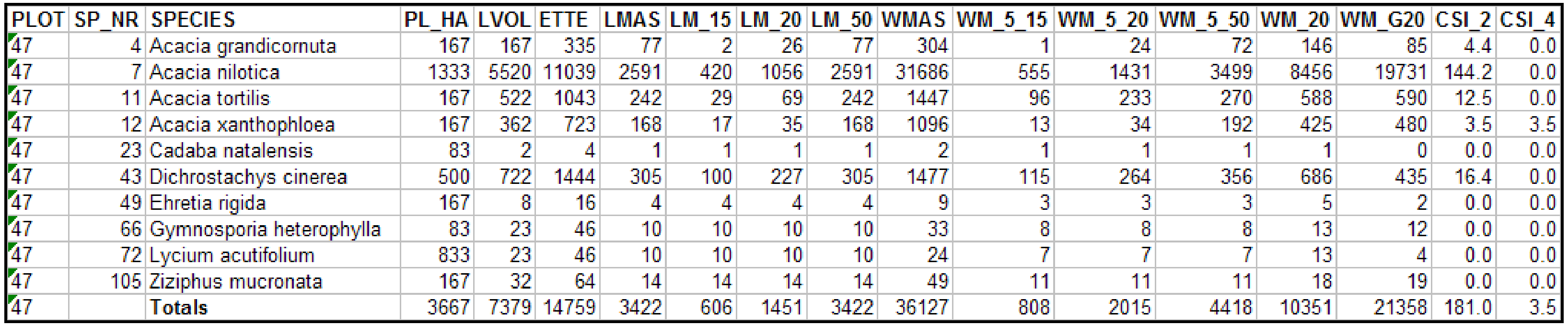
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
45	7	Acacia nilotica	83	9	18	4	4	4	4	4	2	2	2	2	0	0.0	0.0
45	11	Acacia tortilis	750	8300	16600	3960	106	654	3947	143971	279	1072	7092	19767	117086	252.2	102.9
45	36	Codia rudis	83	21	43	9	9	9	9	31	7	7	7	12	11	0.0	0.0
45	42	Cussonia natalensis	83	13	26	6	6	6	6	17	4	4	4	8	5	0.0	0.0
45	43	Dichrostachys cinerea	417	1244	2488	545	36	134	545	5586	46	187	792	1748	3047	31.3	0.0
45	49	Ehretia rigida	250	3	6	1	1	1	1	3	1	1	1	2	0	0.0	0.0
45	59	Get name from Michelle	83	2	3	1	1	1	1	2	1	1	1	1	0	0.0	0.0
45	67	Gymnosporia senegalensis	83	373	746	164	5	43	164	1144	5	38	144	221	779	10.5	0.0
45	105	Ziziphus mucronata	83	8	15	3	3	3	3	9	2	2	2	4	2	0.0	0.0
45		**Totals**	1917	9973	19945	4693	171	856	4681	150767	346	1314	8045	21764	120931	294.0	102.9

Appendix A46: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 46 during the 2011/2012 season.



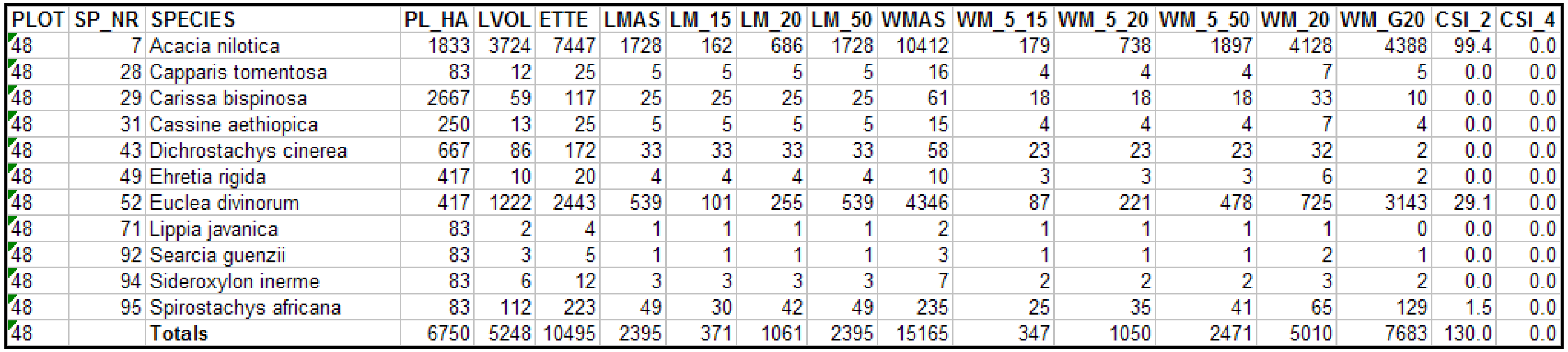
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
46	4	Acacia grandicornuta	333	1292	2584	606	177	353	606	6099	216	443	797	1887	3416	24.0	0.0
46	5	Acacia leuderitzii	250	760	1520	353	125	252	353	1932	135	274	383	823	726	14.3	0.0
46	7	Acacia nilotica	333	496	992	230	27	113	230	1441	25	122	257	563	621	16.6	0.0
46	11	Acacia tortilis	83	24	47	11	11	11	11	16	6	6	6	9	1	0.0	0.0
46	36	Codia rudis	83	3	5	1	1	1	1	3	1	1	1	2	1	0.0	0.0
46	43	Dichrostachys cinerea	2583	1723	3445	726	374	564	726	4210	392	635	854	1684	1672	28.1	0.0
46	66	Gymnosporia heterophylla	83	4	7	2	2	2	2	4	1	1	1	2	1	0.0	0.0
46		**Totals**	3750	4300	8601	1928	715	1295	1928	13704	776	1482	2298	4970	6436	83.0	0.0

Appendix A47: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 47 during the 2011/2012 season.



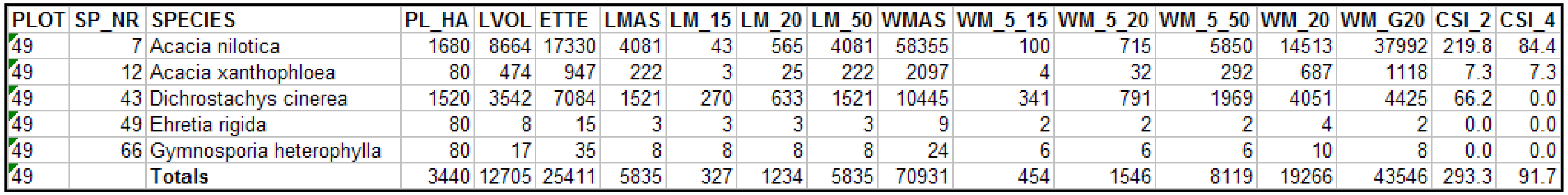
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
47	4	Acacia grandicornuta	167	167	335	77	2	26	77	304	1	24	72	146	85	4.4	0.0
47	7	Acacia nilotica	1333	5520	11039	2591	420	1056	2591	31686	555	1431	3499	8456	19731	144.2	0.0
47	11	Acacia tortilis	167	522	1043	242	29	69	242	1447	96	233	270	588	590	12.5	0.0
47	12	Acacia xanthophloea	167	362	723	168	17	35	168	1096	13	34	192	425	480	3.5	3.5
47	23	Cadaba natalensis	83	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
47	43	Dichrostachys cinerea	500	722	1444	305	100	227	305	1477	115	264	356	686	435	16.4	0.0
47	49	Ehretia rigida	167	8	16	4	4	4	4	9	3	3	3	5	2	0.0	0.0
47	66	Gymnosporia heterophylla	83	23	46	10	10	10	10	33	8	8	8	13	12	0.0	0.0
47	72	Lycium acutifolium	833	23	46	10	10	10	10	24	7	7	7	13	4	0.0	0.0
47	105	Ziziphus mucronata	167	32	64	14	14	14	14	49	11	11	11	18	19	0.0	0.0
47		**Totals**	3667	7379	14759	3422	606	1451	3422	36127	808	2015	4418	10351	21358	181.0	3.5

Appendix A48: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 48 during the 2011/2012 season.



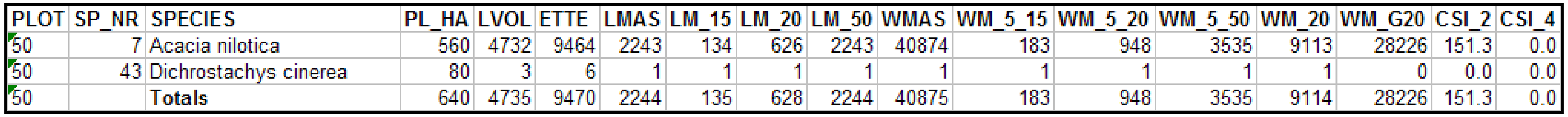
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
48	7	Acacia nilotica	1833	3724	7447	1728	162	686	1728	10412	179	738	1897	4128	4388	99.4	0.0
48	28	Capparis tomentosa	83	12	25	5	5	5	5	16	4	4	4	7	5	0.0	0.0
48	29	Carissa bispinosa	2667	59	117	25	25	25	25	61	18	18	18	33	10	0.0	0.0
48	31	Cassine aethiopica	250	13	25	5	5	5	5	15	4	4	4	7	4	0.0	0.0
48	43	Dichrostachys cinerea	667	86	172	33	33	33	33	58	23	23	23	32	2	0.0	0.0
48	49	Ehretia rigida	417	10	20	4	4	4	4	10	3	3	3	6	2	0.0	0.0
48	52	Euclea divinorum	417	1222	2443	539	101	255	539	4346	87	221	478	725	3143	29.1	0.0
48	71	Lippia javanica	83	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
48	92	Searcia guenzii	83	3	5	1	1	1	1	3	1	1	1	2	1	0.0	0.0
48	94	Sideroxylon inerme	83	6	12	3	3	3	3	7	2	2	2	3	2	0.0	0.0
48	95	Spirostachys africana	83	112	223	49	30	42	49	235	25	35	41	65	129	1.5	0.0
48		**Totals**	6750	5248	10495	2395	371	1061	2395	15165	347	1050	2471	5010	7683	130.0	0.0

Appendix A49: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 49 during the 2011/2012 season.



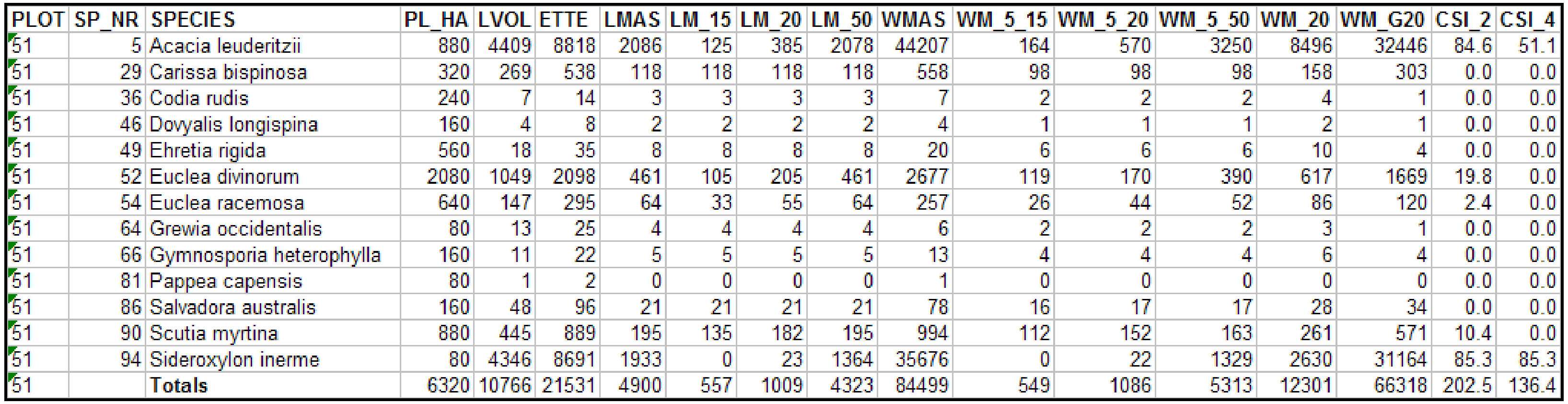
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
49	7	Acacia nilotica	1680	8664	17330	4081	43	565	4081	58355	100	715	5850	14513	37992	219.8	84.4
49	12	Acacia xanthophloea	80	474	947	222	3	25	222	2097	4	32	292	687	1118	7.3	7.3
49	43	Dichrostachys cinerea	1520	3542	7084	1521	270	633	1521	10445	341	791	1969	4051	4425	66.2	0.0
49	49	Ehretia rigida	80	8	15	3	3	3	3	9	2	2	2	4	2	0.0	0.0
49	66	Gymnosporia heterophylla	80	17	35	8	8	8	8	24	6	6	6	10	8	0.0	0.0
49		**Totals**	3440	12705	25411	5835	327	1234	5835	70931	454	1546	8119	19266	43546	293.3	91.7

Appendix A50: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 50 during the 2011/2012 season.



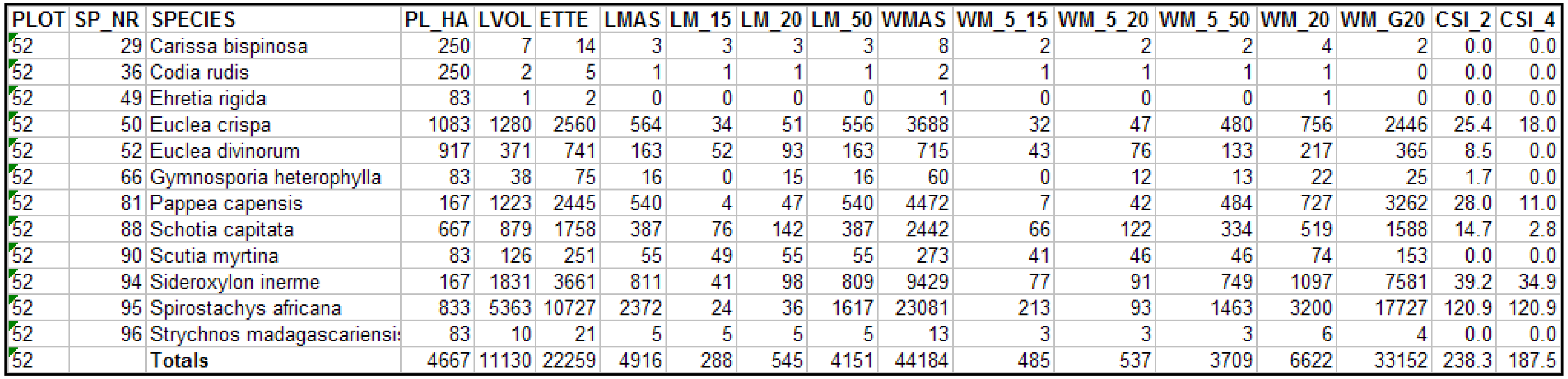
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
50	7	Acacia nilotica	560	4732	9464	2243	134	626	2243	40874	183	948	3535	9113	28226	151.3	0.0
50	43	Dichrostachys cinerea	80	3	6	1	1	1	1	1	1	1	1	1	0	0.0	0.0
50		**Totals**	640	4735	9470	2244	135	628	2244	40875	183	948	3535	9114	28226	151.3	0.0

Appendix A51: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 51 during the 2011/2012 season.



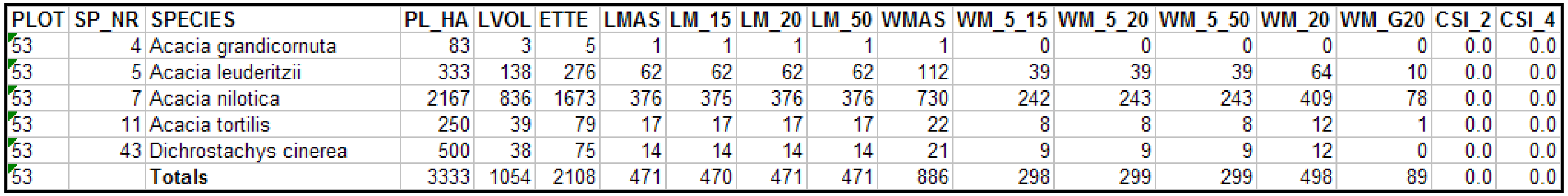
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
51	5	Acacia leuderitzii	880	4409	8818	2086	125	385	2078	44207	164	570	3250	8496	32446	84.6	51.1
51	29	Carissa bispinosa	320	269	538	118	118	118	118	558	98	98	98	158	303	0.0	0.0
51	36	Codia rudis	240	7	14	3	3	3	3	7	2	2	2	4	1	0.0	0.0
51	46	Dovyalis longispina	160	4	8	2	2	2	2	4	1	1	1	2	1	0.0	0.0
51	49	Ehretia rigida	560	18	35	8	8	8	8	20	6	6	6	10	4	0.0	0.0
51	52	Euclea divinorum	2080	1049	2098	461	105	205	461	2677	119	170	390	617	1669	19.8	0.0
51	54	Euclea racemosa	640	147	295	64	33	55	64	257	26	44	52	86	120	2.4	0.0
51	64	Grewia occidentalis	80	13	25	4	4	4	4	6	2	2	2	3	1	0.0	0.0
51	66	Gymnosporia heterophylla	160	11	22	5	5	5	5	13	4	4	4	6	4	0.0	0.0
51	81	Pappea capensis	80	1	2	0	0	0	0	1	0	0	0	0	0	0.0	0.0
51	86	Salvadora australis	160	48	96	21	21	21	21	78	16	17	17	28	34	0.0	0.0
51	90	Scutia myrtina	880	445	889	195	135	182	195	994	112	152	163	261	571	10.4	0.0
51	94	Sideroxylon inerme	80	4346	8691	1933	0	23	1364	35676	0	22	1329	2630	31164	85.3	85.3
51		**Totals**	6320	10766	21531	4900	557	1009	4323	84499	549	1086	5313	12301	66318	202.5	136.4

Appendix A52: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 52 during the 2011/2012 season.



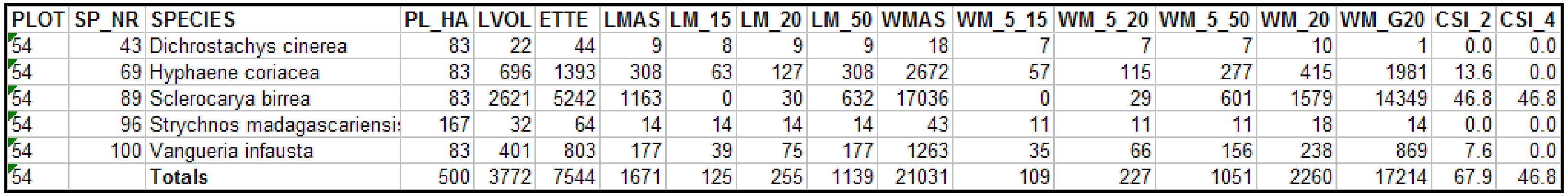
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
52	29	Carissa bispinosa	250	7	14	3	3	3	3	8	2	2	2	4	2	0.0	0.0
52	36	Codia rudis	250	2	5	1	1	1	1	2	1	1	1	1	0	0.0	0.0
52	49	Ehretia rigida	83	1	2	0	0	0	0	1	0	0	0	1	0	0.0	0.0
52	50	Euclea crispa	1083	1280	2560	564	34	51	556	3688	32	47	480	756	2446	25.4	18.0
52	52	Euclea divinorum	917	371	741	163	52	93	163	715	43	76	133	217	365	8.5	0.0
52	66	Gymnosporia heterophylla	83	38	75	16	0	15	16	60	0	12	13	22	25	1.7	0.0
52	81	Pappea capensis	167	1223	2445	540	4	47	540	4472	7	42	484	727	3262	28.0	11.0
52	88	Schotia capitata	667	879	1758	387	76	142	387	2442	66	122	334	519	1588	14.7	2.8
52	90	Scutia myrtina	83	126	251	55	49	55	55	273	41	46	46	74	153	0.0	0.0
52	94	Sideroxylon inerme	167	1831	3661	811	41	98	809	9429	77	91	749	1097	7581	39.2	34.9
52	95	Spirostachys africana	833	5363	10727	2372	24	36	1617	23081	213	93	1463	3200	17727	120.9	120.9
52	96	Strychnos madagascariensi	83	10	21	5	5	5	5	13	3	3	3	6	4	0.0	0.0
52		**Totals**	4667	11130	22259	4916	288	545	4151	44184	485	537	3709	6622	33152	238.3	187.5

Appendix A53: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 53 during the 2011/2012 season.



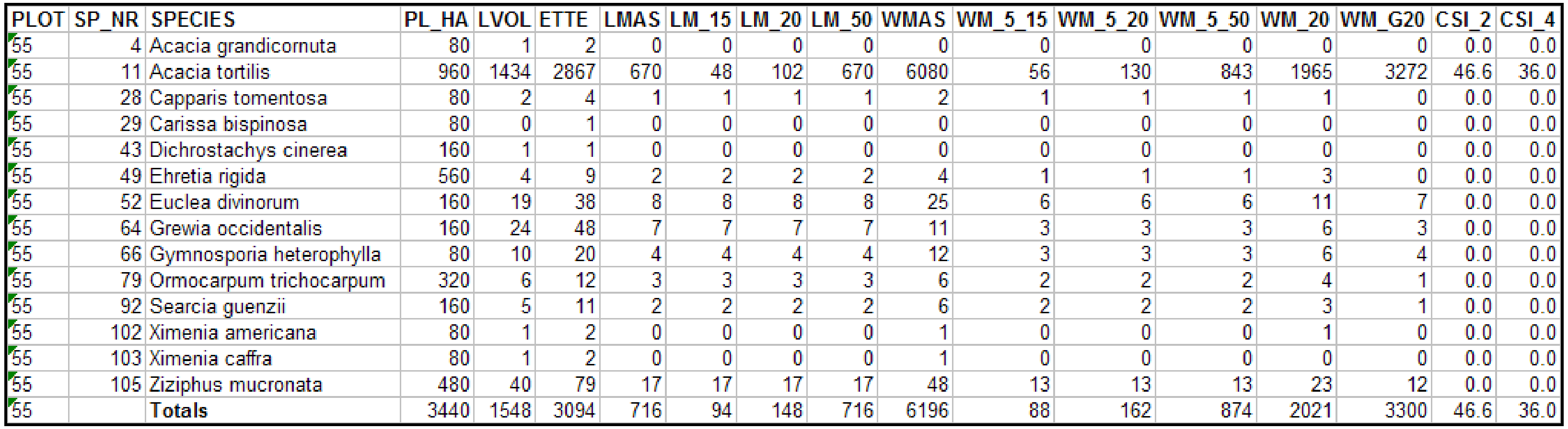
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
53	4	Acacia grandicornuta	83	3	5	1	1	1	1	1	0	0	0	0	0	0.0	0.0
53	5	Acacia leuderitzii	333	138	276	62	62	62	62	112	39	39	39	64	10	0.0	0.0
53	7	Acacia nilotica	2167	836	1673	376	375	376	376	730	242	243	243	409	78	0.0	0.0
53	11	Acacia tortilis	250	39	79	17	17	17	17	22	8	8	8	12	1	0.0	0.0
53	43	Dichrostachys cinerea	500	38	75	14	14	14	14	21	9	9	9	12	0	0.0	0.0
53		**Totals**	3333	1054	2108	471	470	471	471	886	298	299	299	498	89	0.0	0.0

Appendix A54: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 54 during the 2011/2012 season.



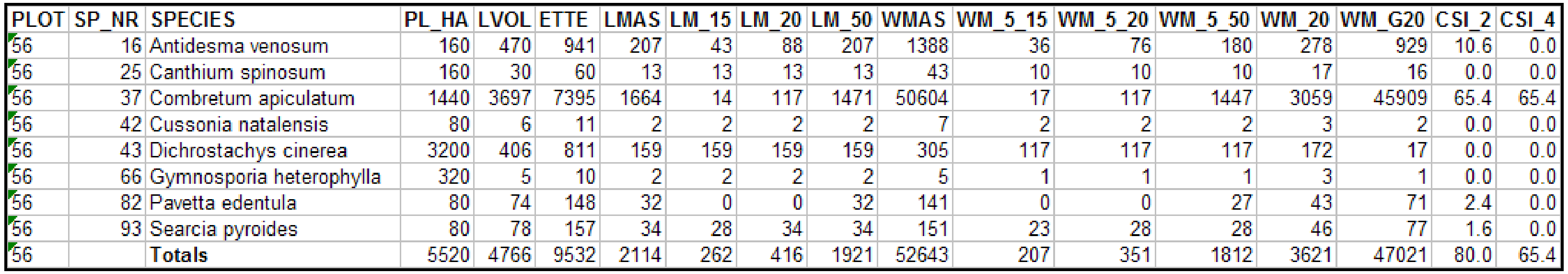
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
54	43	Dichrostachys cinerea	83	22	44	9	8	9	9	18	7	7	7	10	1	0.0	0.0
54	69	Hyphaene coriacea	83	696	1393	308	63	127	308	2672	57	115	277	415	1981	13.6	0.0
54	89	Sclerocarya birrea	83	2621	5242	1163	0	30	632	17036	0	29	601	1579	14349	46.8	46.8
54	96	Strychnos madagascariensi	167	32	64	14	14	14	14	43	11	11	11	18	14	0.0	0.0
54	100	Vangueria infausta	83	401	803	177	39	75	177	1263	35	66	156	238	869	7.6	0.0
54		**Totals**	500	3772	7544	1671	125	255	1139	21031	109	227	1051	2260	17214	67.9	46.8

Appendix A55: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 55 during the 2011/2012 season.



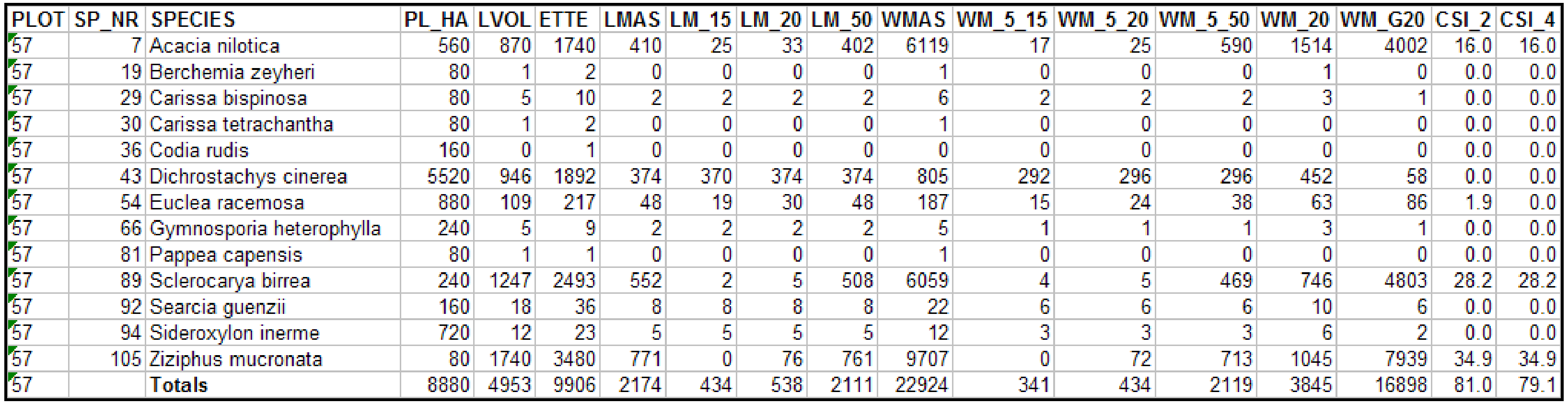
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
55	4	Acacia grandicornuta	80	1	2	0	0	0	0	0	0	0	0	0	0	0.0	0.0
55	11	Acacia tortilis	960	1434	2867	670	48	102	670	6080	56	130	843	1965	3272	46.6	36.0
55	28	Capparis tomentosa	80	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
55	29	Carissa bispinosa	80	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
55	43	Dichrostachys cinerea	160	1	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
55	49	Ehretia rigida	560	4	9	2	2	2	2	4	1	1	1	3	0	0.0	0.0
55	52	Euclea divinorum	160	19	38	8	8	8	8	25	6	6	6	11	7	0.0	0.0
55	64	Grewia occidentalis	160	24	48	7	7	7	7	11	3	3	3	6	3	0.0	0.0
55	66	Gymnosporia heterophylla	80	10	20	4	4	4	4	12	3	3	3	6	4	0.0	0.0
55	79	Ormocarpum trichocarpum	320	6	12	3	3	3	3	6	2	2	2	4	1	0.0	0.0
55	92	Searcia guenzii	160	5	11	2	2	2	2	6	2	2	2	3	1	0.0	0.0
55	102	Ximenia americana	80	1	2	0	0	0	0	1	0	0	0	1	0	0.0	0.0
55	103	Ximenia caffra	80	1	2	0	0	0	0	1	0	0	0	0	0	0.0	0.0
55	105	Ziziphus mucronata	480	40	79	17	17	17	17	48	13	13	13	23	12	0.0	0.0
55		**Totals**	3440	1548	3094	716	94	148	716	6196	88	162	874	2021	3300	46.6	36.0

Appendix A56: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 56 during the 2011/2012 season.



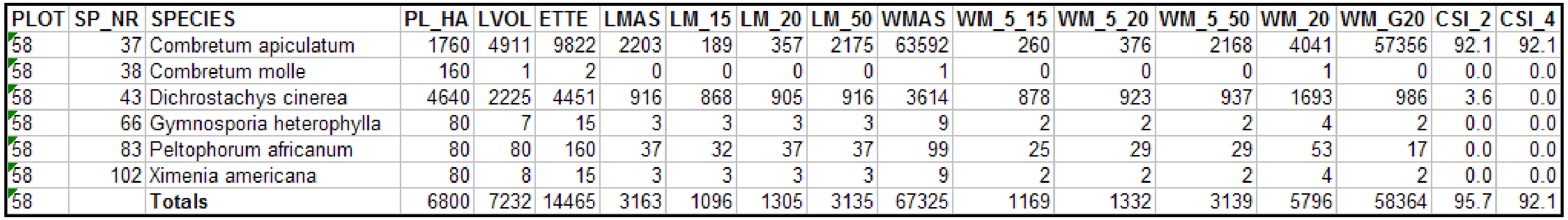
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
56	16	Antidesma venosum	160	470	941	207	43	88	207	1388	36	76	180	278	929	10.6	0.0
56	25	Canthium spinosum	160	30	60	13	13	13	13	43	10	10	10	17	16	0.0	0.0
56	37	Combretum apiculatum	1440	3697	7395	1664	14	117	1471	50604	17	117	1447	3059	45909	65.4	65.4
56	42	Cussonia natalensis	80	6	11	2	2	2	2	7	2	2	2	3	2	0.0	0.0
56	43	Dichrostachys cinerea	3200	406	811	159	159	159	159	305	117	117	117	172	17	0.0	0.0
56	66	Gymnosporia heterophylla	320	5	10	2	2	2	2	5	1	1	1	3	1	0.0	0.0
56	82	Pavetta edentula	80	74	148	32	0	0	32	141	0	0	27	43	71	2.4	0.0
56	93	Searcia pyroides	80	78	157	34	28	34	34	151	23	28	28	46	77	1.6	0.0
56		**Totals**	5520	4766	9532	2114	262	416	1921	52643	207	351	1812	3621	47021	80.0	65.4

Appendix A57: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 57 during the 2011/2012 season.



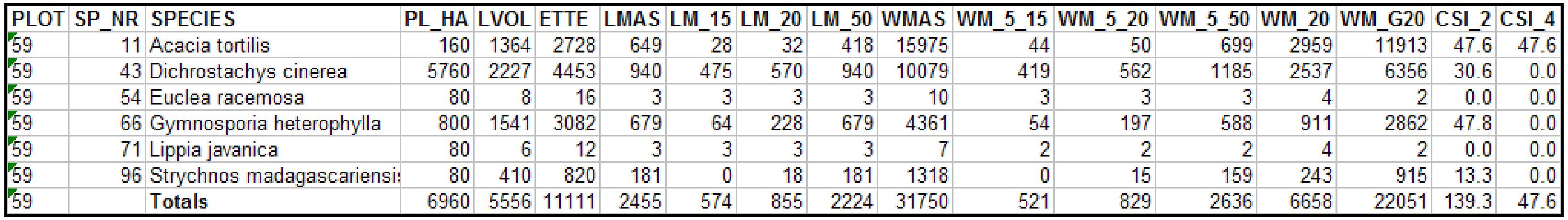
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
57	7	Acacia nilotica	560	870	1740	410	25	33	402	6119	17	25	590	1514	4002	16.0	16.0
57	19	Berchemia zeyheri	80	1	2	0	0	0	0	1	0	0	0	1	0	0.0	0.0
57	29	Carissa bispinosa	80	5	10	2	2	2	2	6	2	2	2	3	1	0.0	0.0
57	30	Carissa tetrachantha	80	1	2	0	0	0	0	1	0	0	0	0	0	0.0	0.0
57	36	Codia rudis	160	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
57	43	Dichrostachys cinerea	5520	946	1892	374	370	374	374	805	292	296	296	452	58	0.0	0.0
57	54	Euclea racemosa	880	109	217	48	19	30	48	187	15	24	38	63	86	1.9	0.0
57	66	Gymnosporia heterophylla	240	5	9	2	2	2	2	5	1	1	1	3	1	0.0	0.0
57	81	Pappea capensis	80	1	1	0	0	0	0	1	0	0	0	0	0	0.0	0.0
57	89	Sclerocarya birrea	240	1247	2493	552	2	5	508	6059	4	5	469	746	4803	28.2	28.2
57	92	Searcia guenzii	160	18	36	8	8	8	8	22	6	6	6	10	6	0.0	0.0
57	94	Sideroxylon inerme	720	12	23	5	5	5	5	12	3	3	3	6	2	0.0	0.0
57	105	Ziziphus mucronata	80	1740	3480	771	0	76	761	9707	0	72	713	1045	7939	34.9	34.9
57		**Totals**	8880	4953	9906	2174	434	538	2111	22924	341	434	2119	3845	16898	81.0	79.1

Appendix A58: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 58 during the 2011/2012 season.



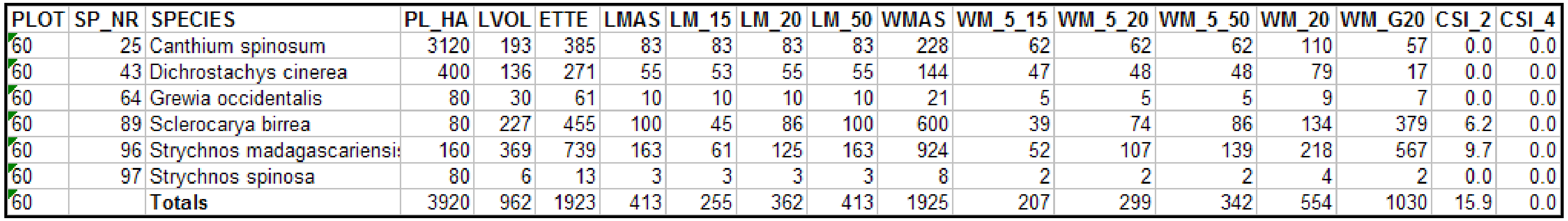
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
58	37	Combretum apiculatum	1760	4911	9822	2203	189	357	2175	63592	260	376	2168	4041	57356	92.1	92.1
58	38	Combretum molle	160	1	2	0	0	0	0	1	0	0	0	1	0	0.0	0.0
58	43	Dichrostachys cinerea	4640	2225	4451	916	868	905	916	3614	878	923	937	1693	986	3.6	0.0
58	66	Gymnosporia heterophylla	80	7	15	3	3	3	3	9	2	2	2	4	2	0.0	0.0
58	83	Peltophorum africanum	80	80	160	37	32	37	37	99	25	29	29	53	17	0.0	0.0
58	102	Ximenia americana	80	8	15	3	3	3	3	9	2	2	2	4	2	0.0	0.0
58		**Totals**	6800	7232	14465	3163	1096	1305	3135	67325	1169	1332	3139	5796	58364	95.7	92.1

Appendix A59: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 59 during the 2011/2012 season.



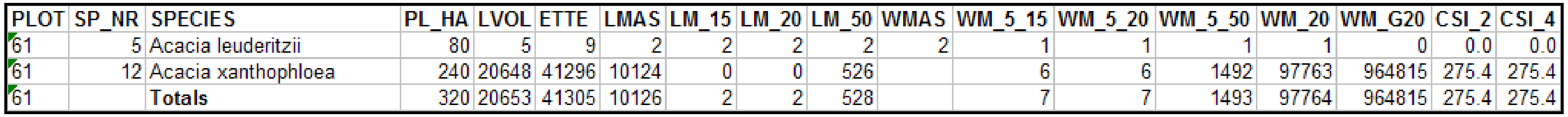
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
59	11	Acacia tortilis	160	1364	2728	649	28	32	418	15975	44	50	699	2959	11913	47.6	47.6
59	43	Dichrostachys cinerea	5760	2227	4453	940	475	570	940	10079	419	562	1185	2537	6356	30.6	0.0
59	54	Euclea racemosa	80	8	16	3	3	3	3	10	3	3	3	4	2	0.0	0.0
59	66	Gymnosporia heterophylla	800	1541	3082	679	64	228	679	4361	54	197	588	911	2862	47.8	0.0
59	71	Lippia javanica	80	6	12	3	3	3	3	7	2	2	2	4	2	0.0	0.0
59	96	Strychnos madagascariensi	80	410	820	181	0	18	181	1318	0	15	159	243	915	13.3	0.0
59		**Totals**	6960	5556	11111	2455	574	855	2224	31750	521	829	2636	6658	22051	139.3	47.6

Appendix A60: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 60 during the 2011/2012 season.



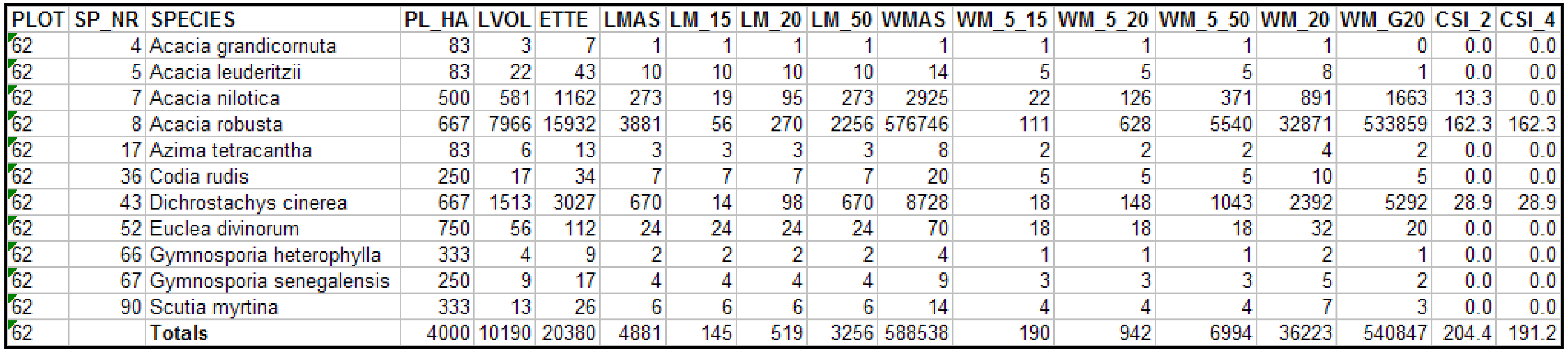
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
60	25	Canthium spinosum	3120	193	385	83	83	83	83	228	62	62	62	110	57	0.0	0.0
60	43	Dichrostachys cinerea	400	136	271	55	53	55	55	144	47	48	48	79	17	0.0	0.0
60	64	Grewia occidentalis	80	30	61	10	10	10	10	21	5	5	5	9	7	0.0	0.0
60	89	Sclerocarya birrea	80	227	455	100	45	86	100	600	39	74	86	134	379	6.2	0.0
60	96	Strychnos madagascariensi	160	369	739	163	61	125	163	924	52	107	139	218	567	9.7	0.0
60	97	Strychnos spinosa	80	6	13	3	3	3	3	8	2	2	2	4	2	0.0	0.0
60		**Totals**	3920	962	1923	413	255	362	413	1925	207	299	342	554	1030	15.9	0.0

Appendix A61: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 61 during the 2011/2012 season.



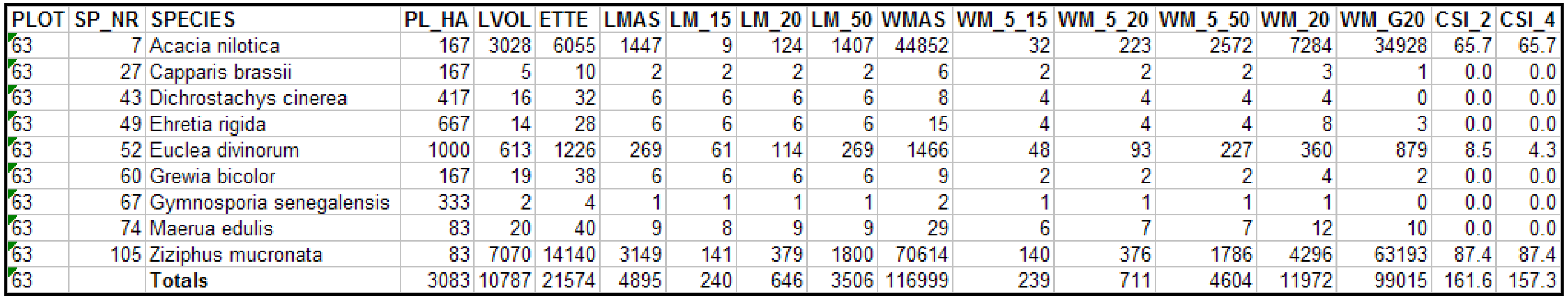
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
61	5	Acacia leuderitzii	80	5	9	2	2	2	2	2	1	1	1	1	0	0.0	0.0
61	12	Acacia xanthophloea	240	20648	41296	10124	0	0	526		6	6	1492	97763	964815	275.4	275.4
61		**Totals**	320	20653	41305	10126	2	2	528		7	7	1493	97764	964815	275.4	275.4

Appendix A62: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 62 during the 2011/2012 season.



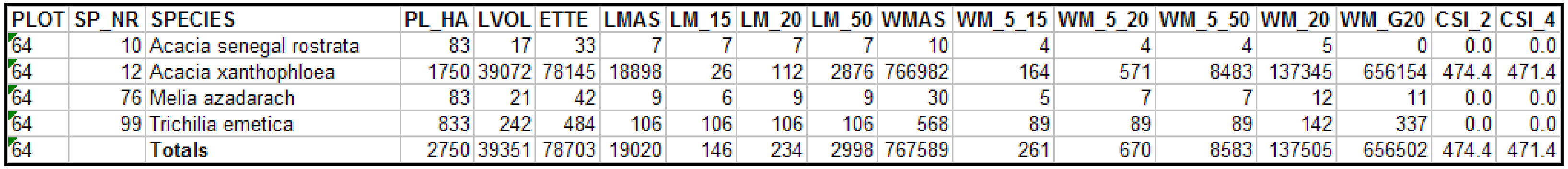
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
62	4	Acacia grandicornuta	83	3	7	1	1	1	1	1	1	1	1	1	0	0.0	0.0
62	5	Acacia leuderitzii	83	22	43	10	10	10	10	14	5	5	5	8	1	0.0	0.0
62	7	Acacia nilotica	500	581	1162	273	19	95	273	2925	22	126	371	891	1663	13.3	0.0
62	8	Acacia robusta	667	7966	15932	3881	56	270	2256	576746	111	628	5540	32871	533859	162.3	162.3
62	17	Azima tetracantha	83	6	13	3	3	3	3	8	2	2	2	4	2	0.0	0.0
62	36	Codia rudis	250	17	34	7	7	7	7	20	5	5	5	10	5	0.0	0.0
62	43	Dichrostachys cinerea	667	1513	3027	670	14	98	670	8728	18	148	1043	2392	5292	28.9	28.9
62	52	Euclea divinorum	750	56	112	24	24	24	24	70	18	18	18	32	20	0.0	0.0
62	66	Gymnosporia heterophylla	333	4	9	2	2	2	2	4	1	1	1	2	1	0.0	0.0
62	67	Gymnosporia senegalensis	250	9	17	4	4	4	4	9	3	3	3	5	2	0.0	0.0
62	90	Scutia myrtina	333	13	26	6	6	6	6	14	4	4	4	7	3	0.0	0.0
62		**Totals**	4000	10190	20380	4881	145	519	3256	588538	190	942	6994	36223	540847	204.4	191.2

Appendix A63: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 63 during the 2011/2012 season.



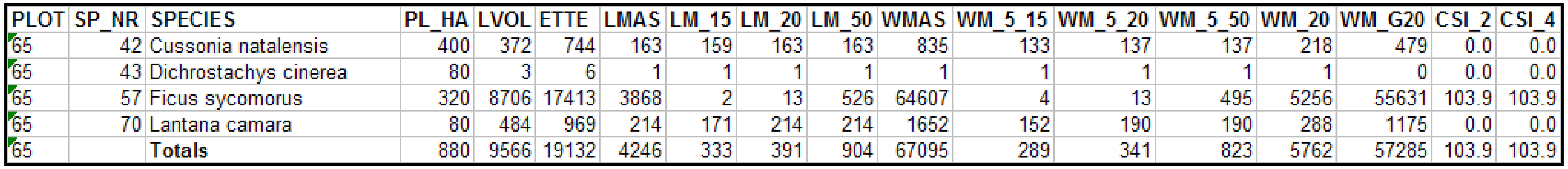
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
63	7	Acacia nilotica	167	3028	6055	1447	9	124	1407	44852	32	223	2572	7284	34928	65.7	65.7
63	27	Capparis brassii	167	5	10	2	2	2	2	6	2	2	2	3	1	0.0	0.0
63	43	Dichrostachys cinerea	417	16	32	6	6	6	6	8	4	4	4	4	0	0.0	0.0
63	49	Ehretia rigida	667	14	28	6	6	6	6	15	4	4	4	8	3	0.0	0.0
63	52	Euclea divinorum	1000	613	1226	269	61	114	269	1466	48	93	227	360	879	8.5	4.3
63	60	Grewia bicolor	167	19	38	6	6	6	6	9	2	2	2	4	2	0.0	0.0
63	67	Gymnosporia senegalensis	333	2	4	1	1	1	1	2	1	1	1	1	0	0.0	0.0
63	74	Maerua edulis	83	20	40	9	8	9	9	29	6	7	7	12	10	0.0	0.0
63	105	Ziziphus mucronata	83	7070	14140	3149	141	379	1800	70614	140	376	1786	4296	63193	87.4	87.4
63		**Totals**	3083	10787	21574	4895	240	646	3506	116999	239	711	4604	11972	99015	161.6	157.3

Appendix A64: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 64 during the 2011/2012 season.



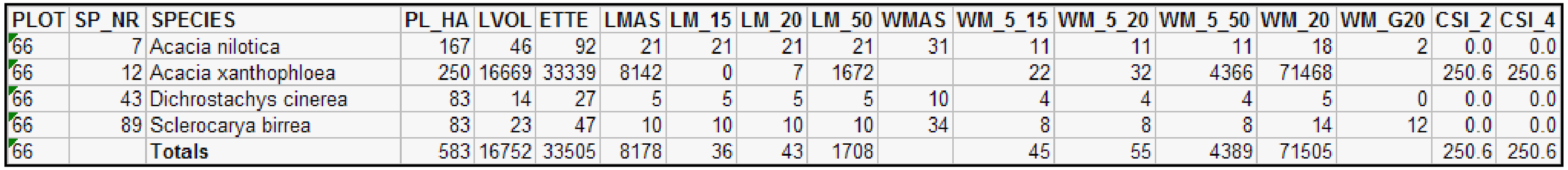
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
64	10	Acacia senegal rostrata	83	17	33	7	7	7	7	10	4	4	4	5	0	0.0	0.0
64	12	Acacia xanthophloea	1750	39072	78145	18898	26	112	2876	766982	164	571	8483	137345	656154	474.4	471.4
64	76	Melia azadarach	83	21	42	9	6	9	9	30	5	7	7	12	11	0.0	0.0
64	99	Trichilia emetica	833	242	484	106	106	106	106	568	89	89	89	142	337	0.0	0.0
64		**Totals**	2750	39351	78703	19020	146	234	2998	767589	261	670	8583	137505	656502	474.4	471.4

Appendix A65: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 65 during the 2011/2012 season.



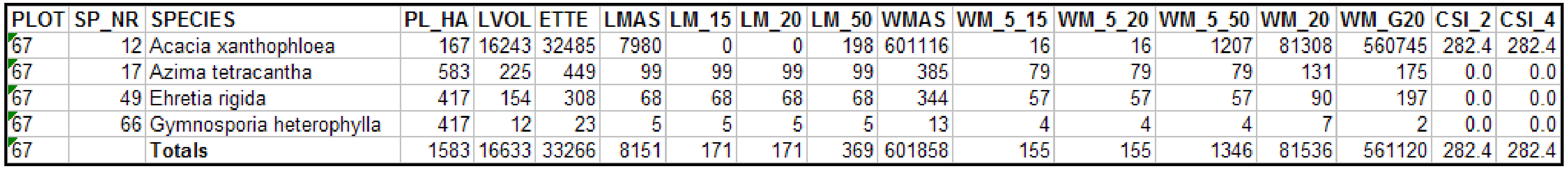
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
65	42	Cussonia natalensis	400	372	744	163	159	163	163	835	133	137	137	218	479	0.0	0.0
65	43	Dichrostachys cinerea	80	3	6	1	1	1	1	1	1	1	1	1	0	0.0	0.0
65	57	Ficus sycomorus	320	8706	17413	3868	2	13	526	64607	4	13	495	5256	55631	103.9	103.9
65	70	Lantana camara	80	484	969	214	171	214	214	1652	152	190	190	288	1175	0.0	0.0
65		**Totals**	880	9566	19132	4246	333	391	904	67095	289	341	823	5762	57285	103.9	103.9

Appendix A66: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 66 during the 2011/2012 season.



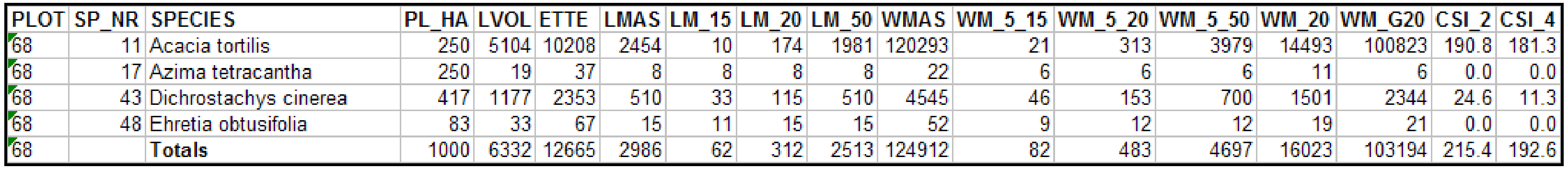
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
66	7	Acacia nilotica	167	46	92	21	21	21	21	31	11	11	11	18	2	0.0	0.0
66	12	Acacia xanthophloea	250	16669	33339	8142	0	7	1672		22	32	4366	71468		250.6	250.6
66	43	Dichrostachys cinerea	83	14	27	5	5	5	5	10	4	4	4	5	0	0.0	0.0
66	89	Sclerocarya birrea	83	23	47	10	10	10	10	34	8	8	8	14	12	0.0	0.0
66		**Totals**	583	16752	33505	8178	36	43	1708		45	55	4389	71505		250.6	250.6

Appendix A67: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 67 during the 2011/2012 season.



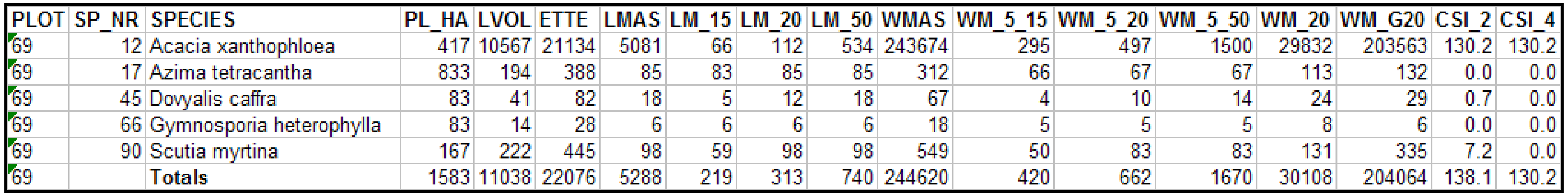
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
67	12	Acacia xanthophloea	167	16243	32485	7980	0	0	198	601116	16	16	1207	81308	560745	282.4	282.4
67	17	Azima tetracantha	583	225	449	99	99	99	99	385	79	79	79	131	175	0.0	0.0
67	49	Ehretia rigida	417	154	308	68	68	68	68	344	57	57	57	90	197	0.0	0.0
67	66	Gymnosporia heterophylla	417	12	23	5	5	5	5	13	4	4	4	7	2	0.0	0.0
67		**Totals**	1583	16633	33266	8151	171	171	369	601858	155	155	1346	81536	561120	282.4	282.4

Appendix A68: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 68 during the 2011/2012 season.



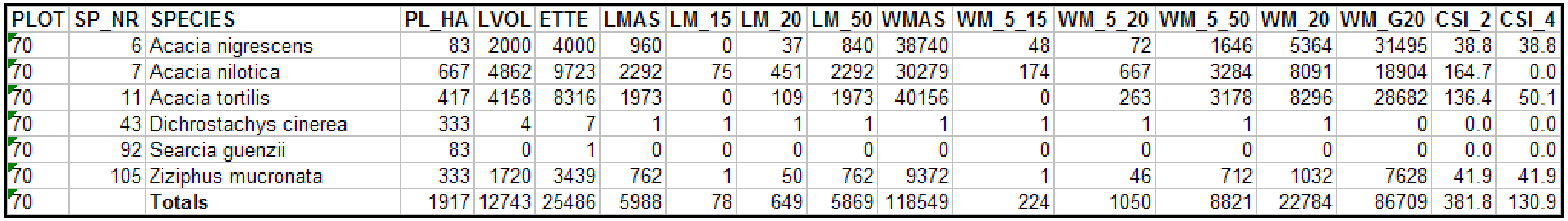
PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
68	11	Acacia tortilis	250	5104	10208	2454	10	174	1981	120293	21	313	3979	14493	100823	190.8	181.3
68	17	Azima tetracantha	250	19	37	8	8	8	8	22	6	6	6	11	6	0.0	0.0
68	43	Dichrostachys cinerea	417	1177	2353	510	33	115	510	4545	46	153	700	1501	2344	24.6	11.3
68	48	Ehretia obtusifolia	83	33	67	15	11	15	15	52	9	12	12	19	21	0.0	0.0
68		**Totals**	1000	6332	12665	2986	62	312	2513	124912	82	483	4697	16023	103194	215.4	192.6

Appendix A69: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 69 during the 2011/2012 season.



PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
69	12	Acacia xanthophloea	417	10567	21134	5081	66	112	534	243674	295	497	1500	29832	203563	130.2	130.2
69	17	Azima tetracantha	833	194	388	85	83	85	85	312	66	67	67	113	132	0.0	0.0
69	45	Dovyalis caffra	83	41	82	18	5	12	18	67	4	10	14	24	29	0.7	0.0
69	66	Gymnosporia heterophylla	83	14	28	6	6	6	6	18	5	5	5	8	6	0.0	0.0
69	90	Scutia myrtina	167	222	445	98	59	98	98	549	50	83	83	131	335	7.2	0.0
69		**Totals**	1583	11038	22076	5288	219	313	740	244620	420	662	1670	30108	204064	138.1	130.2

Appendix A70: Data obtained from the secondary calculations of the BECVOL-3 computer programme for Site 70 during the 2011/2012 season.



PLOT	SP_NR	SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	WMAS	WM_5_15	WM_5_20	WM_5_50	WM_20	WM_G20	CSI_2	CSI_4
70	6	Acacia nigrescens	83	2000	4000	960	0	37	840	38740	48	72	1646	5364	31495	38.8	38.8
70	7	Acacia nilotica	667	4862	9723	2292	75	451	2292	30279	174	667	3284	8091	18904	164.7	0.0
70	11	Acacia tortilis	417	4158	8316	1973	0	109	1973	40156	0	263	3178	8296	28682	136.4	50.1
70	43	Dichrostachys cinerea	333	4	7	1	1	1	1	1	1	1	1	1	0	0.0	0.0
70	92	Searcia guenzii	83	0	1	0	0	0	0	0	0	0	0	0	0	0.0	0.0
70	105	Ziziphus mucronata	333	1720	3439	762	1	50	762	9372	1	46	712	1032	7628	41.9	41.9
70		**Totals**	1917	12743	25486	5988	78	649	5869	118549	224	1050	8821	22784	86709	381.8	130.9

APPENDIX B – POSTER PRESENTATIONS

The population dynamics of *Acacia nilotica* subsp. *kraussiana* in Northern KwaZulu-Natal, South Africa - aspects of a recently initiated project.

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A. nilotica has the tendency to form thickets.

Introduction

Thicket formation is a global problem especially in savannas This affects livestock production and biodiversity. A third of South Africa is classified as savanna, and at least half this is already affected by bush encroachment (Rutherford *et al.* 2006). Thickening by *Acacia nilotica* is a problem in northern KwaZulu-Natal. The increase in density of this species is reducing the area and quality of grazing land, reducing grazing capacity and biodiversity. This thickening is aggravated by disturbances (man-made or natural) thereby causing an imbalance in the ecosystem.

Mkhuze Game Reserve has been chosen as the study area as it is currently experiencing this thickening problem with *A. nilotica* and because it has good historic veld management records and aerial photographs.

Characteristic structure of an *Acacia nilotica* tree.

Objective 1: **To investigate changes in tree density, at specific plots in Mkhuze Game Reserve, over time.**

Methods:
- Analyse historical aerial photographs to assess the tree density change, spanning a period of at least 20 years within Mkhuze Game Reserve.
- From the photographs, the percentage woody plant cover will be estimated in randomly selected plots on similar soil types.
- Ground truthing of these plots will be done to determine current density.

A. nilotica provides good browse to many herbivores.

Objective 2: **The role of past management on density, phytomass & population structure of established *A. nilotica* populations in Mkhuze Game Reserve will be investigated.**

Methods:
- Mkhuze has a well-recorded management history and aerial photographs and detailed climate data are available. These will be used to investigate the role of past management on the initiation of tree growth.
- **The BECVOL*** technique (Smit, 1996) will be used to estimate tree density, tree biomass and population structure of trees on each site.
- **The relationship of tree size and distance to its nearest neighbour** (Smith & Goodman, 1986. J.Cloete, pers comm.) will be used to examine the spatial patterns of *A. nilotica* to determine whether a dominant tree has any competitive effects on establishment, growth and survival of other woody plants within their rooting zone.

(*BECVOL = Biomass Estimates from Canopy VOLume)

Measurements collected for relationship of tree size and distance to nearest neighbour

A: maximum tree height
B: height of maximum canopy
C: height of first leaves/ potential leaf bearing branches
D: maximum canopy diameter
E: diameter of lowest foliage

Illustration of measurements collected for BECVOL calculations

Typical bark morphology of A. nilotica.

Indehiscent seed pods, characteristic of *A. nilotica.*

Objective 3: **Investigate impacts of browsers on seedling recruitment**

Methods:
- Seedlings will be grown in a greenhouse to predetermined height classes
- Seedlings will be pruned at varying heights to simulate browsing.
- Survival of these seedlings to pruning will be investigated.

Conclusion

The results of this study will further the understanding of the dynamics of *A. nilotica*. As part of this study a conceptual model will be developed to guide land users on how to manage this plant effectively to reduce the effect of thicket development.

Both seeds and foliage are utilized by many animals.

References

Rutherford, M. C., Mucina, L., Lotter, M. C., Bredenkamp, G. J., Smit, J. H. L., Scott-Shaw, C. R., Hoare, D. B., Goodman, P. S., Bezuidenhout, H., Scott, L., Ellis, F., Powrie, L. W., Siebert, F., Matthews, W. S., Burrows, J. E., Dobson, L., Van Rooyen, N., Schmidt, E., Winter, P. J. D., Du Preez, P. J., Ward, R. A., Williamson, S. & Hurter, P. J. H. 2006. Savanna Biome. *In:* Mucina, L. & Rutherford, M. C. (ed) 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. Pretoria: South African National Biodiversity Institute.

Smit, G. N. 1996. BECVOL: Biomass Estimates from Canopy VOLume (version 2) – Users Guide. Unpublished manual. University of the Free State, Bloemfontein. 22pp.

Smith, T. M., & Goodman, P. S. 1986. The Effect of Competition of the Structure and Dynamics of *Acacia* Savannas in Southern Africa. Journal of Ecology **74**:1031-1044.

Appendix B1. Poster presented at the 46th annual Grassland Society of Southern Africa (GSSA) Congress held in Middelburg, Eastern Cape (2011).

Assessing *Acacia nilotica* establishment on long-term monitoring sites, uMkhuze Game Reserve.

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INTRODUCTION

Throughout the eastern regions of KwaZulu-Natal, open savanna areas are being altered by the thickening of woody plant species. Within the study area of uMkhuze Game Reserve, the grass-tree balance is important in the ecosystem. The increase of woody plants, specifically *Acacia nilotica* is of concern. This disturbance in the ecosystem decreases the biodiversity and also reduces the grazing capacity of the area. uMkhuze presented an ideal opportunity to study this phenomenon as it is affected by woody plant thickening, it has good veld management records and historic aerial photography coverage for temporal comparisons.

OBJECTIVE

-To analyze the temporal and spatial changes in the occurrence of *A. nilotica* within uMkhuze Game Reserve.

PROCEDURE

- Analyzed photographs from 32 sites where fixed point photographs have been taken annually since the early 1980s. From these repeat photographs, a visual assessment of the changes and impact of *A. nilotica* on the sites was made.
- Qualitative data from these sites that included grass and tree species composition, erosion and woody plant establishment were analyzed. The data presented an "absence or presence" record of tree species for each site. This assisted in detecting seedlings or tree coppice within the fire trap.
- Series of aerial photographs from 1970-2009 were analyses and the observed changes in woody plant abundance were mapped.

FINDINGS

- A large change in vegetation is noted throughout the years (Figure 2 and 4). This change is likely to be due to a combination of edaphic and applied management, most notably stocking densities and burning regimes.
- Preliminary mapping results indicate that approximately 10 000 ha (27%) of the park contains vegetation where *A. nilotica* is very abundant (Figure 1).
- A possible interaction between *A. nilotica* and *Euclea divinorum* was noted; over a 22 year period, an increase of 25% in both *A. nilotica* and *E. divinorum* was found (Figure 3). Of the 27 sites with *A. nilotica* present in 2007, 19 had *E. divinorum*. Only 2 sites were found to comprise *Euclea* only and no *A. nilotica*.
- Limitation of aerial photography: unable to identify actual tree species although it does give an accurate measure of tree density and of when areas were colonized by woody plants.

Figure 2. Change in tree density of one of the sites (MVD1) within uMkhuze. Figure (a) and (c) were taken in 1982, figure (b) and (d) taken in 2004

Figure 1. Preliminary 2009 map of abundant *A. nilotica* coverage. Dots indicate sites of fixed point photographs. At present, about 10 000 ha (27%) of the park is covered by *A. nilotica*.

Figure 4. Series of photographs for site MGR 24. Note the sudden influx of *A. nilotica* plants in the late 1990s.

Figure 3. Increase of *A. nilotica* and *E. divinorum* across sites over the time period 1985-2007.

CONCLUSIONS

- There has been a considerable increase in woody plants in specific areas of the park
- The **next step of the project** will be to develop a model to predict the spread *A. nilotica*. Correlation of soils, rainfall, fire and stocking densities with patterns of spread will give insights to the drivers which promote the thickening of savannas.

Appendix B2. Poster presented at the 47th annual Grassland Society of Southern Africa (GSSA) Congress held in Langebaan, Western Cape (2012).

Predictive habitat modelling for *Acacia nilotica* in KwaZulu-Natal.

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INTRODUCTION

Acacia nilotica has the ability to encroach causing serious management problems. Better understanding of the environmental factors that promote the growth of this plant, and prediction of its potential distribution will aid the prevention or control of encroachment.

OBJECTIVES

- To gain insight into the environmental determinants of *A. nilotica* by modelling the potential habitat of the plant and then predicting its distribution by mapping where this habitat occurs.
- Alert land managers to areas that can possibly be encroached by *A. nilotica* through mapping its potential distribution within KwaZulu-Natal.

METHODS

- We used MaxEnt to model *A. nilotica* distribution.
- We used 324 georeferenced sites where *A. nilotica* presence data had been collected, of which 70% were used to model its distribution and 30% to verify the model.
- After an iterative selection process, we chose four environmental variables considered to be most important in modelling *A. nilotica* distribution. These are:

-Altitude	-Frost frequency
-Geology	-Mean annual precipitation

- Sites and variables are run through the MaxEnt (maximum entropy) program, (Phillips et al., 2006). This tool is used to model the probability of distributions of a species and create a potential distribution map (Pearson, 2008).

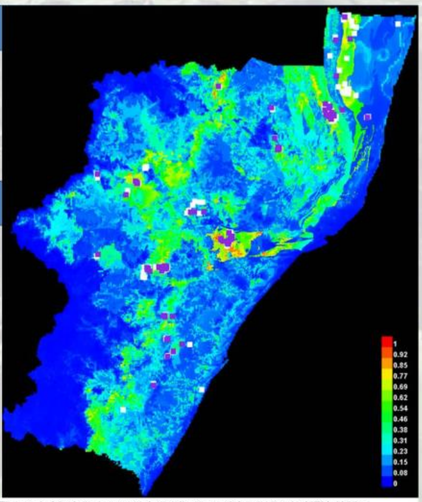

Figure 1. Modelled potential distribution of *A. nilotica* in KZN. White squares show sites used to create the model, while violet squares show sites used to verify the model.

RESULTS

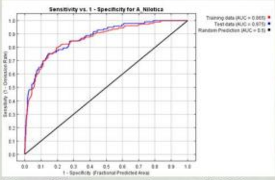

Figure 2. Receiver operating curve (ROC) for test and training data of *A. nilotica* sample data (AUC = 0.865).

- Much of the suitable *A. nilotica* habitat is located in the central and northern regions of KZN (Figure 1). Reds, yellows and greens indicate areas with higher probabilities of occurrence while the blues indicate unsuitable habitats. To the west, altitude and frost frequency are too high. Substantiating information shows that geology contributes highly to *A. nilotica* distribution patterns. Dominating geological formations included Amphibolite, Siltstone and Lebombo and Nsuze Group Basalt. All these geologies are fine grained and are known for their relatively high clay contents. Results also indicated that *A. nilotica* establishment was not common in high (>1000mm) rainfall regions.
- The fit of the model is shown in Figure 2, the black line indicates what one would expect if simulation was no better than random, red indicates the simulated curve and blue the verification curve. The further the blue line is from the black line the more accurate the model is. The area under curve (AUC) = 0.865 for the simulation, indicating that the fit of the model to training data is good.
- The jackknife test of variable importance explains the distribution patterns in relation to the *A. nilotica* training model (red line). The most important variables are elevation and geology, this assists Maxent to obtain a good fit to the training data. The other two variables described here (frost and precipitation) are far less useful in estimating *A. nilotica* habitat by themselves (Figure 3).

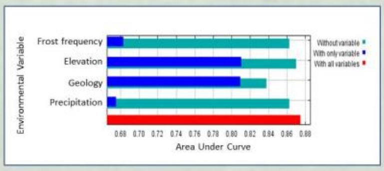

Figure 3. Jackknife test of variable importance using area under curve (AUC) on the test data.

CONCLUSIONS

The MaxEnt program has been used to produce a potential distribution map of *A. nilotica* throughout KZN. This map will be particularly useful for conservation and rangeland planning. In doing so, insights have been gained relating to the key determinants for its habitat selection. This map is also an indicator of the threats *of A. nilotica* to the rangeland areas of KZN. The uses of this program are diverse and further studies on the effects of climate change on this species could be investigated.

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Appendix B3. Poster presented at the 48th annual Grassland Society of Southern Africa (GSSA) Congress held in Modimolle, Limpopo Province (2013).