PROSPECTS FOR SUSTAINED HARVESTING OF MOPANE (*Colophospermum mopane*) ON THE VENETIA LIMPOPO NATURE RESERVE AND ITS IMPLICATIONS FOR BROWSING UNGULATES

by

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DECLARATION

I the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

Signature: **Date:**

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ABSTRACT

This project aims to investigate the ecological feasibility of sustained utilisation of mopane for charcoal and firewood production. Small scale charcoal production is a possible method of sustainable exploitation of savannas. There is little need to argue the importance of stimulating rural economies as well as the problem that dense mopane poses in certain areas of Southern Africa. This study investigates the potential that mopane has for utilisation by humans and the ecological implications thereof, especially for dependant browsing ungulates.

A review of all relevant literature on *Colophospermum mopane* (*C.mopane*) is presented in Chapters 1 to 4. Three mopane vegetation types were compared with regards to density, size-class, senility, age, growth rate and biomass. Particular

emphasis was given to *C.mopane* woodland as this vegetation type is very dense and covers large parts of Venetia Limpopo Nature Reserve. The correlation between mopane performance and selected physical properties was examined using simple multiple and stepwise regression analysis as well as analysis of variance for certain factors. A preliminary harvesting model was also developed to determine harvestable yields and to establish the potential of mopane for sustainable harvesting (Chapter 8.2).

Oakleaf (OaB) soils are closely associated with *C.mopane* woodland. The woodland has a mean density of 2 289 trees/ha with mean heights and circumferences of 2.3m and 14.2cm respectively. The tree population is generally in a healthy condition with up to 77.6% of trees in a senility class of <25% canopy dead. Average age per tree is 25 years and mean growth rate is 0.59cm/yr. Total biomass is 23 668kg/ha with a total potential charcoal biomass of 14 787kg/ha. At a harvesting rate of 25%, mean available charcoal biomass for *C.mopane* woodland is 3 697kg/ha. The harvesting model suggests an optimum harvest rate of 27% which would ensure best yields and be sustainable at 5 year harvest intervals, for up to 60 years. An initial total yield of ±8 000kg/ha is expected to decrease to ±1 500kg/ha after 60 years. The actual amount of charcoal derived from this potential available charcoal biomass will depend on the charcoal making technique used (retort vs kiln).

Harvesting in rectangular strips by hand saw (where labour is cheap) during the winter season in Endora, Lizulea and Hilda areas, should provide the best charcoal yields and would be the most ecologically acceptable harvesting strategy to follow. Depending on the strategy followed, the effects on browsing ungulates, especially elephant, should be negligible. In fact, harvesting could benefit browsers by distributing available browse proportionately over the year (See 9.1.2). Grass production should also increase with harvesting, thus increasing available food for grazers. This could have an influence on distribution patterns as well as carrying capacity for grazers. The study concludes with a brief summary of the main conclusions derived from the research.

ACKNOWLEDGEMENTS

The successful completion of this study is a tribute to a number of individuals and organisations.

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CHAPTER 1

CHAPTER 1: INTRODUCTION

Wood is the most widely used household fuel in non-industrialized areas of the world and in many cities, wood and charcoal remain the predominant cooking fuels (F.A.O., 1985). In rural areas of Africa, wood provides up to 96 per cent of the energy used, with each person needing up to 1.5 cubic meters per year (Prior & Cutler, 1992). In the SADC (Southern African Development Community) region, an estimated 79 million people out of a total population of 82.2 million in 10 Southern African countries, depend on biomass fuels as their major source of domestic energy (Karekezi & Ewagata, 1994). Moreover, biomass energy is an important fuel for many small and medium scale industries in the region. Africa's expanding population means its demand for firewood keeps on increasing and by the year 2 000, over 50 per cent of the population will face a scarcity of firewood (Prior & Cutler, 1992), while close to 2 400 million rural people world-wide will experience fuel wood shortages (De Montalembert & Clement, 1983). On the other hand, Pearce (1994) suggests that Africa may contain twice as much wood as previously believed, in trees on privately owned farms that are simply ignored in official statistics.

Approximately 33 per cent of South Africa is covered by bush scrub or savanna covering some 53 million ha (Dyer, 1983). As far back as 1957, Van der Schijff (1957) suggested that approximately 18 million ha of bushveld had already been damaged by the abnormal coppicing of bush or was endangered by bush encroachment. *Colophospermum mopane* savanna is the dominant vegetation type in the far North Western Transvaal (Louw, 1970), making up 9% of the total area of Transvaal (Verster, 1974). It is also seen as a major problem in certain areas due to the development of dense monospecific stands under certain conditions (Dyer, 1983; Smit & Swart, 1991; Smit, *pers.comm.* 1994). These include climatic, edaphic, biotic or human induced factors. According to Stoddart (1978), the need for harvesting is obvious when there is severe overcrowding of tree crowns, spindly stems, narrow growth rings, and frequent dead and dying trees. Mopane stands comply with these criteria. The fact that it tends to form dense monospecific stands, which become a problem for farming activities, and has the potential for other economic uses, makes it an obvious candidate for utilization by humans.

The present project aims to investigate the ecological feasibility of sustained utilization of mopane for small scale charcoal and firewood production. There is little need to argue the importance of stimulating rural economies and of addressing the problem caused by dense mopane stands on farmed land. The possibility of meeting both these objectives was investigated in a pilot study undertaken on VLNR.
Key questions were:

What is the distribution and density of mopane with specific reference to dense *C.mopane* woodland? What is the structure of the vegetation in terms of the live stem circumference, height and the incidence of senility (% canopy dead)? What is the total biomass (dead and alive) as well as biomass potentially available for charcoal production? What feasible and ecologically viable harvesting methods and harvesting strategies must be followed, so as to implement and ensure an economically harvestable and sustainable yield? What is the population dynamics (age/growth rate/mortality) of mopane over a long period of time? What are the ecological implication of harvesting mopane on dependant browsing ungulates as well as grazers? What ecological estimations (browse damage/insect life) should be made for the reserve?

After evaluating the key questions posed, the following hypotheses was made:

- *C.mopane* should yield a harvestable proportion of wood available for charcoal production.
- Harvesting should be sustainable as mopane coppices vigorously.
- Harvesting should be ecologically acceptable and economically viable.
- Harvesting should have a negligible effect on browsers, especially elephant, if harvested in areas not frequented by them.
- Harvesting should result in an increased grass biomass as well as an increased grazer carrying capacity.

Before above mentioned hypotheses could be accepted or rejected, the key questions mentioned, should be investigated.

CHAPTER 2

CHAPTER 2: STUDY AREA

LOCATION:

The Venetia Limpopo Nature Reserve (VLNR) lies in the north western corner of the Northern province of South Africa. It is situated between 22°08'S and 22°27'S and 29°13'E and 29°28'E, where South Africa, Zimbabwe and Botswana converge (Figure 1). VLNR is bounded by the Limpopo river in the north and privately owned farms on the rest of its perimeter. It comprises an area of 35 000ha acquired by De Beers Consolidated Mines through the purchase of 19 farms. With the exception of approximately 3 000ha which is devoted to mining and the associated infrastructure, the rest (32 000ha) has been consolidated into one conservation area - Venetia Limpopo Nature Reserve. The nearest towns are Alldays (50km) and Messina (90km) with Pietersburg (200km) being the closest large town.

HISTORY

Archaeologically the area is extremely rich with a long history of human activity ranging from Early Stone Age (1 million - 250 000 years B.C.) to the Iron Age (AD 300 - 1 800). Several areas of historic occupation associated with the Khami period (1 450 -1 750) have been identified on the reserve and the Zhizo site (AD 700 - 900) at Schroda is of particular archaeological importance (Figure 2)(Fouche, 1937; Gardner, 1967; Voigt, 1983).

Although this specific area was first occupied by Europeans in 1871, the region north of the Soutpansberg remained sparsely inhabited until 1914 when farmers were encouraged to settle there. It soon became clear that the area was ecologically unsuited to domestic livestock farming. In 1945 the

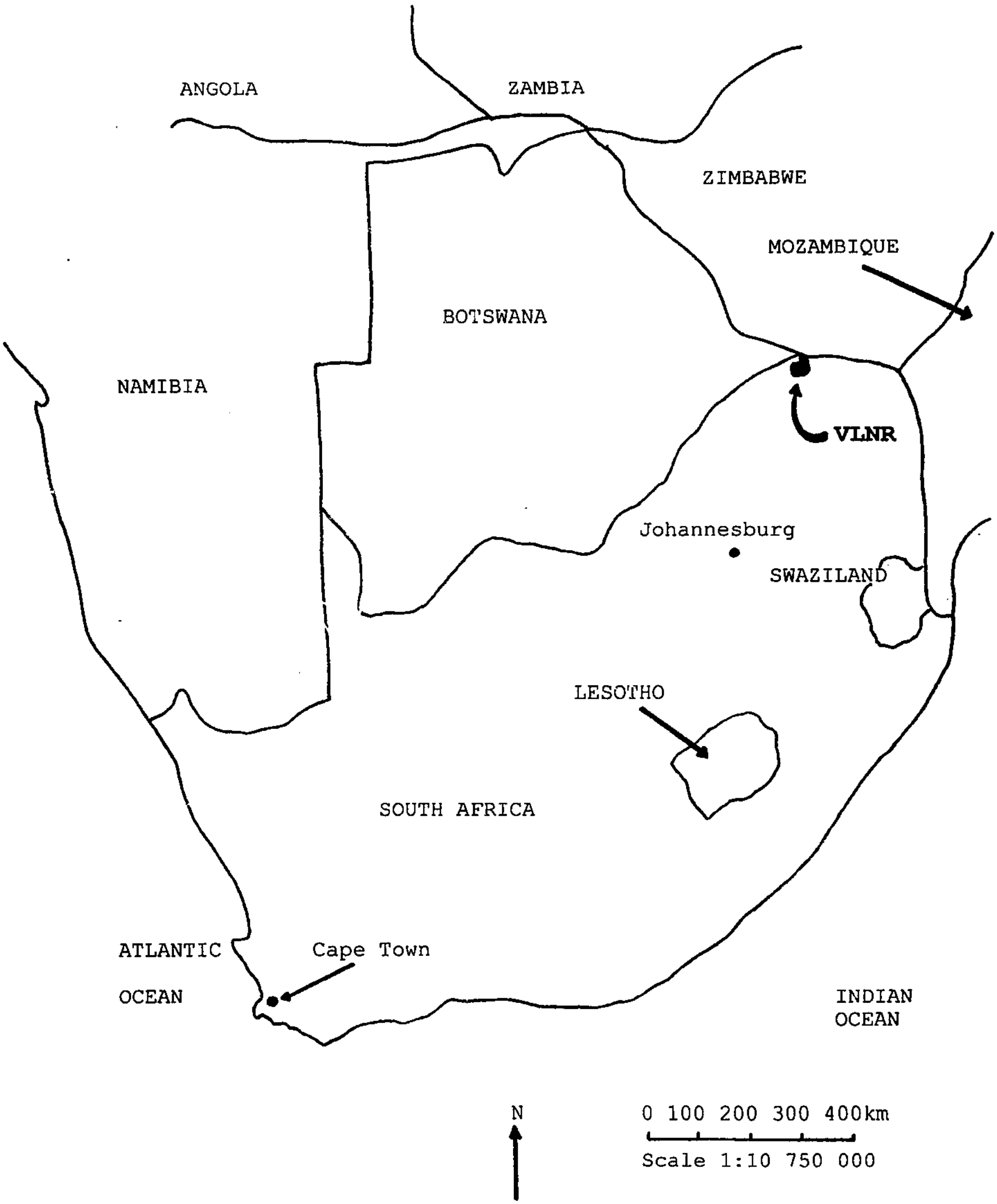


Figure 1: Location of Venetia Limpopo Nature Reserve (VLNR).

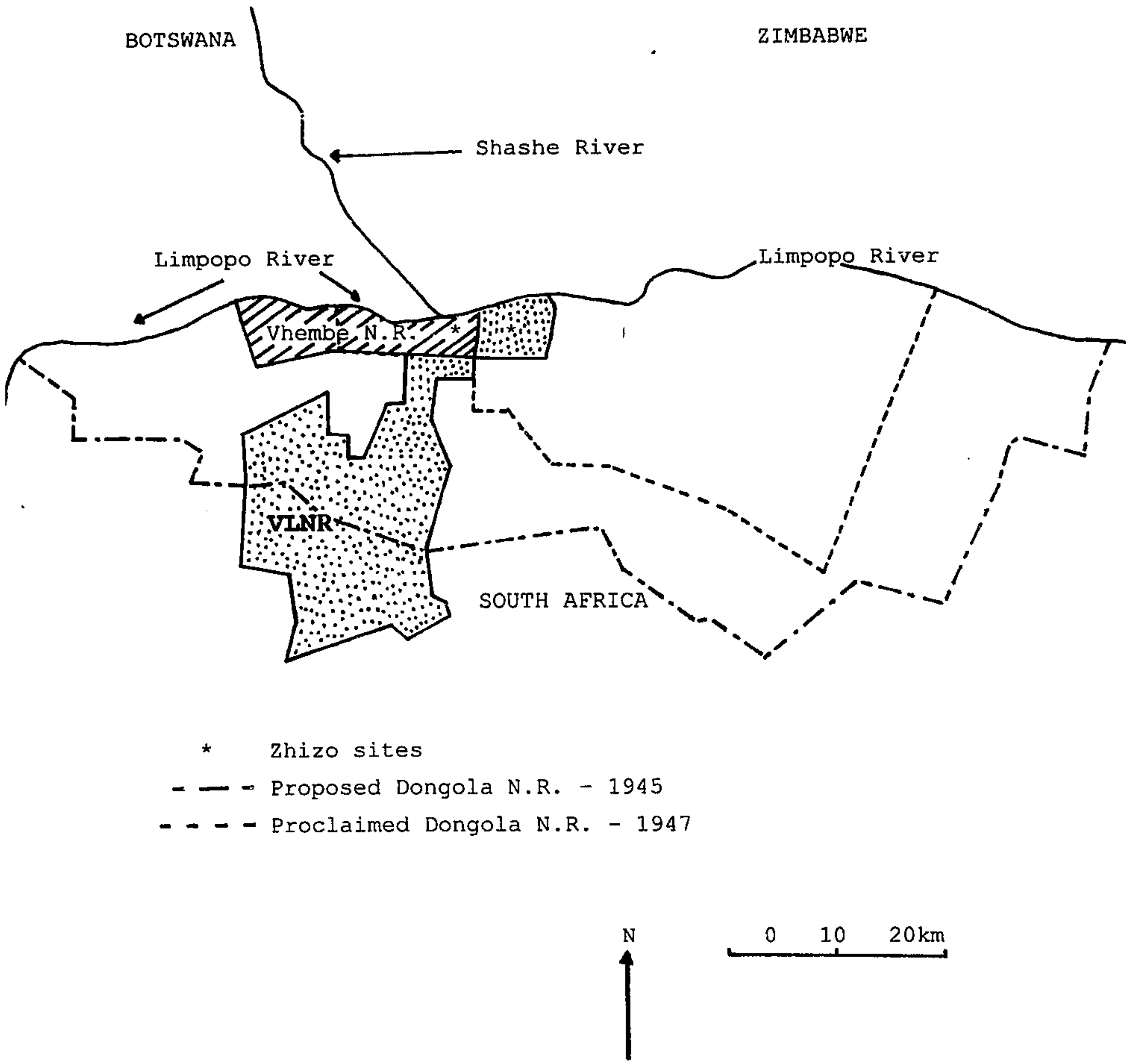


Figure 2: VLNR relative to the proposed Dongola Wildlife Sanctuary and Vhembe Nature Reserve.
Source: Berry (1992)

Government, at the request of General Jan Smuts, introduced a bill to establish the Dongola Wildlife Sanctuary (Figure 2) totalling 117 000ha, but a revised bill proposed a much reduced area of 46 000ha, and was finally passed in 1947. After the Smuts government lost the elections of 1948, the Dongola Wildlife Sanctuary was deproclaimed and the land re-allocated to farmers. De Beers acquired the surface rights of portions of the farms Venetia and Krone in 1981 after the discovery of kimberlite pipes on these areas. The purchase of other farms followed and also gave access to the Limpopo river which was to provide water to the mine.

CLIMATE

The monthly mean minimum temperature at Messina (90km east of VLNR) ranges from 7.2°C (June - July) to 20.3°C (December), while the monthly mean maximum temperature ranges from 24.7°C (June) to 32°C (October to December)(O'Connor, 1992). Frost does not generally occur but McKenzie (1990) states that temperatures may drop to -5°C during Winter. The rainy season extends from November to March (Harrison, 1984). The mean annual rainfall at Alldays (50km south) is 384mm (recorded from July to June, over 48 years), with a 40% coefficient of variation (O'Connor, 1992). Precipitation generally takes the form of thunderstorms.

Rainfall in peak years may be as high as 660mm (1976) while in drought years it may be as low as 180mm (1989) (Styles, 1993). The annual actual evapotranspiration for Messina is equal to the annual precipitation, and the region experiences a perennial water deficit of 85.6cm (Schulze, 1958).

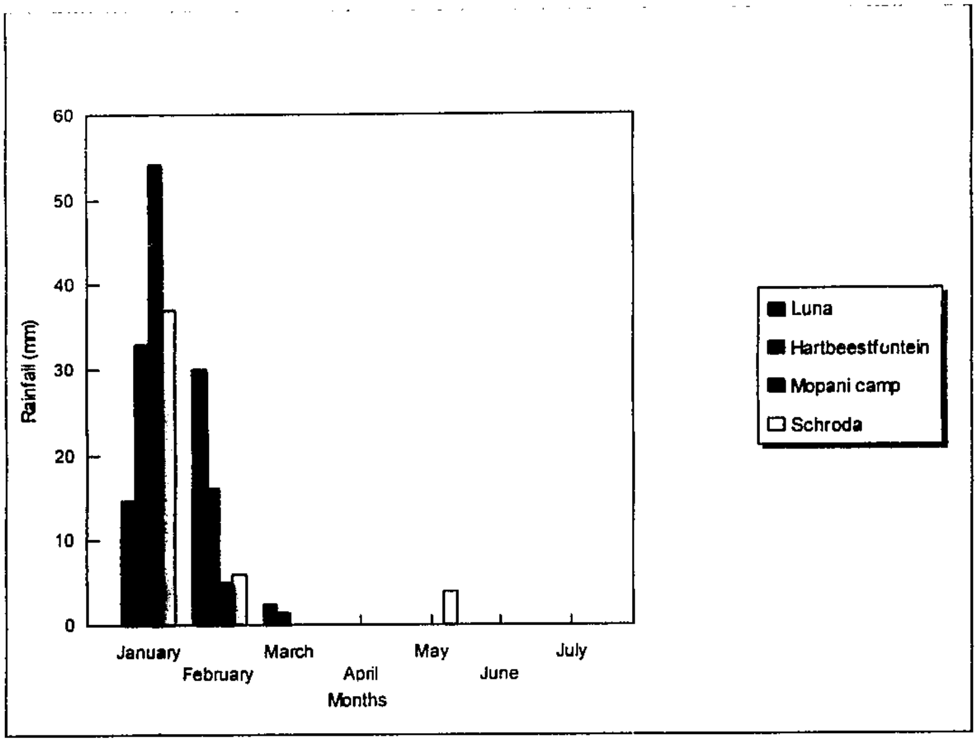


Figure 3: Rainfall measured at four different sites for the first seven months of 1994 on the VLNR.

GEOLOGY AND SOILS

The following geological description, specifically for the VLNR, is based on O'Connor (1991 & 1992). The area lies in the central zone of the Limpopo Mobile Belt, and includes the southern edge of the more recent Limpopo Karoo sedimentary basin. Older rocks of the mobile belt have suffered several periods of high-grade metamorphism. These metamorphic rocks include various old and young gneisses, quartzite, marbles, amphibolites, granulite and metaquartzites known as the Messina formation. The surface geology of most of the area consists of Karoo group exposures or of colluvial outwash derived from them. Travelling from south to north, the underlying basement is successively covered by a sequence of conglomerates, grit sandstone's and shale's (Ecca and Beaufort series) overlain by sandstone's, marls, mudstones (Elliot Red beds) and siltstones of the Stormberg series. Calcretisation of either carbonate rich rocks or soil has been extensive, but most exposures are limited to areas of active scarp retreat. Geological diversity and physiography have resulted in a range of substrate types. O'Connor (1983) identifies substrate as the primary determinant of the woody vegetation types for this area.

Mopane does not favour alkaline conditions *per se* and grows better on fertile, slightly acid, friable and permeable soils (Thompson, 1960). Mopane usually forms mono-dominant stands on sodic soils (Dye & Walker, 1980). According to Louw (1970), mopane is dominant on red and dark coloured loam and clay soils derived from the Ecca series.

A soil reconnaissance of the reserve was done by the Agricultural Research Council Institute for Soil, Climate and Water. The dominant soil families were found to be Hutton, Oakleaf, Dundee, Arcadia, Valsrivier, Swartland, Coega and Glenrosa. The soils vary from deep, well drained, red/sandy/stony and loamy soils of the Hutton family to red/brown and sandy alluvium soils of the Oakleaf family. The Dundee family soils are deep/sandy, young stratified alluvial found near rivers. Clay soils include the Arcadia, Valsrivier and Swartland families with the most rocky and shallowest soils being the Glenrosa and Coega families. The soil depth varies from less than 450mm (Glenrosa and Coega) to more than 1200mm in the sandy soils of the Hutton family. The highest percentage of clay is found in the Arcadia (40-50%) and Valsrivier (20-30%) families. High clay content can be responsible for stunted mopane growth (Dye & Walker, 1980). MacVicar *et al.* (1991) provide more information on the classification of the above mentioned soils.

C.mopane woodland (vegetation type 3), is mostly associated with the Oakleaf (OaB) family; *C.mopane/C.apiculatum* open woodland (vegetation type 5) with the Hutton (HuA) family and *C.mopane* shrubland (vegetation type 4) with the Valsrivier and Swartland families (Table 7)(See Chapter 7). According to Ellis (1994, *pers.comm.*) Hutton and Oakleaf family types are some of the best soils in the region.

TOPOGRAPHY AND DRAINAGE

Physiographically the region comprises of a plateau (Oriental, Hartebeestfontein, Luna and Stindal) in the eastern half of the reserve. An extensive level basin of colluvium is found between the Setoka river in the east and the Kolope/Setonki rivers in the west (Lizzulea, Flora, Endora and Edmonsburg). To the west of the Kolope river, are low, undulating hills (Regina, Patricia and Mellisande) with generally east-west tending siltstone/sandstone hills to the north (Hilda, Blyklip and Anglican)(Figure 4).

The area is drained by the Setoka river in the east. The Matotwane river flows north-west until it confluence's with the Kolope river, which flows from south to north. The Setonki river flows north-east with the Kolope/Setonki confluence eventually draining into the Limpopo river to the north. All these rivers flow sporadically during the rainy season (November to March) and are dry, except for a few isolated pools in the Limpopo river, during winter.

VEGETATION

Vegetation of the VLNR falls within the broad classification of Mopane Veld (Irvine, 1941; Hutchinson, 1946 and Acocks, 1975). Louw (1970) gives a detailed distribution of mopane veld, classifying it into shrub and tree components north of the Soutpansberg. O'Connor (1991) classifies the vegetation of the VLNR (Figure 4) as follows:

1. *Acacia stuhlmannii - Salvadora angustifolia* open woodland
2. *Colophospermum mopane - Salvadora angustifolia* open woodland
3. *Colophospermum mopane* woodland on colluvial soils
4. *Colophospermum mopane* shrub woodland
5. *Colophospermum mopane - Combretum apiculatum* open woodland
6. Fine sandveld
7. Escarpment vegetation types
8. Rugged Karoo hills
9. *Combretum apiculatum* mixed woodland
10. Mixed deciduous open woodland on diabase dykes
11. Grasslands
12. *Sesamothamnus lugardii* stands
13. Tall riverine *Colophospermum mopane*

These vegetation types bear closer resemblance to landscape units of the Kruger National Park (Gertenbach, 1983) than communities traditionally described by phytosociologists (O'Connor, 1991).

Rare and threatened species found on the reserve include: *Adansonia digitata, Adenium* spp.(*A.oleifolium* & *A.obesum) Aloe littoralis, Peristrophe* spp.(*P.cliffordii* & *P.gillilandiorum* - Acanthaceae) and *Sesamothamnus lugardii.*
Appendix 1 provides common names of tree species encountered.

Research was limited to vegetation types 3, 4 and 5 (Figure 4) as described by O'Connor (1991). They are briefly described in Chapter 4.

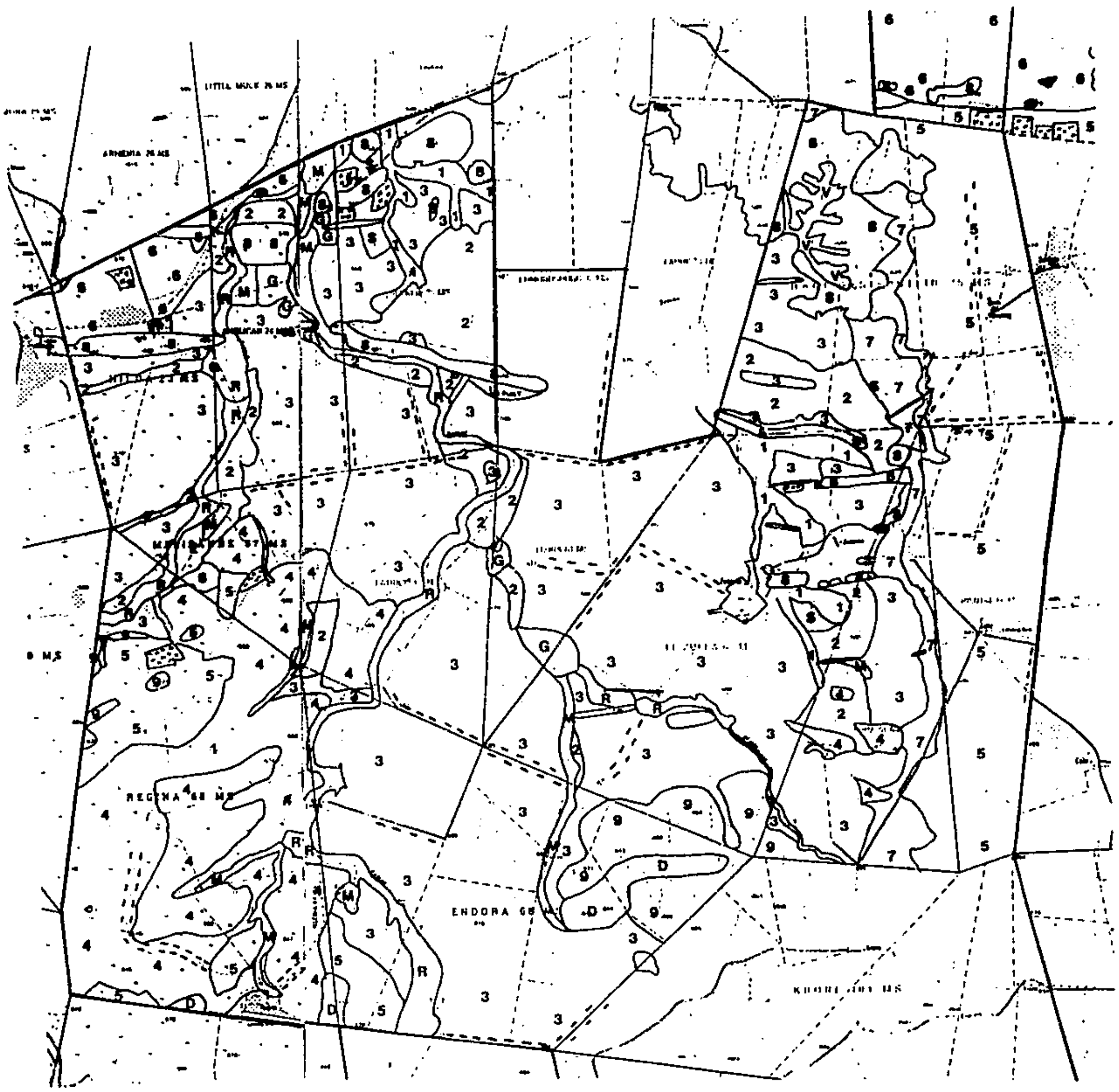


Figure 4: Classification of the different vegetation types for VLNR.

- Indicates the different plot positions

3 = C.mopane woodland*

4 = *C.mopane* shrubland*

5 = *C.mopane/C.apiculatum* open woodland*

* = Vegetation types where research was conducted.

Source: O'Connor (1991)

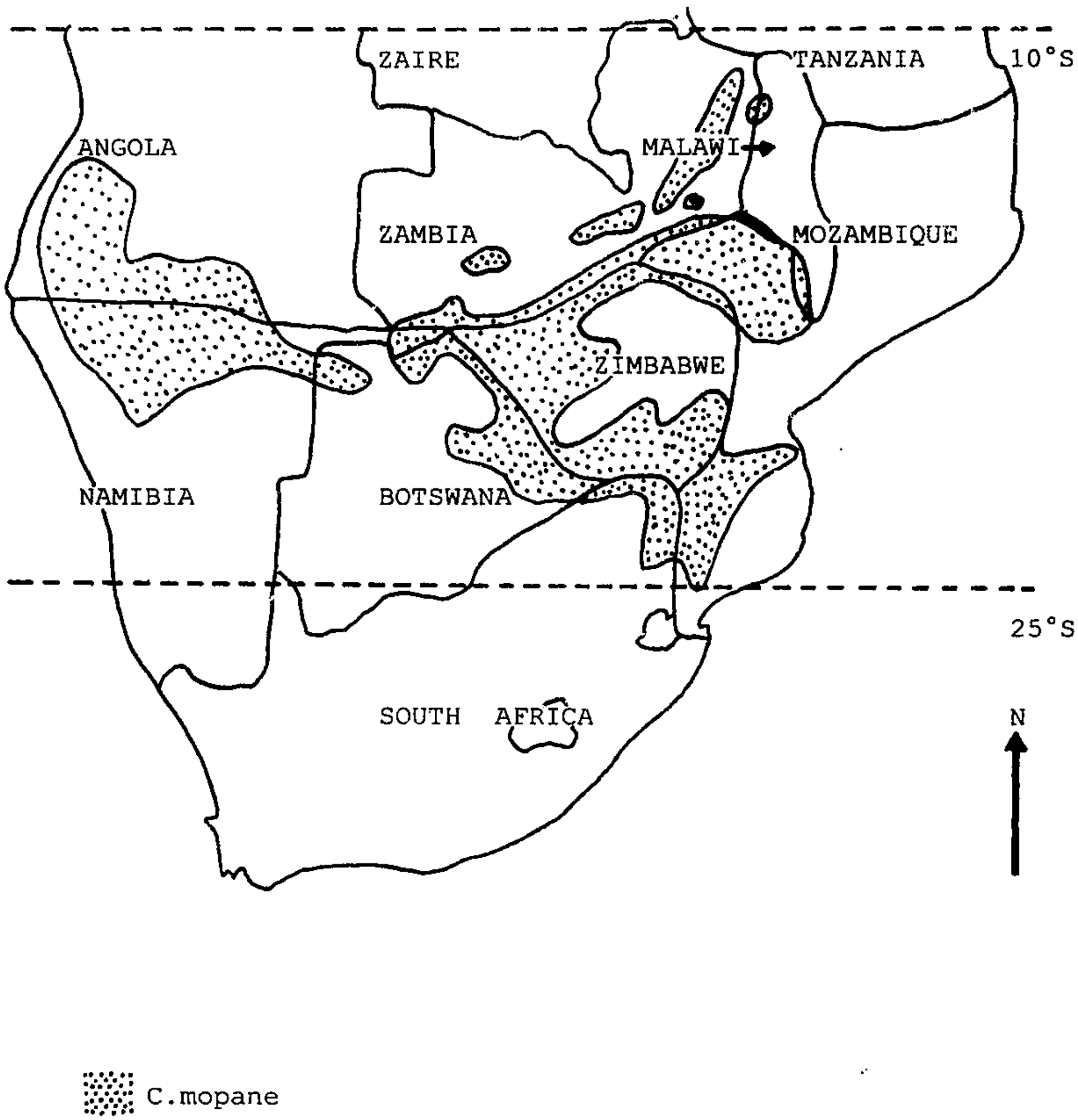


Figure 5: Distribution of *C.mopane* in Southern Africa.
Source: Gertenbach (1987)

FAUNA

A list of the most common mammals found on the VLNR is as follows (Fairhead, *pers.comm.*):

SPECIES	COMMON NAME
Order Perissodactyla:	
Ceratotherium simum	White rhino
Equus burchelli	Burchell's zebra
Order Artiodactyla:	
Phacochoerus aetheopicus	Warthog
Potamochoerus porcus	Bushpig
Hippopotamus amphibius	Hippopotamus
Giraffe camelopardalis	Giraffe
Sylvicapra grimmia	Common Duiker
Raphicerus campestris	Steenbok
Oreotragus oreotragus	Klipspringer
Kobus ellipsiprymnus	Waterbuck
Aepyceros melampus	Impala
Oryx gazella	Gemsbok
Hippotragus equinus	Roan
Alcelaphus bucelaphus	Red Hartebeest
Damaliscus lunatus	Tsessebe
Connochaetes taurinus	Blue Wildebeest
Tragelaphus scriptus	Bushbuck
Tragelaphus strepsiceros	Kudu
Taurotragus oryx	Eland
Order Proboscidea:	
Loxodonta africana	Elephant
Order Carnivora:	
Canis mesomelas	Black-backed Jackal
Mungus mungo	Banded Mongoose
Herpestes sanguineus	Slender Mongoose
Crocuta crocuta	Spotted Hyaena
Felis libyca	Wild Cat

Felis caracal	Caracal
Panthera pardus	Leopard
Panthera leo	Lion
Acinonyx jubatus	Cheetah
Order Primates:	
Papio ursinus	Chacma Baboon
Cercopithecus pygerythrus	Vervet Monkey
Order Tubulidentata:	
Orycteropus afer	Aardvark

Wild dog (*Lycaon pictus*) were introduced to the reserve but there have been no recent sightings.

HUMAN ACTIVITIES

In addition to daily general maintenance and administrative tasks involved in running the reserve effectively, biltong and trophy hunting is also allowed under supervision. A permanent hunting camp (Mopane camp) with all necessary facilities has been established in the Regina area, and a second tented hunting camp is situated in the Endora area next to the Kolope river for up-market hunting clients. An old farm house in the Patricia area is maintained as a guest house for visiting dignitaries. Game viewing and seasonal daytime picnic sites are other activities still under consideration. Mining activities are confined to the southern boundary outside the designated reserve, in the Venetia area.

CHAPTER 3

CHAPTER 3: DESCRIPTION OF VEGETATION TYPES

3.1. *Colophospermum mopane* Woodland

This vegetation type is found predominantly in the central, western and north western parts of the reserve, on the farms Lizzulea, Flora, Endora, Patricia, Edmonsburg, Blyklip, Anglican and Hilda (Figure 4).

The substrate is a large colluvial basin, a Pleistocene relic, of up to 20m thick in places. The predominant soil type is the Oakleaf (OaB) family, which is a deep alluvial, sandy loam soil (Ellis, 1994; *pers.comm.*).

This vegetation comprises dense woodland with a median cover of 51-75%, while *C.mopane* constitutes up to 90% of the shrub and tree component (O'Connor, 1991). The only other consistently occurring and relatively abundant species is *Boscia foetida*. Other common species are *Salvadora angustifolia*, *Ximenia americana*, *Cadaba termitaria*, *Terminalia prunioides* and *Maerua parvifolia* (See Appendix 1 for common tree names).

Herbaceous cover is low with a median value of 20% (O'Connor, 1991) and is associated with the protection offered by trees and bushes. Annual grass species such as *Enneapogon* spp., *Tragus* spp., *Urochloa* spp. and *Brachiaria* spp. are abundant while desirable perennials are infrequent.

3.2. *Colophospermum mopane* Shrubland

This vegetation type is almost exclusively limited to the western and south western parts of the reserve, on the farms Regina and Melisande (Figure 4). Smaller patches are also found on Patricia and Luna.

The substrate is shallow and rocky with soils dominated by the Valsrivier (VaA) and Swartland (SwA) families. Swartland (SwA) soils have shallow, sandy loam/sandy clay loam topsoils on dense clay, while Valsrivier (VaA) is a better quality soil (Ellis, *pers.comm.*).

Vegetation is relatively open with a median cover of between 25% and 50% *Colophospermum mopane,* while hills support denser (50-75%) stands (O'Connor, 1991). Large areas are bare and have been stripped of soil down to bedrock, possibly due to overgrazing and incorrect farming practices in the past. Other common tree species are *Boscia foetida, Boscia albitrunca, Combretum apiculatum* and *Grewia bicolor.*

The herbaceous sward is sparse, with a median value of between 5% and 10% (O'Connor, 1991). It is dominated by short lived perennials such as *Enneapogon* spp. and *Aristida* spp. and annuals such as *Brachiaria* and *Tragus* spp.

3.3. *Colophospermum mopane* and *Combretum apiculatum* Open Woodland

This vegetation type is found in the eastern parts of the reserve, on the farms Hartbeestfontein and Oriental (Figure 4).

The soils are deep (0.5-1m) and derived from Karoo sediments. The Hutton (HuA) family is the dominant soil type. It is well drained, deep red and sandy.

The woodland is relatively open (25-50% median cover) (O'Connor, 1991) and diverse with *Colophospermum mopane* and *Combretum apiculatum* ubiquitous. Other common tree species found are *Commiphora glandulosa* and *Commiphora mollis, Lannea scweinfurthii* and *Terminalia prunioides. Adansonia digitata* is strongly associated with this vegetation type.

Herbaceous cover is high with a median value of up to 70% (O'Connor, 1991) in places. Desirable perennials such as *Stipagrostis* spp., *Schmidtia* spp. and *Aristida* spp. make up the bulk of the sward.

CHAPTER 4

CHAPTER 4: LITERATURE REVIEW

Colophospermum mopane is a well known tree species in the far Northern province. According to Palmer and Pitman (1972) the name is derived from the Greek word "Colophon" in Ionia, meaning "oily seed". Colophon is also the birthplace of Homer and thus in a most unlikely way the name links this genus with the classics. The species is not without its quota of African romanticism. Livingstone, in his travels noted that the Zambezi inhabitants feared mopane during thunderstorms as "lightning hated it" (Palmer & Pitman, 1961).

Mopane belongs to the family Leguminosae, sub-family Caesalpinioideae and is variously referred to as Rhodesian ironwood/mahogany, butterfly tree, balsam tree, turpentine tree, mupani/mutanari (Venda), mophane (Tswana), nxanatsi (Tsonga), musharo/shanatse (Shona), ipane/ilipani (Ndebele), omutati (Herero), omufiadi (Owambo) and mupani in India. It was successfully introduced to the Rajasthan area of India in 1965 (Ayensu *et al.*, 1980).

The distribution is limited to South Central Africa (Figure 5) with the trans-continental extension including countries such as Angola, Namibia, Zambia, Zimbabwe, Botswana, Malawi, Mozambique and South Africa (Obermeijer, 1933; Coates Palgrave, 1956; Palmer & Pitman, 1961; Von Breitenbach, 1965; De Winter *et al.*, 1966; Kromhout, 1967; Palmer & Pitman, 1972; Coates Palgrave, 1983; Louw, 1972).

Mopane is generally confined to areas of low to moderate rainfall (200-800mm p.a.) and is intolerant of severe frosts (Obermeijer, 1933; Van Wyk, 1972; Henning, 1976; Ayensu *et al.*, 1980). The northern and southern boundaries of its range appear to be determined by the 1 000mm mean annual rainfall isohyet and the 5°C July mean daily minimum isotherm, respectively (Henning, 1976). Mopane grows best at altitudes below 900m (Ayensu *et al.*, 1980). Although the range extends over a wide variety of geological formations and soil types, it is conspicuously absent on deep sandy soils (Van der Schijff, 1969; Van Wyk, 1972). It is essentially a shallow rooted species, growing predominantly on shallow to moderately shallow, lime-accumulating sands over loamy sands or sandy loam's over sandy clay loam's (Wild, 1953 & 1955; Thompson, 1960 & 1965; Henning, 1976; Gertenbach, 1987). Soils usually have a high ph (Cole, 1963; Van Rooyen *et al.*, 1981). Mopane can tolerate poorly drained soils when other species cannot exist (Coates Palgrave, 1956).

It is a deciduous, resiniferous, gregarious (Obermeijer, 1933; Coates Palgrave, 1956; Von Breitenbach, 1965; De Winter *et al.*, 1966) endomycorrhizal tree species which usually dominates the vegetation in which it occurs (van Wyk & Fairall, 1969; Hall-Martin, 1974; Acocks, 1975; Kelly & Walker, 1976; le Roux, 1980; Scholes, 1983; Nott & Stander, 1991,. Leaves turn yellow to red-brown before being shed. It does not bear spines and may be a multi-stemmed tree, or as a rule, a ragged looking shrub (Palmer & Pitman, 1961; Von Breitenbach, 1965; De Winter *et al.*, 1966; Henning,1976). The leaves alternate, with two opposite leaflets (butterfly shape), the flowers are small and occur in racemes, arranged in panicles. Petals are absent and up to 25 stamens may be present; the pods are leathery, wrinkled and kidney shaped and the seed single with resinous dots. Roots do not bear nodules.

Morphologically mopane varies in size from less than half a metre high, to a medium sized tree exceeding twelve metres (Palmer & Pitman, 1961; Von Breitenbach, 1965; De Winter *et al.*, 1966; Kromhout, 1967; Henning, 1976) and occasionally specimens may attain heights of up to twenty three metres

(Coates Palgrave, 1956; De Winter *et al.*, 1966; Van Wyk, 1972; Ayensu *et al.*, 1980). According to Van Wyk (1972) the biggest local specimens have stems of up to 150cm in diameter but usually the larger diameters range from 15 to 45cm (De Winter *et al.*, 1966; Kromhout, 1967).

Factors that limit the growth and size of mopane are: climatic factors such as rainfall, temperature, frost and altitude (Codd, 1951; Coates Palgrave, 1956; Kromhout, 1967; Louw, 1970; Palmer & Pitman, 1972); soil type and structure (Obermeijer, 1933; Louw, 1970; Henning, 1976; Dye & Walker, 1980; Van Rooyen *et al.*, 1981; Gertenbach, 1987; Johnson & Johnson, 1993) and browsing intensity, especially by elephants (Caughley, 1976; Guy, 1976; Jachmann & Bell, 1985; Lewis, 1991; Styles, 1993).

The timber is most attractive (yellow sapwood and dark red heartwood), durable, hard and heavy, fine textured and produces a very smooth finish. Because of heart rot, large knots and usually poor form, the wood is difficult to work although some attractive pieces of furniture have been made (Kromhout, 1967). Mopane wood is also very termite resistant because of a high calcium oxalate content (Prior & Cutler, 1992) which affects its density. It was widely used for fenceposts and mine props in the past.

It is an excellent firewood (Codd, 1951; Palmer & Pitman, 1961; De Winter *et al.*, 1966; Palmer & Pitman, 1972; Ayensu *et al.*, 1980; Coates Palgrave, 1983) and yields a good charcoal (Coates Palgrave, 1956; Von Breitenbach, 1965; De Winter *et al.*, 1966; Palmer & Pitman, 1972). The wood ash can contain more than 50 per cent of lime, and is consequently used as a fertiliser (Coates Palgrave, 1956; Von Breitenbach, 1965; Van Wyk, 1972). It burns slowly and without sparks, producing non-toxic smoke and long-lasting glowing embers which are necessary for open rural fires (Prior & Cutler, 1992).

Probably the most valuable economic attribute of mopane is its browsing potential (Henning, 1976). It is browsed by a wide range of wild game (De Winter *et al.*, 1966; Jarman & Thomas, 1969; Palmer & Pitman, 1972; Van Wyk, 1972; Funston, 1993; Styles, 1993; Van Wyk, 1994) and even though the leaves have a strong turpentine smell, the milk of cattle feeding off it, is not tainted (Codd, 1951; Von Breitenbach, 1965; De Winter *et al.*, 1966). The nutritional value of the leaves compares very favourably with a number of dry tropical browse species (Lawton, 1967; Palmer & Pitman, 1972; Styles, 1993), making it a sought after browse species, especially during the dry season or under drought conditions (Oates, 1972; Hall-Martin & Basson, 1974; Sauer *et al.*, 1977; Styles, 1993). Mopane has a high summer crude protein content varying between 12.60% and 15.92% (Lawton, 1968; Palmer & Pitman, 1972; Styles, 1993). The spring flush, which emerges independently of rain, has a crude protein content as high as 17.5% (Styles, 1993).

Mopane is host to a number of insect species with the mopane moth/worm (*Gonimbrasia belina*) and the mopane bee/fly (Family Apidae-*Trigona* spp.) being the best known. Caterpillars of the mopane moth feed predominantly on the leaves of mopane (Pinhey, 1975; Skaife, 1979) and are considered a delicacy amongst rural Africans. The caterpillars are also a source of protein (Henning, 1976; Dreyer & Wehmeyer, 1982; Brandon, 1993; Funston, 1993) for the indigenous population. The honey of the stingless mopane bees is also utilised as a source of food (Skaife, 1979). Mopane's value as an indigenous gardening species is also being increasingly recognised by gardeners because of its hardiness and colourful autumn leaves (Johnson & Johnson, 1993).

CHAPTER 5

CHAPTER 5: METHODOLOGY

5.1. Selection of sample sites:

C.mopane woodland (type 3, O'Connor, 1991, Figure 4) was selected for intensive study with comparative data collected from *C.mopane* shrubland (type 4) and *C.mopane/C.apiculatum* open woodland (type 5). Field work was conducted from April to July 1994.

5.2. Field measurements:

Research was conducted as a sampling survey and not as an experiment. This survey was conducted on a stratified basis and sample plots were regularly placed along the survey path at intervals of 300m. This was done in order to cover the full range of variation within the strata. Sample plots measured 10 x 10m. For ease of access they were located 1-5m from the edges of roads, the distance depending on the width of vegetation cleared along the roads. 200 plots were set out, 126 in dominant *C.mopane* woodland; 44 in *C.mopane/C.apiculatum* open woodland and 30 in *C.mopane* shrubland.

Plots surveyed were distributed as follows on the farm units and vegetation types (numbers represent plots per farm):

Table 1. Distribution of plots per farm unit and vegetation type.

Vegetation Type	**Farm**	**Plots**
Type 3:	Lizulea	28
(C.mopane woodland)	Flora	21
	Endora	19
	Patricia	15
	Blyklip	8
	Hilda	8
	Edmonsburg	8
	Anglican	8
	Melisande	8
	Krone	3
Type 4:	Regina	30
(C.mopane shrubland)		
Type 5:	Hartbeesfontein	29
(C.mopane/C.apiculatum open woodland)	Oriental	15
Total Number of plots:		200

126 plots were done in the *C.mopane* woodland as this is the dominant and most dense veld type of the reserve. *C.mopane* shrubland (30 plots) and *C.mopane/C.apiculatum* open woodland (44 plots) results, were used for comparative reasons. Altogether 200 plots were done in these three vegetation types during the research period.

5.3. Data collection:

5.3.1. Plot data:

The following data was collected and recorded in each plot:

1. Density:

The numbers of mopane and "other" trees and shrubs were counted and were expressed as trees/ha.

2. Stem circumference:

For each mopane tree the circumference of each stem was measured to the nearest centimetre at basal height, using a metal measuring tape. Basal height is the stem area 3-5cm from the ground where circumference measurements where conducted. Measurements were then classified as follows:

C1= <10cm

C2= 10-20cm

C3= 20-30cm

C4= 30-40cm

C5= >40cm .

3. Stem height:

The height of the tallest stem of each mopane tree was measured using a rod calibrated in metres. The data were placed into height classes as follows:

H1= <1m

*H2= 1-2.5m

H3= 2.5-3.5m

H4= 3.5-4.5m

H5= >4.5m.

*H2 has a height class of 1.5m compared to 1m for H1/H3/H4/H5. The reason therefore is that most trees were found to be in this specific range.

4. Senility:

Senility of each mopane tree was determined by assessing the % of the canopy which was dead. Trees were placed into senility classes as follows:

S1= <25 %

S2= 25-50 %

S3= 50-75 %

S4= >75 % canopy dead.

5. Browse:

The number of trees per plot with recent browse damage positively linked to utilization by elephant and eland was noted to determine the percentage of mopane utilized by these two species. No differentiation was made between the browse damage made by these two species, because both species utilize mopane extensively on the VLNR. In certain cases it is also difficult to differentiate between browse damage done by these two species, especially when the damage is reasonably old.

6. Insects:

Any obvious resident insects present, were noted per mopane tree per plot where possible, to determine the degree of utilisation by insects.

5.3.2. Sample tree data:

To estimate biomass and determine charcoal yield, one mopane tree per plot was selected randomly for harvesting. The harvested tree was of no particular height, circumference or certain senility proportion. Although this would seem to have unnecessarily variable results in yield and biomass, it was decided to proceed as randomly as possible so as to cover the full range of variation for the tree strata. The distance to its nearest mopane neighbour was measured to investigate effects of intra-specific competition. Harvesting comprised cutting the tree off at basal height (3-5cm from ground level) with a bowsaw. The best possible aboveground biomass yield would be ensured by harvesting at basal height. Material was weighed on a spring balance calibrated in kilograms and measured to the nearest half kilogram.

1. Harvestable yield:

1.1. Total mass:

The total aboveground biomass of the sample tree was determined by weighing it to the nearest half kilogram. The tree was cut into manageable sections and weighed the same day on which it was felled. This would ensure the exact "wet" weight of the wood. As mopane is a very hard wood, cutting it into manageable sections directly after harvesting, was deemed to be the most convenient way.

1.2.Charcoal mass:

The mass of wood suitable for conversion into charcoal was determined by discarding the branches with circumferences less than 7-8cm together with all foliage and weighing the remainder to the nearest half kilogram.

1.3.Aboveground biomass per hectare:

Aboveground biomass/ha was calculated as follows:

mean.mass/tree/plot x mean.density/plot x 100 = kg/ha

2. Age calculations:

Growth rings were counted in a cross section of the thickest stem of each sample tree. The section was polished and rings identified with the aid of a magnifying glass. Although this is not the most accurate method of determining the age of wood, it seemed to be the most practical as mopane wood is very difficult to age (Caughley, 1976). Growth rings are obscured by the deposition of heartwood, which is initiated when the stems are about 50mm in diameter (Scholes, 1990).

3. Growth rate calculations:

The growth rate of mopane was determined for each vegetation type, by dividing mean circumference of trees by average age of trees.

5.4. Analysis of data:

Field data were entered into a Lotus spreadsheet for subsequent analysis and interpretation. Most data were analyzed using the Statgraphics Statistical Program with certain graphs of the data drawn using a Lotus spreadsheet. The correlation between mopane performance and selected physical properties was examined using simple, multiple and stepwise regression analysis. One-way and multifactorial analysis of variance was also used to analyze the effects of certain factors (vegetation type/soil type) on certain variables (density/height/circumference/senility/age/growth rate/biomass) . The results are presented in Chapters 6 & 7. A preliminary harvesting model was also drawn up using the Quattro Pro data analysis system (Chapter 8.2).

CHAPTER 6

RESULTS AND DISCUSSION

CHAPTER 6: VEGETATION TYPES AND *C.MOPANE* DYNAMICS

6.1. Density

Mopane densities (trees/ha) estimated for the three vegetation types as well as comparable data from other areas in Southern Africa, are presented in Table 2.

Table 2: Density estimations of mopane (trees/ha) for VLNR and other areas in Southern Africa.

Areas	**Trees/ha**	**Other spp./ha**	**Trees/km**
VLNR:			
*3	2289	187 (8.2%)*	
*4	830	147(17.7%)*	
*5	727	300(41.3%)*	
KPNR:	475-2833		
Kruger N.P.:	369-1757		
Etosha: (Namibia)	189-381		
SLNP (Zambia):			1500-1900*
S/E Zimbabwe:	150-380		
SWRA(Zimbabwe)			
Trees:	542-581		
Shrubs:	2181-4730		
Tuli(Zimbabwe)	3896		

*3/4/5 = indicate three different vegetation types for the VLNR (See 3.1, 3.2 & 3.3).

*Other spp/ha(%): trees other than mopane as a percentage of total number of trees.

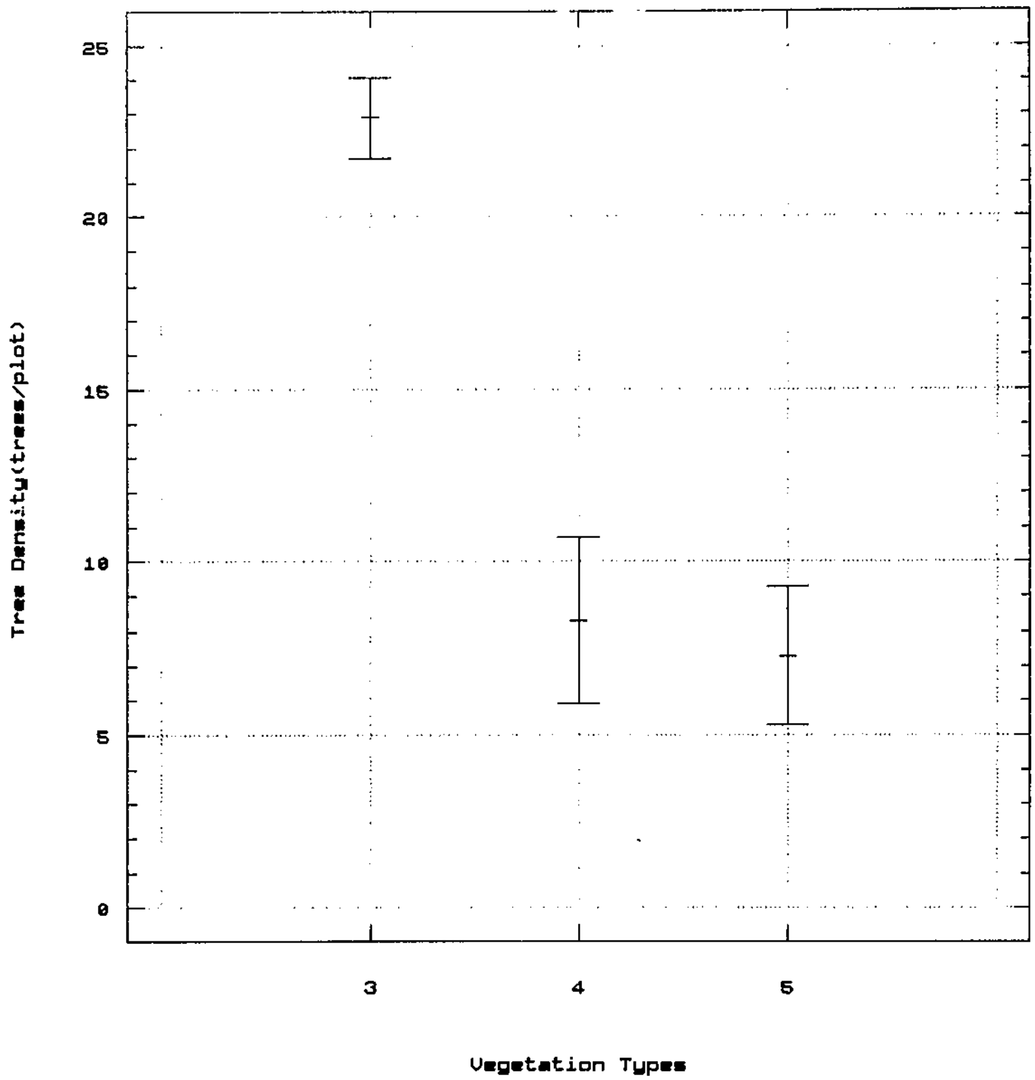
*SLNP density results were presented as km² by Lewis (1991).

Sources: VLNR (Venetia Limpopo Nature Reserve)(This study).
Klaserie Private Nature Reserve, RSA (Scholes, 1990).
Kruger National Park, RSA (Van Rooyen *et al.*, 1981).

Etosha, Namibia (Nott & Stander, 1991).
SLNP (Southern Luangwa N.P., Zambia) (Lewis, 1991).
South-Eastern Zimbabwe (Kelly & Walker, 1976).
SWRA (Sengwa Wildlife Research Area) (Guy, 1981).
Tuli Lowveld (South-West Zimbabwe)(Dye & Spear,1982).

In the VLNR the tree density of *C.mopane* woodland was 2289 ±72trees/ha compared to 830 ±68trees/ha and 727 ±44trees/ha for *C.mopane* shrubland and mixed *C.mopane/C.apiculatum* open woodland, respectively. Tree density for each vegetation type is illustrated in Figure 6. The density of mopane trees/ha in *C.mopane* woodland (3) was almost three times as high as in *C.mopane* shrubland (4) and mixed *C.mopane/C.apiculatum* open woodland (5). *C.mopane* woodland (8.2%) had the lowest density of "other" tree species present compared to *C.mopane* shrubland (17.7%) and *C.mopane/C.apiculatum* open woodland (41.3%)(Table 2).

There was a significant difference in density between *C.mopane* woodland and the other two vegetation types (Figure 6 & Appendix 4). There was no significant difference in density between *C.mopane* shrubland and *C.mopane/C.apiculatum* open woodland (Figure 6). Results for VLNR do not differentiate between shrub and tree components of mopane. If the shrub component is also taken into consideration (Table 2), there does not seem to be much difference between the range of densities in Klaserie Private Nature Reserve with between 475 and 2833 trees/ha (Scholes, 1990), Kruger National Park with 369 and 1759 trees/ha (Van Rooyen *et al.*, 1981), Sengwa Wildlife Research Area with 542 and 5730 trees/ha (Guy, 1981) and those on VLNR. Dye & Spear (1982) reported up to 3896 trees/ha but they did not exclude other tree species although mopane dominated the vegetation type studied. Although data for the "other" areas do not indicate mean mopane densities,



Vegetation types:
3 = *C.mopane* woodland
4 = *C.mopane* shrubland
5 = *C.mopane/C.apiculatum* open woodland

Figure 6: Mean tree density (trees per plot) per vegetation type.

the density range is useful as an indication of the variability of mopane in the subregion. According to the data presented in Table 2, VLNR mopane densities are within the range of densities that occur in the subregion.

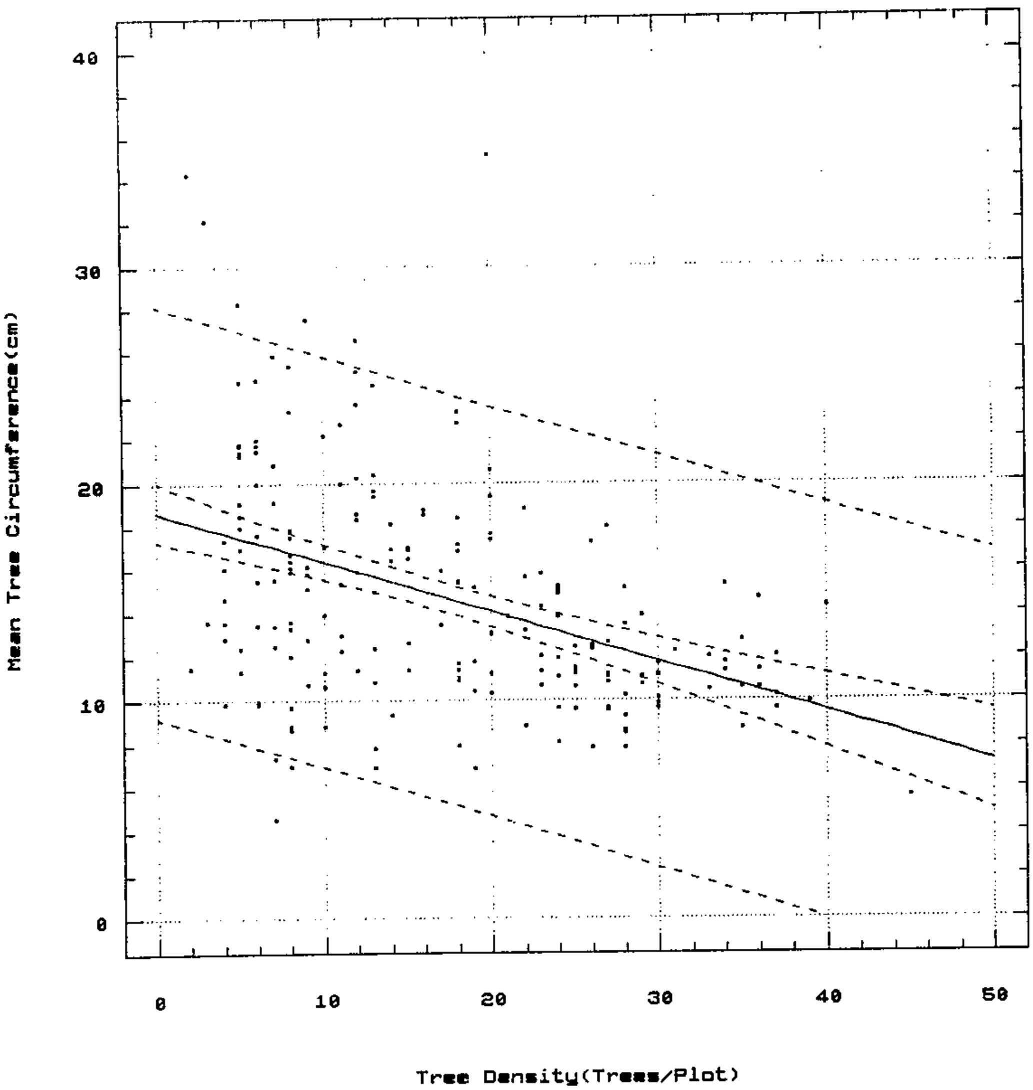
Mopane dominated the vegetation structure of *C.mopane* woodland with other tree species comprising only 8.2% of all trees present. This could be attributed to competition between mopane and other species. The percentage grass cover is also directly influenced by density of mopane on VLNR (O'Connor, 1991).

Results indicated negative correlations between density and both circumference (Figure 7) and height (Figure 8) for mopane. Mean circumference of mopane decreases with an increase in density (Figure 7) as does mean heights, but to a lesser extent (Figure 8). Intra-specific competition for resources is suggested.

6.2.2. Height and circumference classes

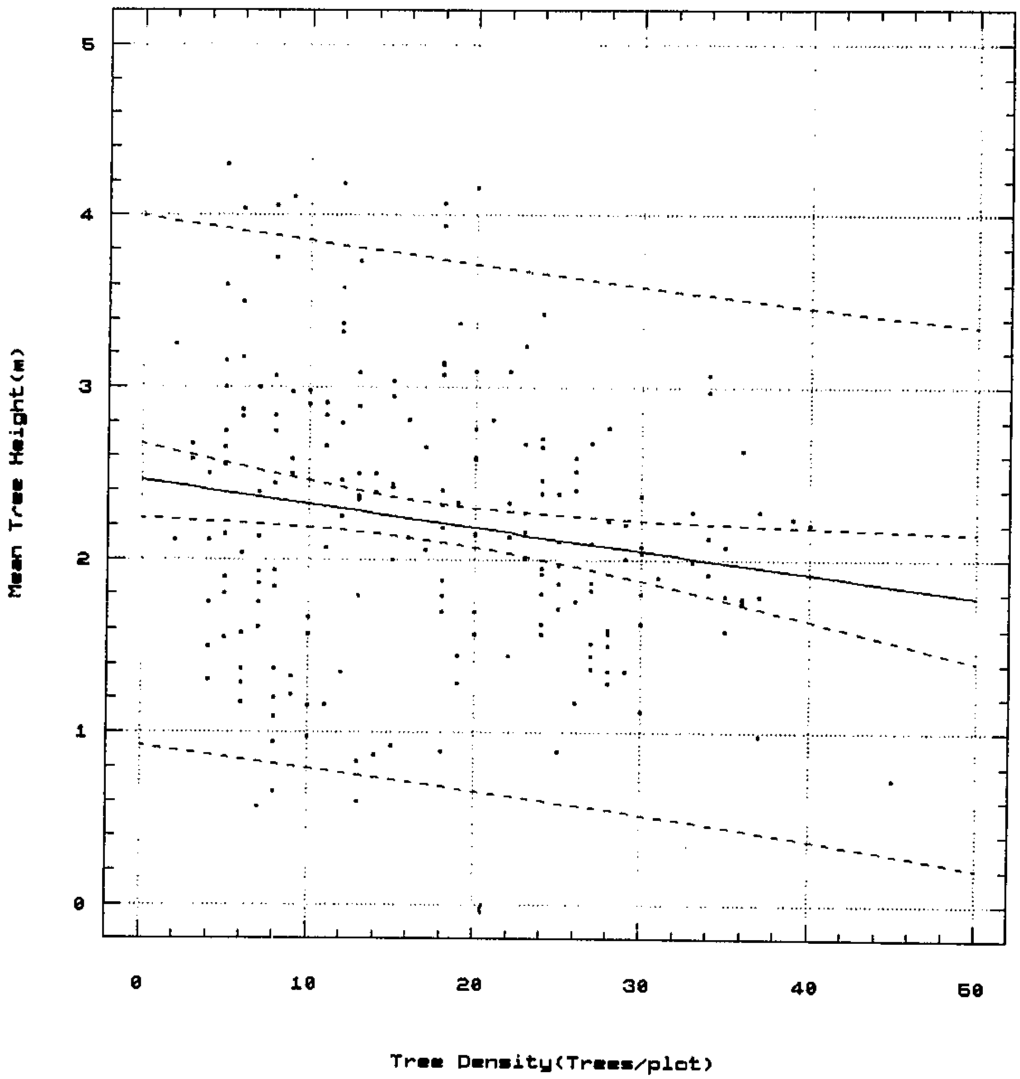
Data on mean height and mean circumference for each vegetation type are presented in Figures 9 & 10.

Mean heights were 2.3 ±0.06m, 1.4 ±0.11m and 2.6 ±0.11m and mean circumferences were 14.2 ±0.43cm, 13.9 ±1.27cm and 16.6 ±0.72cm for vegetation types 3, 4 and 5 respectively. The smallest mopane trees on average were found in *C.mopane* shrubland (1.4m/13.9cm) and the largest in *C.mopane/C.apiculatum* open woodland (2.6m/16.6cm). *C.mopane* shrubland growth had stunted plants (1.4m) but resembled *C.mopane* woodland in circumference (13.9cm vs 14.2cm). Distribution of height and circumference classes in each vegetation type are presented in Table 3.



$r = -0.43$
DF = 198
$p < 0.05$
$r^2 = 0.19$

Figure 7: Correlation between mean tree circumference(cm) and mean tree density(trees/plot).



r = -0.17
DF = 198
p < 0.015
r^2 = 0.029

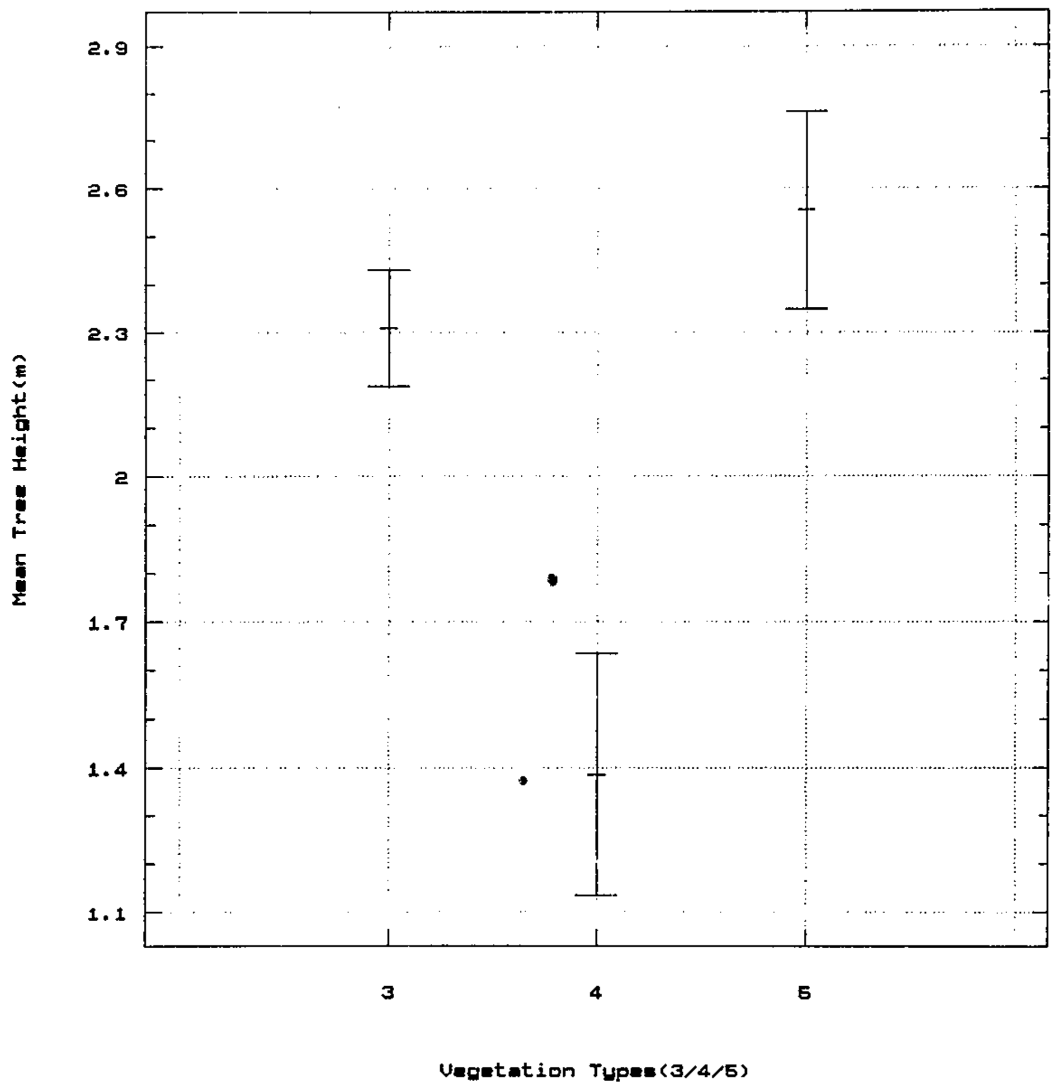
Figure 8: Correlation between mean tree height(m) and mean tree density(trees/plot).

Table 3: Distribution of *C.mopane* within different height and circumference classes.

				Vegetation Types		
		3		4		5
Height class (m)	**No.Trees**	**%**	**No.Trees**	**%**	**No.Trees**	**%**
<1	581	20.1	135	54.2	46	14.4
1-2.5	1386	48.1	93	37.4	125	39.1
2.5-3.5	608	21.1	21	8.4	83	25.9
3.5-4.5	260	9.0	0	0	48	15.0
>4.5	49	1.7	0	0	18	5.6
Total:	2884	100	249	100	320	100
Circumference class (cm)						
<10	5398	49.2	135	54.2	517	33.9
10-20	4022	36.6	93	37.4	559	36.7
20-30	1176	10.7	21	8.4	295	19.4
30-40	271	2.5	0	0	98	6.4
>40	111	1.0	0	0	55	3.6
Total:	10978	100	249	100	1524	100

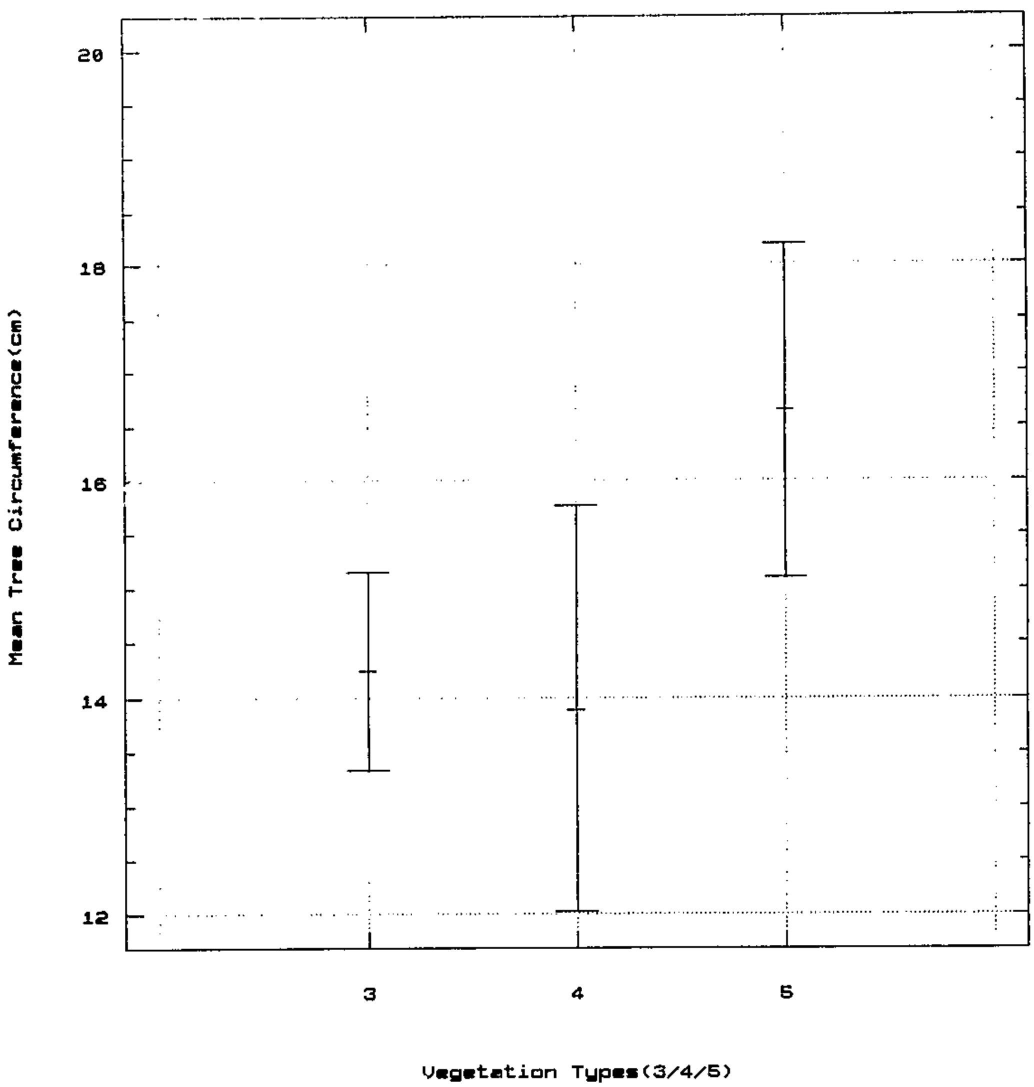
The majority of trees in *C.mopane* woodland (48.1%) and mixed *C.mopane/C.apiculatum* open woodland (39.1%) occurred in the height class 1-2.5m, while most trees in *C.mopane* shrubland (54.2%) were below 1m in height. In the *C.mopane* shrubland, no specimens were found to be higher than 3.5m compared to 10.7% and 20.6% in the classes >3.5m for *C.mopane* woodland and *C.mopane/C.apiculatum* open woodland respectively.

Most trees in *C.mopane/C.apiculatum* open woodland occurred in a circumference class of 10-20cm (36.7%), while in *C.mopane* woodland (49.2%) and *C.mopane* shrubland (54.2%) most were below 10cm. Maximum circumference was 30cm in *C.mopane* shrubland, compared to 3.5% and 10% of trees >30cm for *C.mopane* woodland and *C.mopane/C.apiculatum* open woodland



Vegetation types:
3 = *C.mopane* woodland
4 = *C.mopane* shrubland
5 = *C.mopane/C.apiculatum* open woodland

Figure 9: Mean tree height(m) per vegetation type.



Vegetation types:
3 = *C.mopane* woodland
4 = *C.mopane* shrubland
5 = *C.mopane/C.apiculatum* open woodland

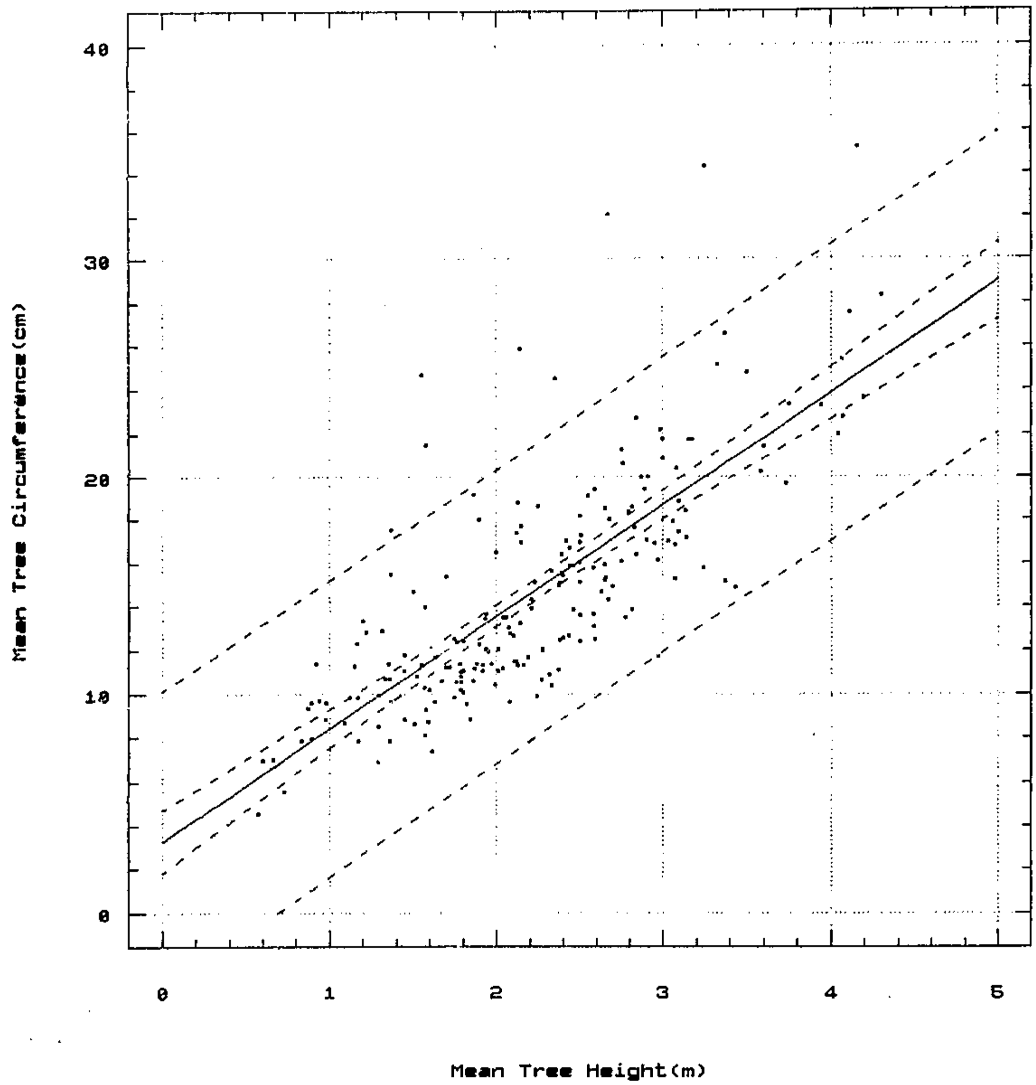
Figure 10: Mean tree circumference(cm) per vegetation type.

respectively.

Mean tree heights differed significantly between the three vegetation types (Figure 9 & Appendix 4), while the only significant difference for mean circumference was between *C.mopane/C.apiculatum* open woodland and the other two vegetation types (Figure 10 & Appendix 4). There was a strong positive correlation between height and circumference (Figure 11).

Height: The distribution of plants in the different height classes indicates that the majority of the *C.mopane* population is less than 2.5m high (Table 3). The proportion ranges from 91.6% for *C.mopane* shrubland to 53.5% in *C.mopane/C.apiculatum* open woodland. *C.mopane* shrubland was dominated by shrubs below 1m in height (54.2%). Nott & Stander (1991) suggest that a population below 1m in height reflects a healthy population. This is not necessarily correct for VLNR, as most trees in *C.mopane* shrubland were stunted, possibly due to edaphic and climatic factors. Many of them seemed to have "bonsai" characteristics. Only 1.7% of trees in *C.mopane* woodland and 5.6% in *C.mopane/C.apiculatum* open woodland were above 4.5m, while none were higher than 3.5m in *C.mopane* shrubland.

Circumference: In all three vegetation types the circumference of the majority of mopane was below 20cm (Table 3). The proportion ranges from 91.6% for *C.mopane* shrubland to 70.6% in *C.mopane/C.apiculatum* open woodland. In *C.mopane* woodland and shrubland the circumference of most mopane plants was less than 10cm, while *in C.mopane/C.apiculatum* open woodland it was between 10 and 20cm. Values above 40cm were present in only 1% of *C.mopane* woodland and 3.6% of *C.mopane/C.apiculatum* open woodland, while no trees were larger than 30cm in circumference in *C.mopane* shrubland.



r = 0.76
DF = 198
$p < 0.05$
$r^2 = 0.58$

Figure 11: Correlation between mean tree height(m) and mean tree circumference(cm).

The only tall mopane plants on VLNR, were found adjacent to river and stream courses . Lewis (1991) found that in Zambia (Luangwa Valley), the mean height of mopane woodland varied from 9.3 ±5.7m to 14.8 ±7.0m and the mean circumference from 24.1 ±11.7cm to 43.5 ±16.2cm. Coppiced trees varied from 0.5m to 3.0m in height. However, soil, rainfall and other climatic factors differ from VLNR.

6.2.3. Senility

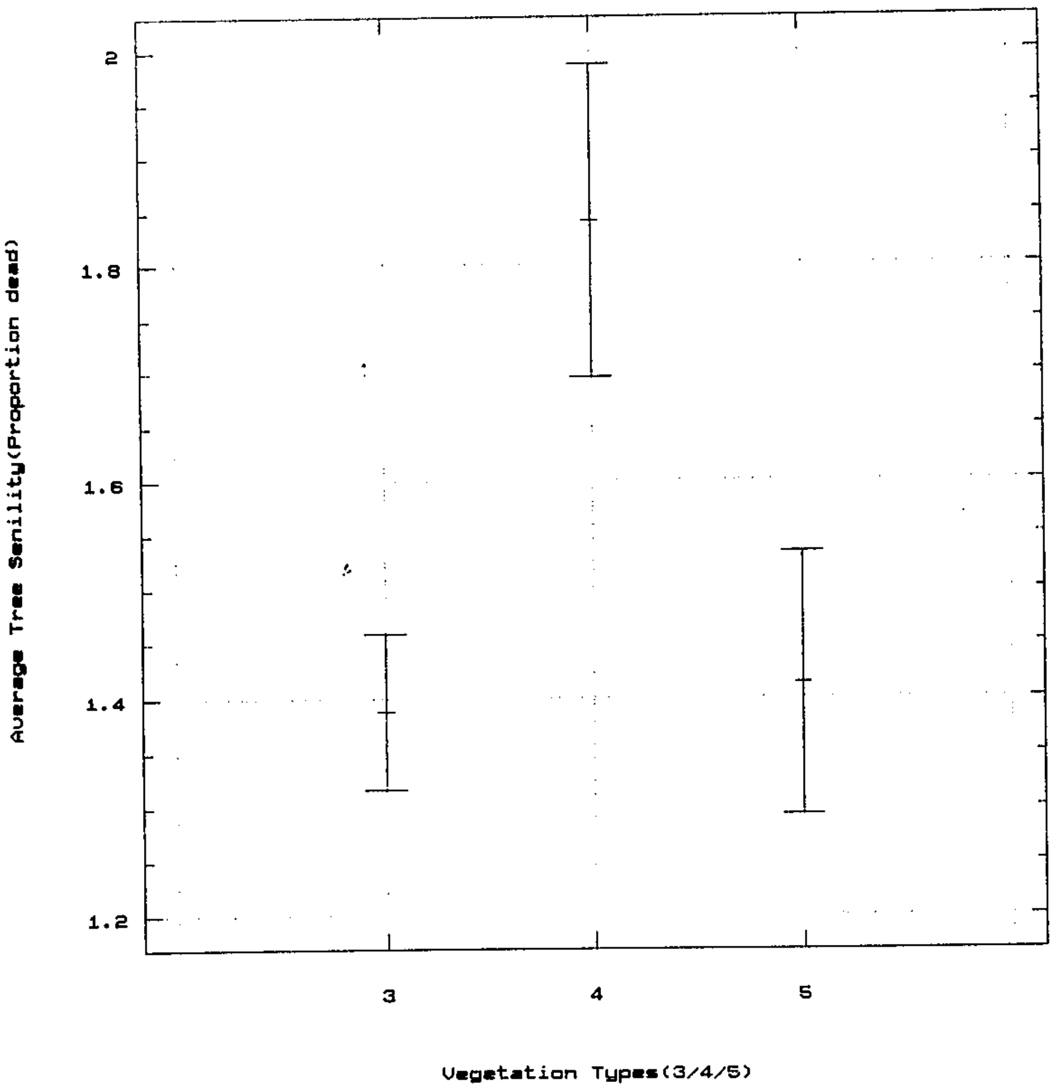
The incidence of senility (% canopy dead) in each vegetation type is presented in Table 4.

Table.4. Distribution of *C.mopane* within different senility classes.

			Vegetation Types			
		3		**4**		**5**
Senility class (% canopy dead)	**No.Trees**	**%**	**No.Trees**	**%**	**No.Trees**	**%**
<25%	2238	77.6	141	56.6	232	72.5
25-50%	379	13.1	50	20.1	57	17.8
50-75%	144	5.0	32	12.9	11	3.4
>75%	123	4.3	26	10.4	20	6.3
Total:	2884	100	249	100	320	100

Senility was highest in *C.mopane* shrubland with 23.3% of mopane having more than 50% canopy dead, compared to 9.3% and 9.7% for *C.mopane* woodland and *C.mopane/C.apiculatum* open woodland, respectively. Senility was lowest in *C.mopane* woodland, with 77.6% of trees with less than 25% canopy dead. Average senility (number of mopane trees dead per vegetation type) is illustrated in Figure 12.

There was a significant difference in average senility between *C.mopane* shrubland and the other two vegetation types (Figure



Vegetation types:
3 = *C.mopane* woodland
4 = *C.mopane* shrubland
5 = *C.mopane/C.apiculatum* open woodland

Figure 12: Average tree senility(proportion of trees dead) per vegetation type.

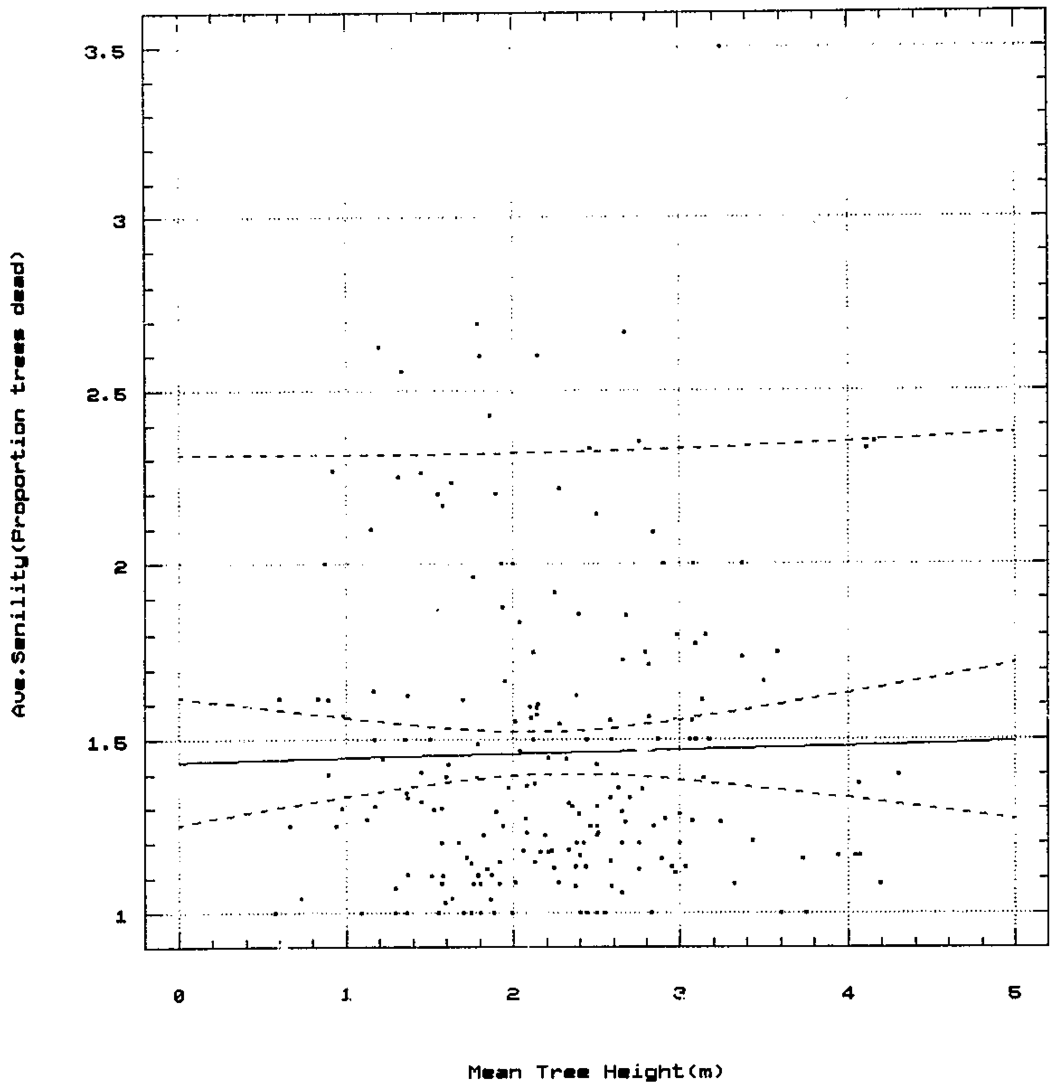
12 & Appendix 4). No significant difference in average senility occurred between *C.mopane* woodland and *C.mopane/C.apiculatum* open woodland (Figure 12). Senility distribution depicts a healthy population in *C.mopane* woodland and *C.mopane/C.apiculatum* open woodland with only 9.3% and 9.7% of trees with more than 50% of canopy dead, respectively. *C.mopane* shrubland on the other hand does not show the same healthy trend (Table 4). There are slight positive correlations between senility and height (Figure 13) and circumference (Figure 14). Senility decreases with an increase in height and circumference. The highest incidence were in trees between 1m and 3m in height and between 10cm and 20cm in circumference. Patches of dead mopane were found in all vegetation types but the reason therefore is not clear.

Mopane seems to be a very hardy species, as trees felled or partially barked by elephant, carry on growing without a seemingly detrimental effect to the tree. Naturally this would depend on elephant density as well as severe climatic influences. A dense elephant population combined with drought show the destructive effect of these animals on mopane communities (Guy, 1981; Lewis, 1991).

6.2.4. Age and growth rate

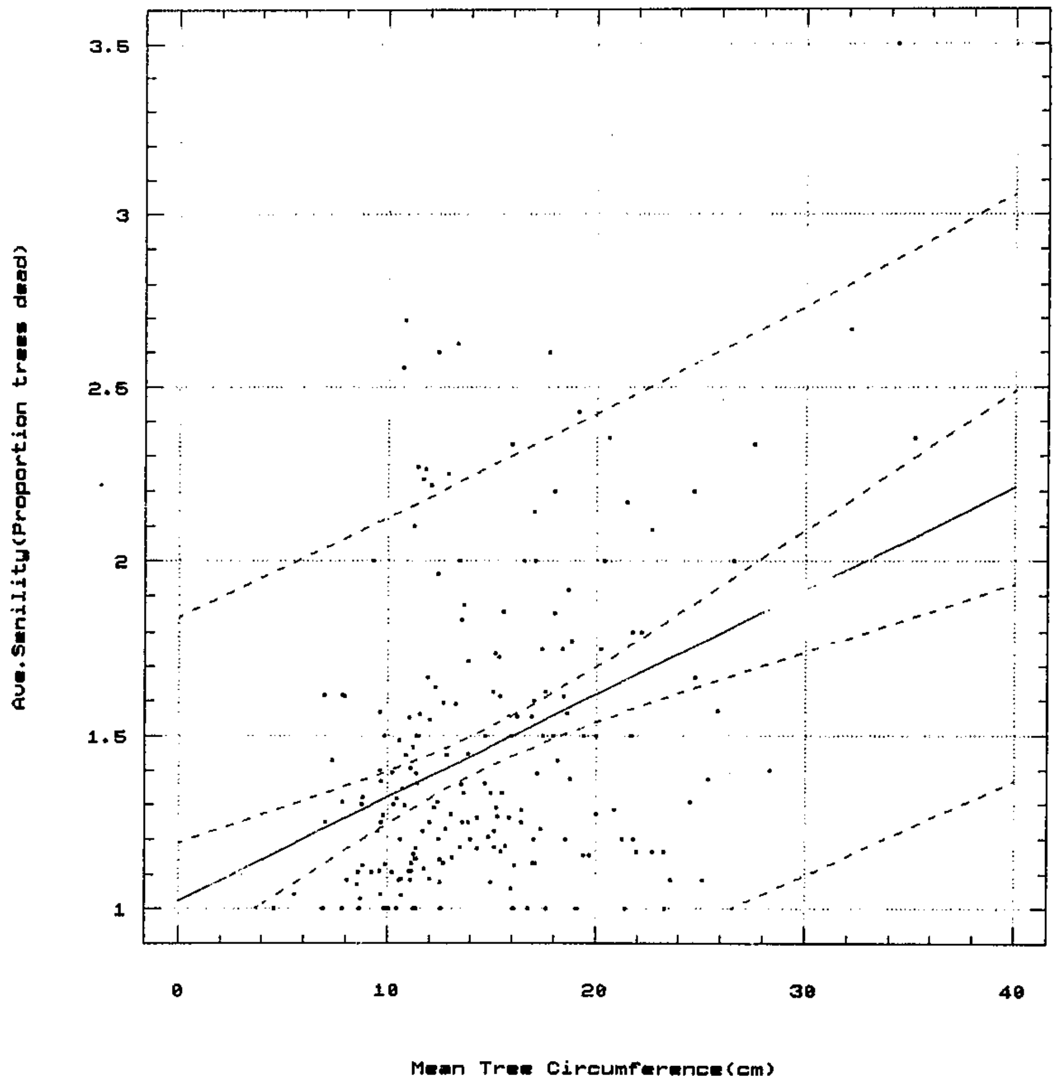
Average age and mean annual growth rate for the three different vegetation types is illustrated in Figures 15 & 18.

The average ages are 25 ±1.05yrs, 21 ±2.06yrs and 20 ±0.99yrs for *C.mopane* woodland, *C.mopane* shrubland and *C.mopane/C.apiculatum* open woodland, respectively. Oldest trees on average are thus found in *C.mopane* woodland and the youngest trees in *C.mopane/C.apiculatum* open woodland (Appendix 4).



r = 0.02
DF = 198
$p < 0.77$
$r^2 = 0.004$

Figure 13: Correlation between average tree senility(proportion of trees dead) and mean tree height(m).



r = 0.36
DF = 198
$p < 0.05$
$r^2 = 0.013$

Figure 14: Correlation between average tree senility(proportion of trees dead) and mean tree circumference(cm).

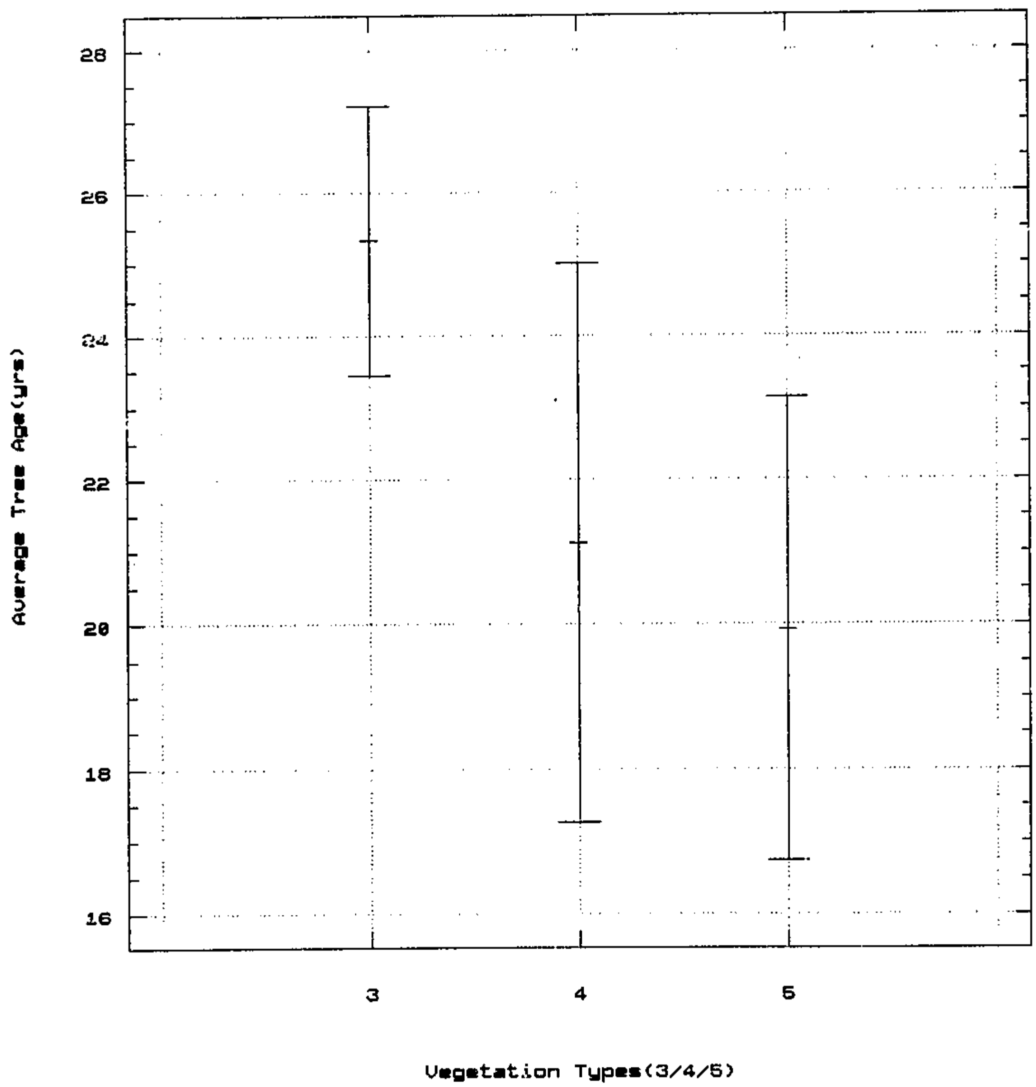
Table 5: Mean annual growth rate (cm/yr) and regeneration time (yrs) per vegetation type.

		Vegetation Type	
	3	**4**	**5**
N (Plots)	126	30	44
Mean growth rate(cm/yr)	0.59	0.56	0.71
SD	0.02	0.04	0.03
Regeneration time(yrs)*	24	25	23

*Regeneration time = time for growth rate (cm/yr) to reach mean circumference for each vegetation type.

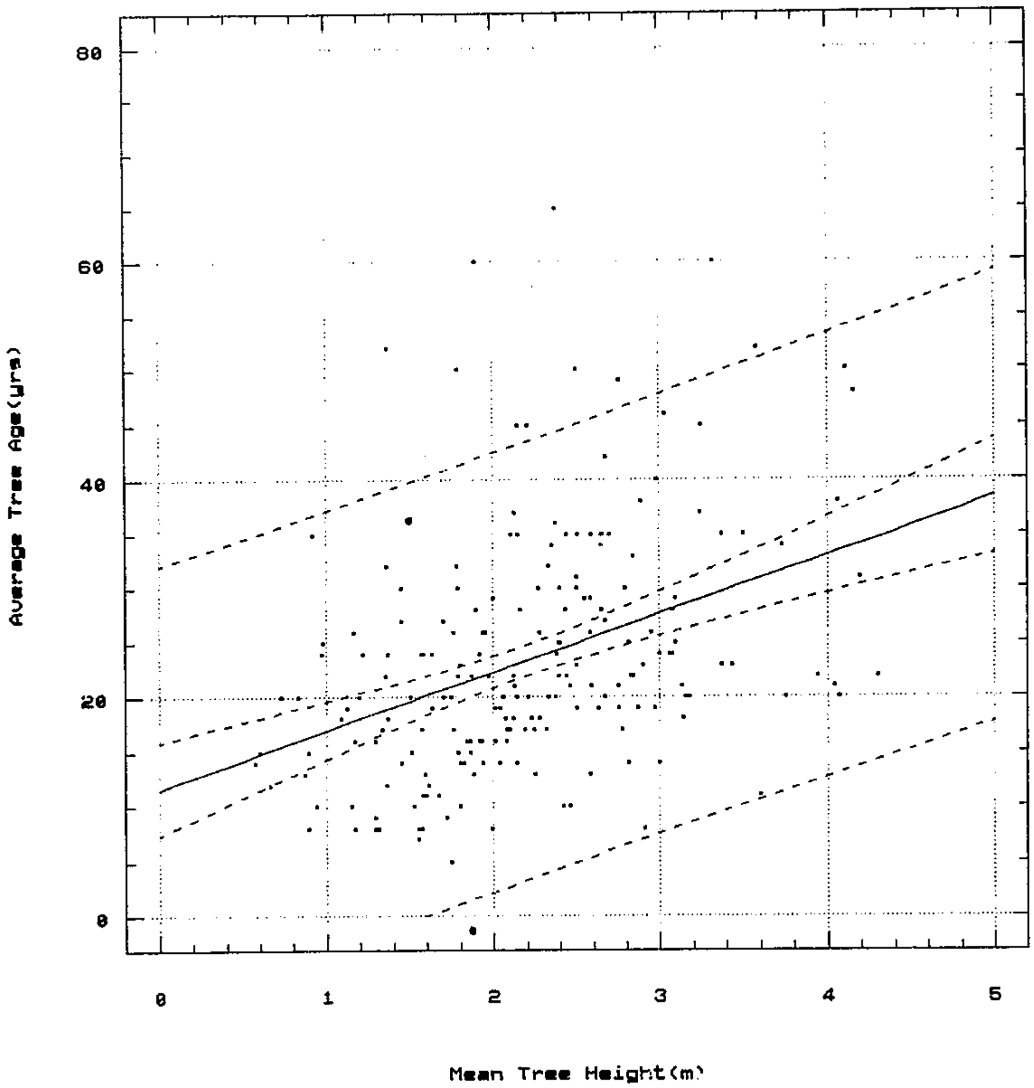
C.mopane woodland has an annual growth rate of 0.56 ±0.04cm/yr. The highest annual growth rate of 0.71 ±0.03cm/yr was found in *C.mopane/C.apiculatum* open woodland and the lowest in *C.mopane* shrubland (0.59 ±0.02cm/yr)(Table 5).

Age: There is a significant difference in average age per tree between *C.mopane* woodland and the other two vegetation types (Figure 15 & Appendix 4). Highest values (oldest trees) are found in *C.mopane* woodland (25yrs) and lowest (youngest trees) in *C.mopane/C.apiculatum* open woodland (20yrs). It was expected that *C.mopane* shrubland would have the highest average age, as trees are stunted and bonsai-like, but values do not differ significantly between this vegetation type and *C.mopane/C.apiculatum* open woodland (Figure 15 & Appendix 4). There are slight positive correlations between age, height (Figure 16) and circumference (Figure 17) of mopane. Increasing age tends to be associated with taller, and specially thicker trees (Figure 16 & 17). Circumference thus seems to be a slightly better determinant of age than height.



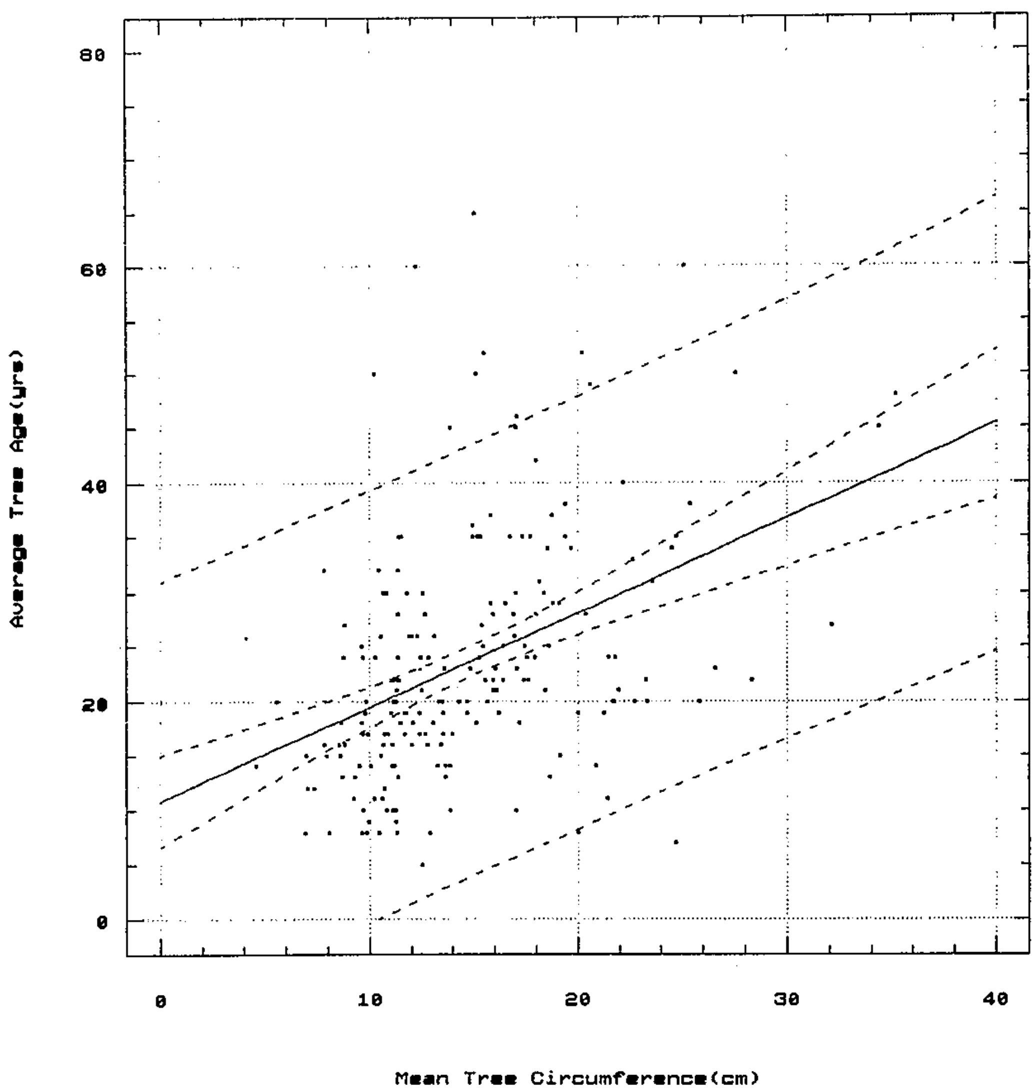
Vegetation types:
3 = *C.mopane* woodland
4 = *C.mopane* shrubland
5 = *C.mopane/C.apiculatum* open woodland

Figure 15: Average tree age(yrs) per vegetation type.



$r = 0.38$
DF = 198
$p < 0.05$
$r^2 = 0.14$

Figure 16: Correlation between average tree age(yrs) and mean tree height(m).



$r = 0.41$
DF = 198
$p < 0.05$
$r^2 = 0.17$

Figure 17: Correlation between average tree age(yrs) and mean tree circumference(cm).

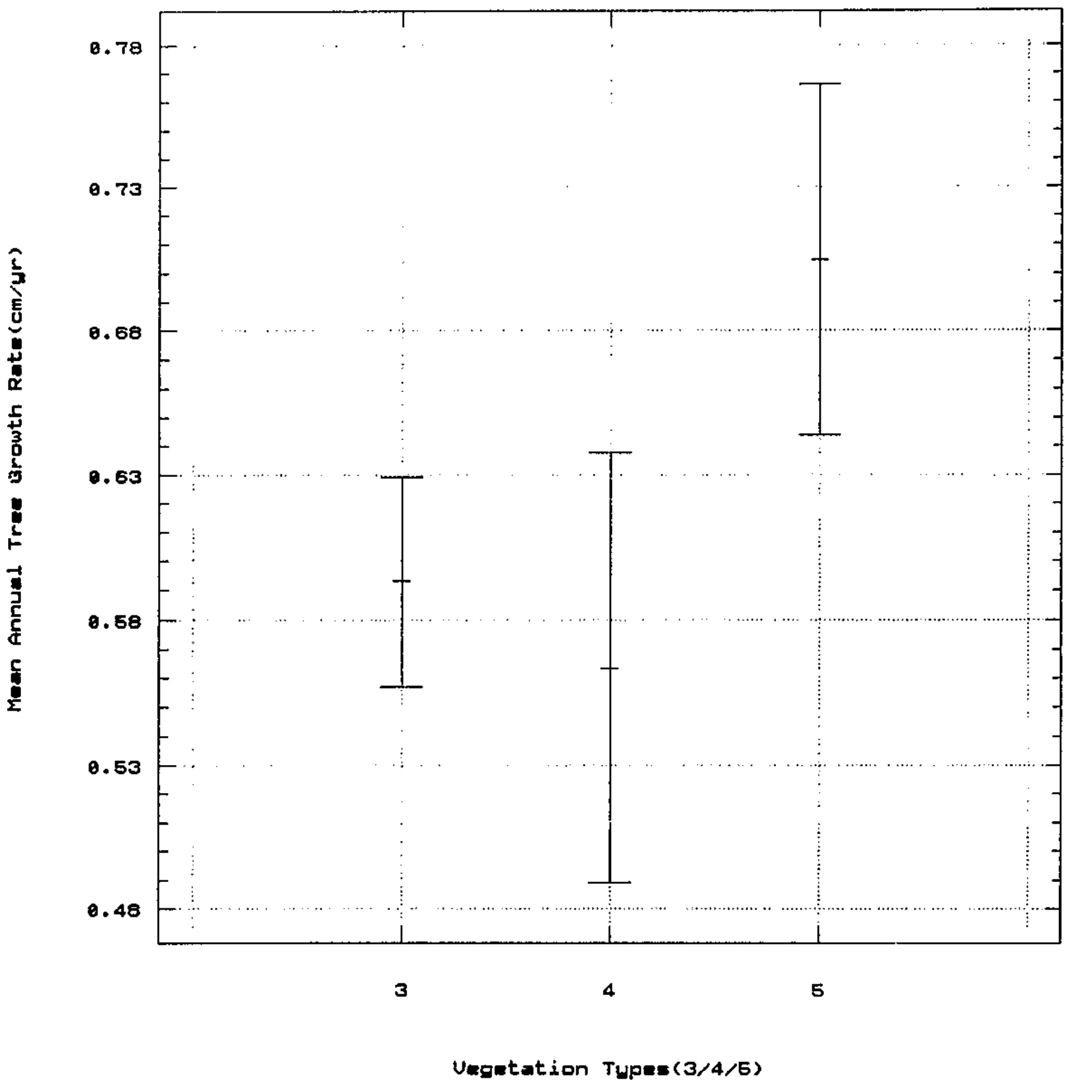
(Figure 16 vs Figure 17).

Growth rate: Mean annual growth rate differs significantly between *C.mopane/C.apiculatum* (0.71cm/yr) open woodland and the other two vegetation types (Figure 18 & Appendix 4). There is no significant difference in growth rate between *C.mopane* woodland (0.59cm/yr) and *C.mopane* shrubland (0.56cm/yr) (Figure 18). The slower growth rate for *C.mopane* shrubland was expected because of the bonsai-like attributes of the trees. It seems that climatic (growth rings show annual variation) and edaphic (Hutton soils vs other) factors influence growth rate of mopane.

At these growth rates it would take *C.mopane* woodland 24yrs, *C.mopane* shrubland 25yrs and *C.mopane/C.apiculatum* open woodland 23yrs, to reach mean circumferences (14.24cm, 13.89cm & 16.64cm respectively) for each vegetation type. A minimum cut-off circumference of 7cm (big enough to provide quality charcoal), would be attained in 12yrs, 13yrs and 10yrs, for *C.mopane* woodland, *C.mopane* shrubland and *C.mopane/C.apiculatum* open woodland, respectively.

Scholes (1990) states that mopane recovers to a pre-cleared state in the Eastern Transvaal (Klaserie Private Nature Reserve-KPNR), within 14 years while Von Breitenbach (1965) states that mopane coppices so vigorously that an entirely cleared area regenerates fully to dense forest within 15 years. Recovery period is shortened by higher rainfall and lengthened by drought according to growth simulations done on mopane. Regeneration from seed to a pre-cleared state could take up to 40 years (Scholes, 1990).

The regression equation of height and circumference for growth rate for all three vegetation types is as follows:



Vegetation types:
3 = *C.mopane* woodland
4 = *C.mopane* shrubland
5 = *C.mopane/C.apiculatum* open woodland

Figure 18: Mean annual tree growth rate(cm/yr) per vegetation type.

lng = -1.67 + 0.12 lnh + 0.48 lnc

where: lng = loge(growth)

lnh = loge(height)

lnc = loge(circumference)

Based on the following statistics:

N = 200

Multiple correlation coefficient (r) = 0.264 ($p<0.05$)

Coefficient of determination (r^2) = 0.431

The regression equation accounted for 43% of the variation in weight.

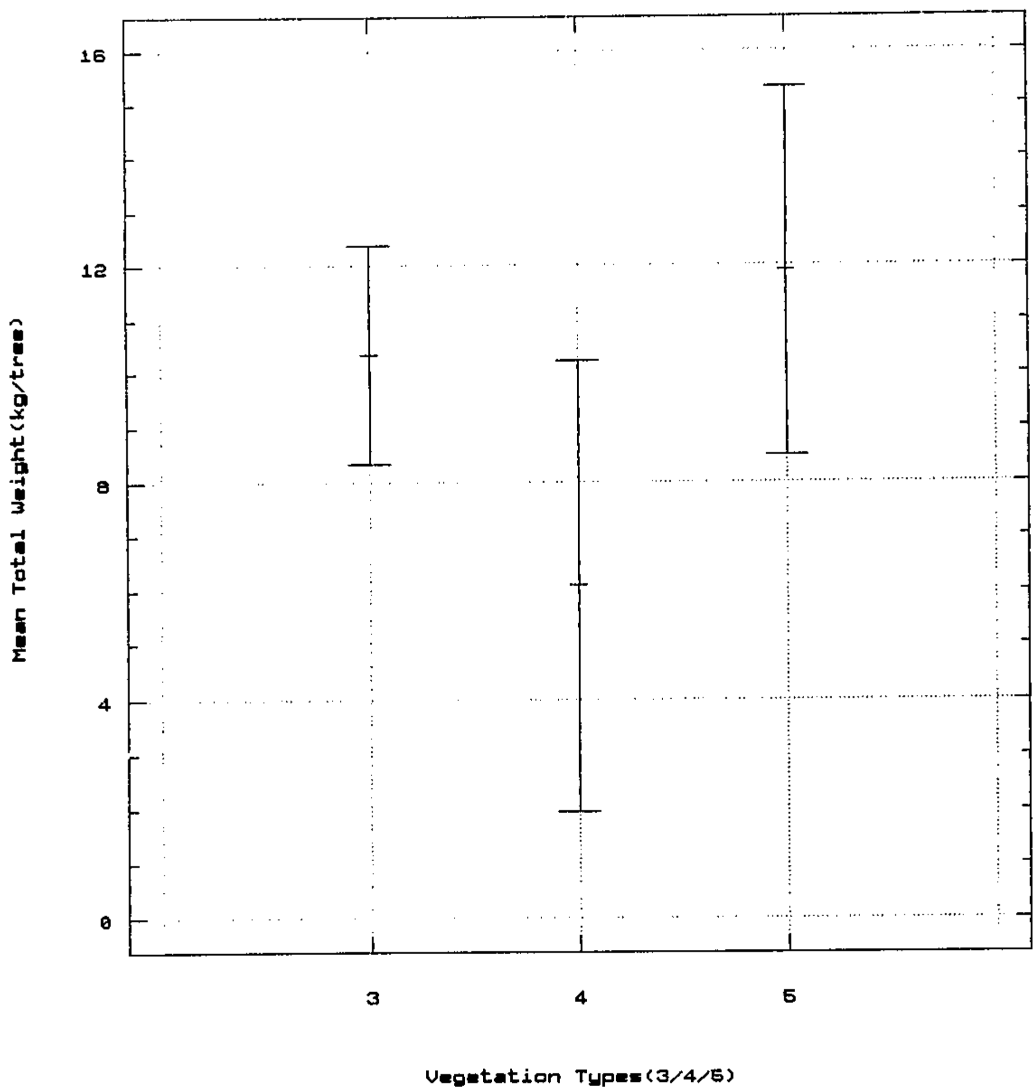
6.2.5. Biomass

Figures 19 & 20 illustrate mean total weight (browse included) per tree and mean charcoal weight (browse excluded) per tree for each vegetation type. Total and mean weights per tree per vegetation type are presented in Table 6.

Table 6: Mean, total and charcoal weights per tree per vegetation type (kg).

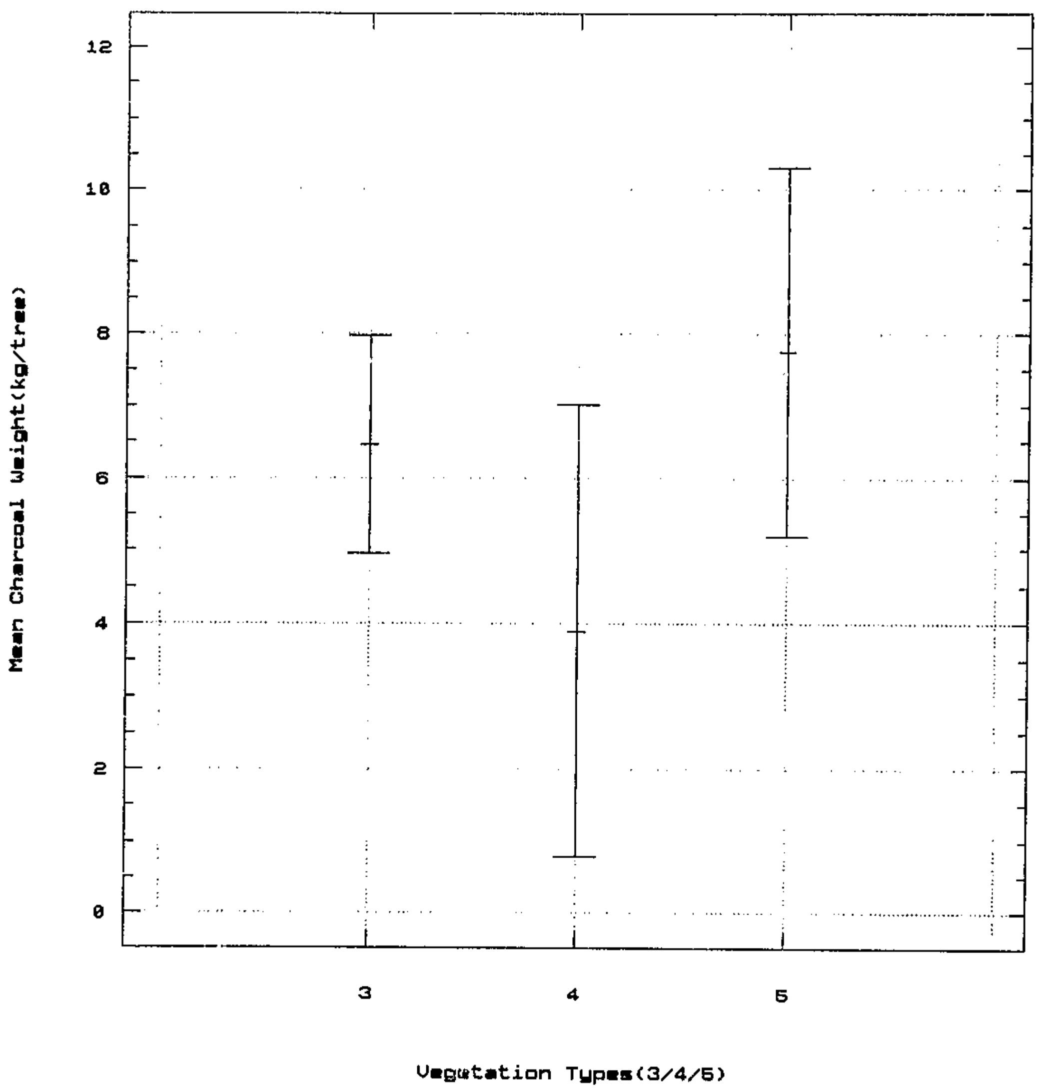
		Vegetation types	
	3	**4**	**5**
Number of tree harvested:	126	30	44
Heaviest tree/veg.type:	53	29	81.5
Mean total weight/tree:	10.4	6.1	12
Mean charcoal weight/tree:	6.5	3.9	7.8
Total weight harvested per veg.type:	1 303	179	524
Total charcoal weight harvested per veg.type:	814	117	341
Total weight/ha (kg/ha):	23 668	4 939	8 651
Charcoal weight/ha (kg/ha):	14 787	3 237	5 624
% Wood available for charcoal:	62.5	65.6	65.1

*All weights are mean weights unless otherwise stated.



Vegetation types:
3 = *C.mopane* woodland
4 = *C.mopane* shrubland
5 = *C.mopane/C.apiculatum* open woodland

Figure 19: Mean total weight per tree per vegetation type.



Vegetation types:
3 = *C.mopane* woodland
4 = *C.mopane* shrubland
5 = *C.mopane/C.apiculatum* open woodland

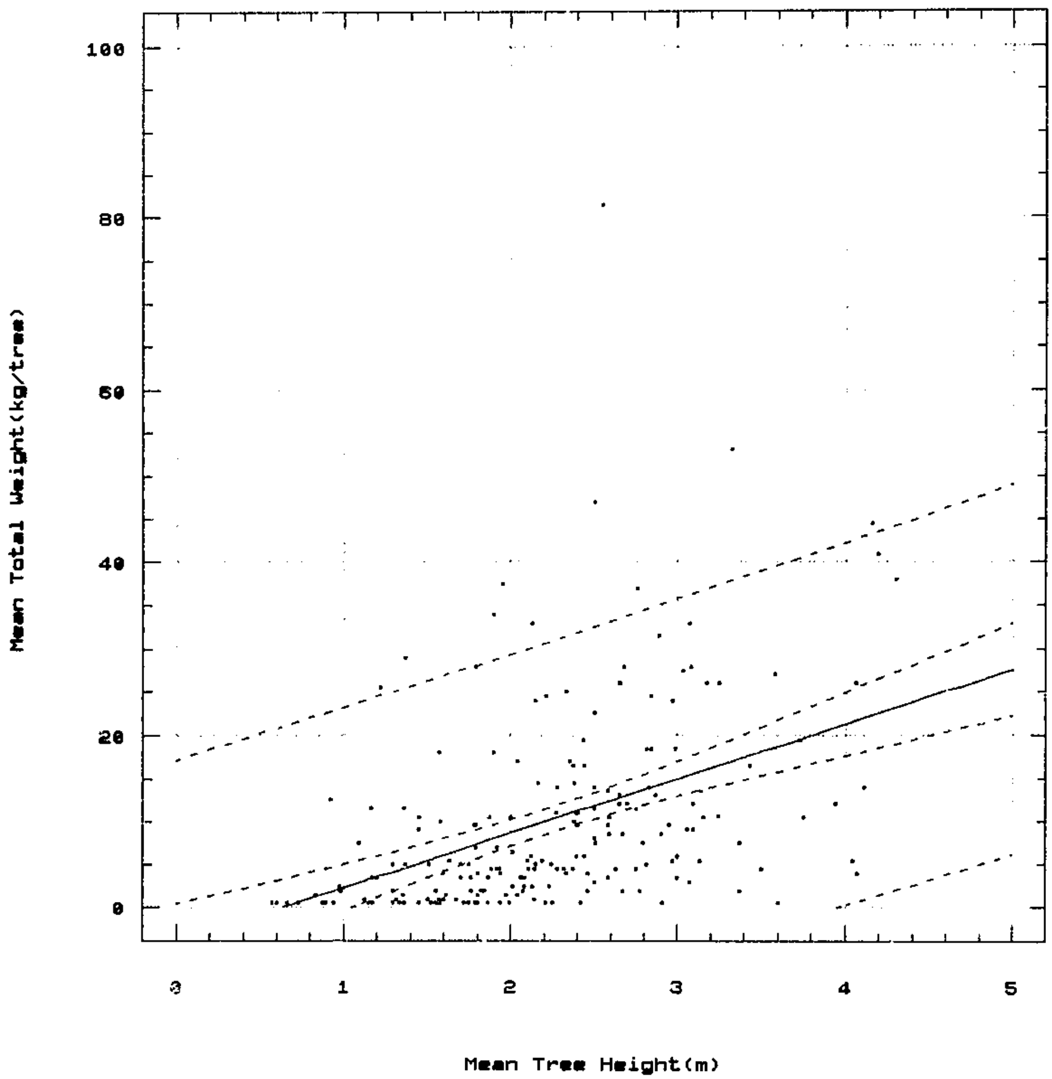
Figure 20: Mean charcoal weight per tree per vegetation type.

*All weights calculated in kg or kg/ha.
*SD± = standard deviation at 95% confidence interval (CI).
*Charcoal weight = wood with a charcoal making potential.
*Mean total weight/tree = browse included.
*Mean charcoal weight/tree = browse excluded.
*Total weight harvested = Total weight (kg) of mopane harvested per vegetation type during study period.
*Browse = foliage & branches smaller than 7-8cm in circumference.
*Heaviest tree/veg.type = heaviest tree harvested (randomly selected - See 5.3.2)

Total weight:

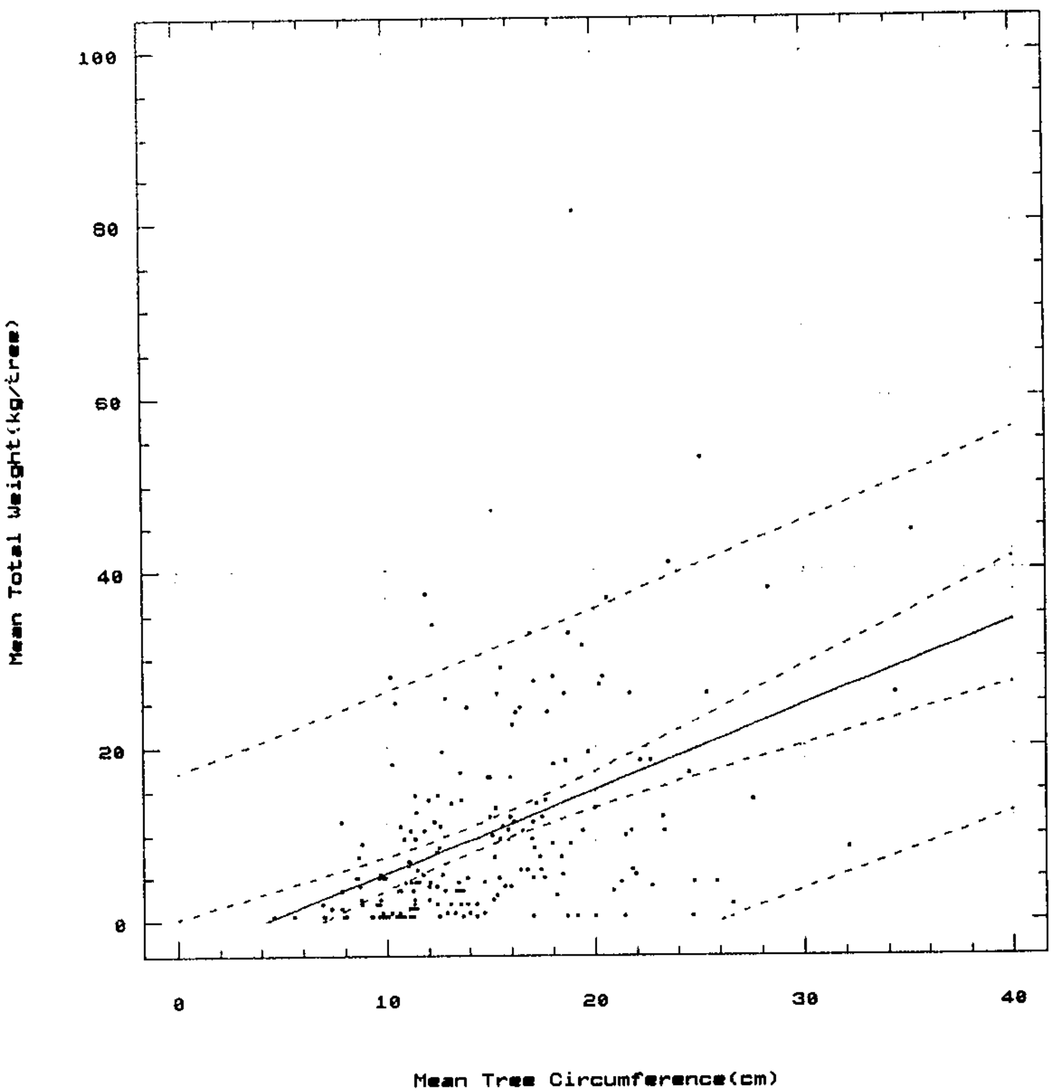
C.mopane woodland had a mean total weight per tree of 10.4 ±0.96kg. C.mopane/*C.apiculatum* open woodland (11.9 ±2.24kg) had the highest and *C.mopane* shrubland (6.1 ±1.52kg) the lowest. The heaviest specimen of 81.50kg was harvested in the *C.mopane/C.apiculatum* open woodland. Total weight of 23 668kg/ha was highest for *C.mopane* woodland and the lowest for *C.mopane* shrubland (3 237kg/ha)(Table 6). These calculations include browse and represent total available above ground weight ("wet weight"), calculated at basal height.

There was a significant difference in total weight per tree between *C.mopane* shrubland and the other two vegetation types (Appendix 4). Mean weights ranged from 6.1kg/tree for *C.mopane* shrubland to 10.4kg/tree and 11.9kg/tree for *C.mopane* woodland and *C.mopane/C.apiculatum* open woodland. Last mentioned two vegetation types did not differ significantly (Appendix 4). A positive correlation exists between height (Figure 21), circumference (Figure 22) and total weight per tree. Height and circumference thus play a significant role in determining total weight for vegetation types.



r = 0.42
DF = 198
$p < 0.015$
$r^2 = 0.18$

Figure 21: Correlation between mean tree height(m) and total weight per tree(kg).



$r = 0.43$
$DF = 198$
$p < 0.05$
$r^2 = 0.18$

Figure 22: Correlation between mean tree circumference(cm) and total weight per tree(kg).

The regression equations of height and circumference for total weight for all three vegetation types are as follows:

1. lnw = -1.04 + 1.36 lnh = 0.71 lnc

where: lnw = loge(weight)
lnh = loge(height)
lnc = loge(circumference)

Based on the following statistics:
N = 200
Multiple correlation coefficient (r) = 0.596 ($p<0.05$)
Coefficient of determination (r^2) = 0.829

2. lnw = -0.93 + 1.38 lnh + 0.57 lnc + lnh2

where: lnh2 = (lnh)**2, etc.
Based on the following statistics:
N = 200
Multiple correlation coefficient (r) = 0.567 ($p<0.05$)
Coefficient of determination (r^2) = 0.846
The regression equation accounted for 85% of the variation in weight. (The plots have suggested that it is better to base the regression analyses on the log transformed data than on the original data).

Regression equations for each vegetation type is as follows:

***C.mopane* woodland:**

lnw = -0.81 + 1.42 lnh + 0.49 lnc + 0.25 lnh2

Where: lnw = loge(weight)
lnh = loge(height)
lnc = loge(circumference)
lnh2 = (lnh)**2, etc.

Based on the following statistics:

N = 126

Multiple correlation coefficient (r) = 0.583 ($p<0.05$)

Coefficient of determination (r^2) = 0.810

The regression equation accounted for 81% of the variation in weight.

***C.mopane* shrubland:**

lnw = -0.98 + 1.58 lnh + 0.60 lnc + 0.43 lnh2

Where: lnw = loge(weight)
lnh = loge(height)
lnc = loge(circumference)
lnh2 = (lnh)**2, etc.

Based on the following statistics:

N = 30

Multiple correlation coefficient (r) = 0.403 ($p<0.05$)

Coefficient of determination (r^2) = 0.951

The regression equation accounted for 95% of the variation in weight.

***C.mopane/C.apiculatum* open woodland:**

lnw = -0.106 + 2.02 lnh + 0.139 lnc + 0.218 lnh2

Where: lnw = loge(weight)
lnh = loge(height)
lnc = loge(circumference)
lnh2 = (lnh)**2, etc.

Based on the following statistics:

N = 44

Multiple correlation coefficient (r) = 0.574 ($p<0.05$)

Coefficient of determination (r^2) = 0.857

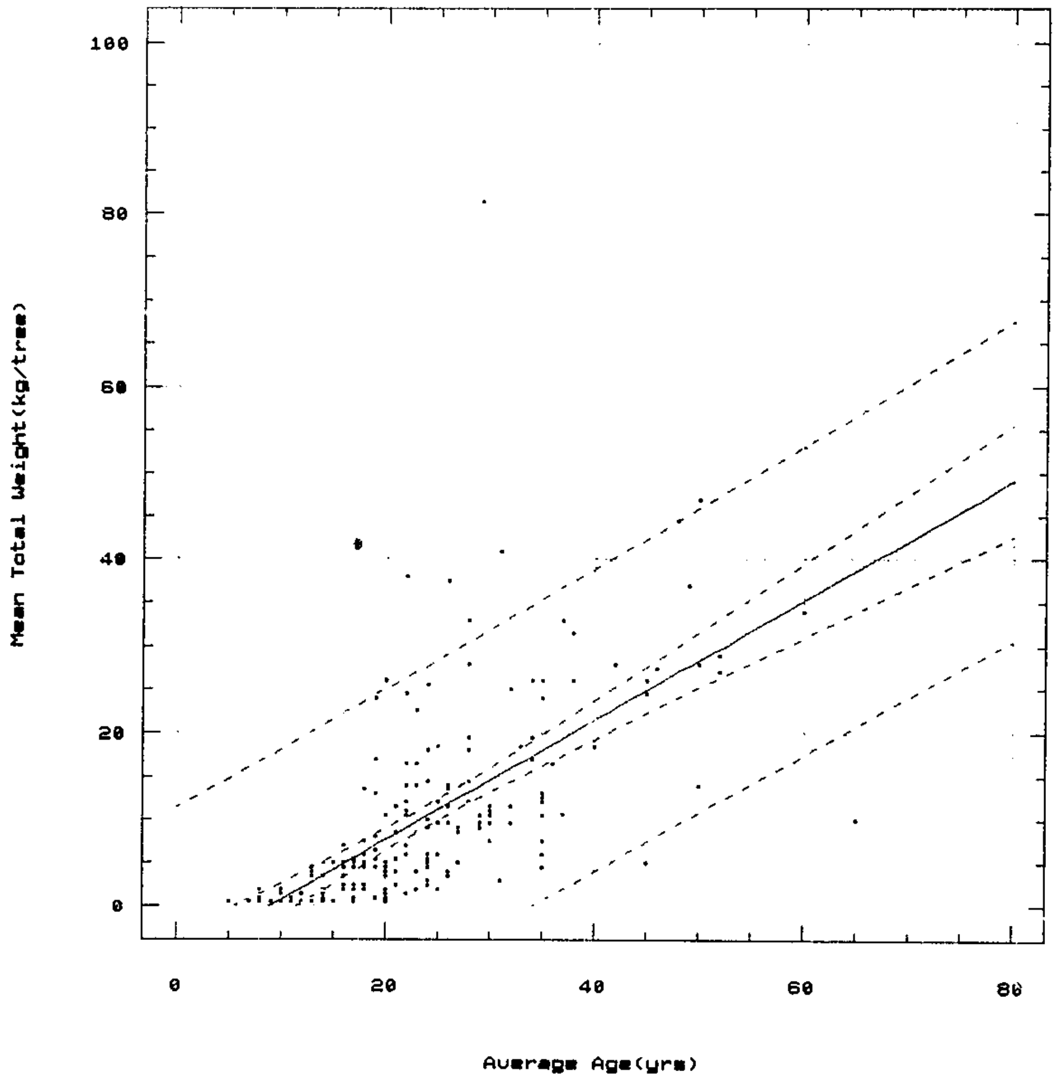
The regression equation accounted for 86% of the variation in weight.

Both age, circumference and weight are positively correlated with height and circumference so that age and weight also show a positive correlation (Figure 23). Weight increases with an increase in age.

"Wet" or fresh weight per hectare (kg/ha) for *C.mopane* woodland (23 668kg/ha) was greatest, followed by *C.mopane/C.apiculatum* open woodland (8 681kg/ha) and *C.mopane* shrubland (4 939kg/ha)(Table 6). Kelly & Walker (1976) recorded total weights of mopane in southern Zimbabwe of between 20 832kg/ha to 3 701kg/ha at different sites. Rutherford (1979) obtained values of up to 13 002kg/ha in a *Colophospermum mopane* community in Zimbabwe. These figures compare well with VLNR estimations. However, Guy (1981) estimated biomass of mopane woodland in Zimbabwe (Sengwa Wildlife Research Area) at between 64.5t/ha and 60.6t/ha (trees) and 1.3t/ha to 0.6t/ha for shrubs. These are considerably higher than other subregion mopane figures, possibly due to differences between height and circumference, higher rainfall and different soils.

Charcoal weight:

The proportion of wood available for charcoal production, with a cut-off of 7-8cm circumference, varied from 3.9 ±1.25kg/tree for *C.mopane* shrubland to 6.5 ±0.73kg/tree for *C.mopane* woodland and 7.8 ±1.62kg/tree for *C.mopane/C.apiculatum* open woodland. *C.mopane* woodland at 14 787kg/ha had almost 4.5 times more wood available for charcoal production than *C.mopane* shrubland (3 237kg/ha) and 2.5 times more than *C.mopane/C.apiculatum* open woodland (5 634kg/ha), respectively. The percentage of wood with a charcoal potential, was virtually the same in all these vegetation types (62.5% vs 65.5% vs 65.1%).



r = 0.65
DF = 198
$p < 0.05$
$r^2 = 0.42$

Figure 23: Correlation between average tree age(yrs) and total weight per tree(kg).

There was no significant difference in potential charcoal weights available between the three vegetation types (Figure 20 & Appendix 4). Mean weight of 7.8kg/tree was highest for *C.mopane/C.apiculatum* open woodland followed by 6.5kg/tree for *C.mopane* woodland and 3.9kg/tree for *C.mopane* shrubland. Although last mentioned figure is much the lowest, values are highly variable (Figure 20).

The proportion of wood available for charcoal production does not differ greatly between vegetation types: 62.5% in *C.mopane* woodland, 65.6% in *C.mopane* shrubland and 65.1% in *C.mopane/C.apiculatum* open woodland (Table 6). The above-ground material not suitable for good quality charcoal production (browse & wood smaller than 7-8cm in circumference), constitutes only 37.5% to 34.9% of total biomass. In Kenya, charcoal producers prefer trees with a girth at basal height of more than 64cm and discard branches with a circumference less than 15cm, while in Zambia wood was discarded with a girth less than 11.6cm (Chidumayo, 1987).

Wood available for charcoal production per unit area differed considerably, from 14 787kg/ha for *C.mopane* woodland to 3 237kg/ha for *C.mopane* shrubland. Differences between the latter and *C.mopane/C.apiculatum* open woodland (5 634kg/ha) were not as great. Yields depend largely on tree density, which is highest in *C.mopane* woodland (See 6.2.1). All other correlations with total weight - height, circumference and age - also apply to charcoal weight.

The actual amount of charcoal produced, will depend on what technique is used (retort vs kiln) as well as the final carbon content decided on (See 8.2.3. & Appendix 2). Higher charcoal yields are possible at lower carbon contents (Gaylard charcoal retort results), and decisions as to what levels of carbon content is desirable, will depend on customer requirements. Potential charcoal yields at different harvesting levels are discussed in 8.3.

CHAPTER 7

CHAPTER 7: SOIL TYPES AND *C.MOPANE* DYNAMICS

7.1. Introduction

A soil reconnaissance for VLNR was done by the Agricultural Research Council Institute for Soil, Climate and Water (Botha, n.d.). A detailed description of soil types is given in Chapter 1. Dominant soils are the Oakleaf, Valsrivier, Dundee, Hutton and Swartland families. O'Connor (199?) found that mopane cover was highest on colluvial (55%) and calcrete (40%) substrate types for VLNR. Soil appears to play a significant role in determining growth rate and growth form of the different vegetation types. *C.mopane* woodland seems to favour Oakleaf, Dundee and Valsrivier soils, mixed open woodland the Hutton soils and *C.mopane* shrubland the Swartland and rocky soils. Associations between soil families and vegetation types are summarised in Table 7.

Table 7. Associations between soil families and vegetation types. Number of plots situated in each soil family is given in brackets.

		Vegetation types	
Soil types	**3**	**4**	**5**
OaB	X (87)		
VaA	X (11)	X (14)	
VaB	X (13)		
SwA		X (12)	
SwB	X (10)		
HuA			X (43)
HuB			X (1)
Du	X (5)		
S/R		X (4)	

* Oakleaf (OaB); Valsrivier (VaA & VaB); Swartland (SwA & SwB); Hutton (HuA & HuB); Dundee (Du) and Shallow/Rocky (S/R).

7.2. Results

7.2.1. Density

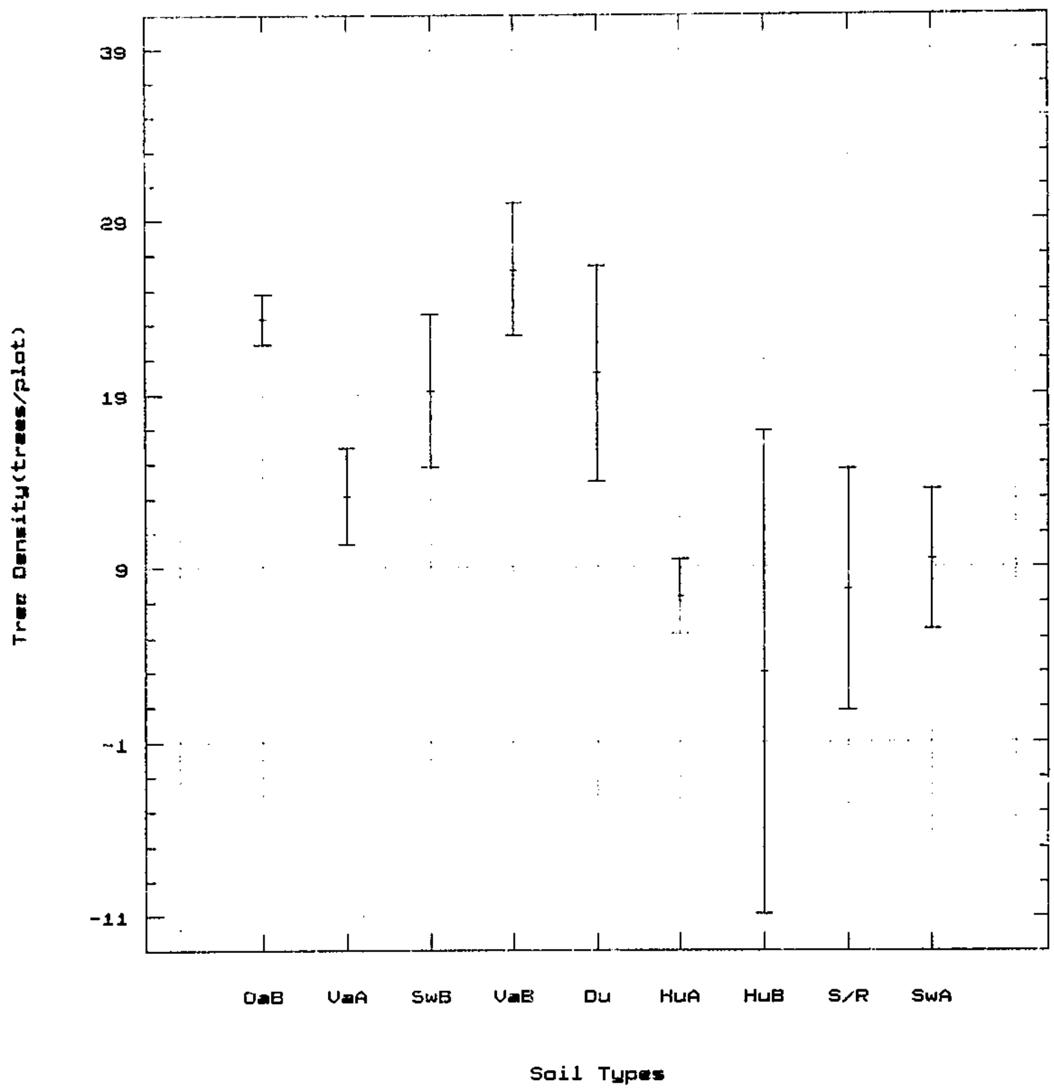
Mopane tree densities for different soil types are illustrated in Figure 24.

Highest tree densities are found on Oakleaf (OaB = 2 329 ±88trees/ha), Valsrivier (VaA = 1 312 ±174trees/ha & VaB = 2 615 ±160trees/ha), Dundee (Du = 2 020 ±215trees/ha) and Swartland (SwB = 1 920 ±272trees/ha) soils. These soils support *C.mopane* woodland, except the Valsrivier (VaA) family, where *C.mopane* shrubland is also present. Hutton (HuA = 737 ±44trees/ha & HuB) soils support mixed *C.mopane/C.apiculatum* open woodland. Swartland (SwA = 950 ±129trees/ha), Valsrivier (VaA) and S/R (shallow/rocky = 775 ±175trees/ha) soils, support *C.mopane* shrubland with lowest mopane densities.

Soil types OaB, SwB, VaB and Du with higher tree densities, were found exclusively in association with *C.mopane* woodland. Lower tree densities were found on soils (HuA and HuB), associated with *C.mopane/C.apiculatum* open woodland, as well as soils (SwA and S/R) associated with *C.mopane* shrubland. There were no significant difference in tree density for soils associated with two last mentioned vegetation types. Although VaA soils were found in association with both *C.mopane* woodland and *C.mopane* shrubland, lower densities occurred here than on other soils specifically associated with *C.mopane* woodland.

7.2.2. Height and circumference classes

Mean height and mean circumference values for the three mopane communities occurring on different soil types are illustrated in Figures 25 & 26.



Soil types:
OaB = Oakleaf
VaA/VaB = Valsrivier
SwA/SwB = Swartland
Du = Dundee
HuA/HuB = Hutton
S/R = Shallow & Rocky

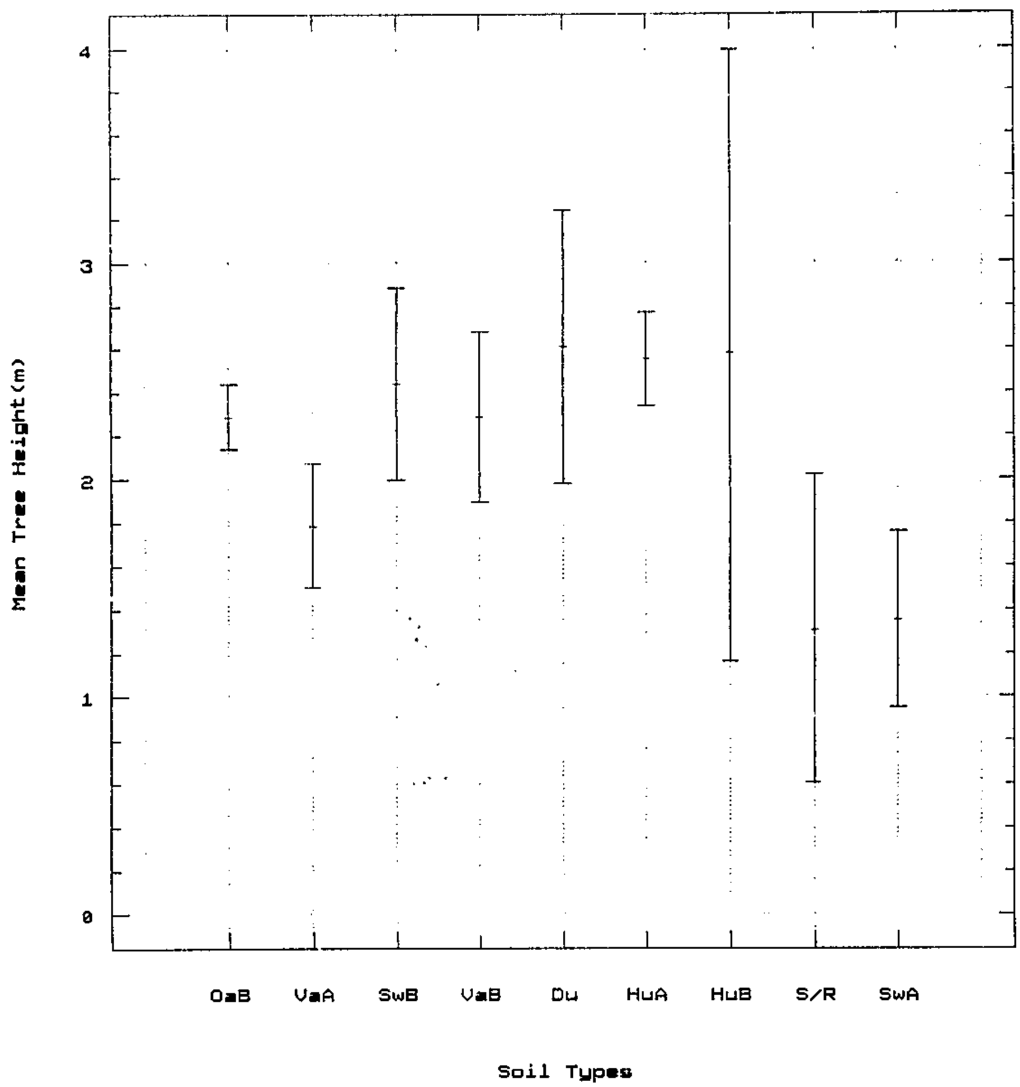
Figure 24: Mean tree density(trees/plot) per soil type.

Mean heights were greatest on Du (2.61 ±0.27m) and HuA (2.55 ±0.11m) soils. Soil types with the lowest mean heights (below 2m) are Swartland (SwA = 1.36 ±0.21m), Valsrivier (VaA = 1.79 ±0.14m) and shallow and rocky (S/R = 1.31 ±0.07m) soils. These soils were associated with *C.mopane* shrubland except VaA, which was also associated with *C.mopane* woodland.

Mean circumferences were greatest on Swartland (SwB = 19.63 ±2.45cm) and Hutton (HuA = 16.71 ±0.73cm) soils (Figure 16). The Huttons were found exclusively in association with *C.mopane/C.apiculatum* open woodland. S/R (12.17 ±1.03cm) soils had the lowest mean circumferences.

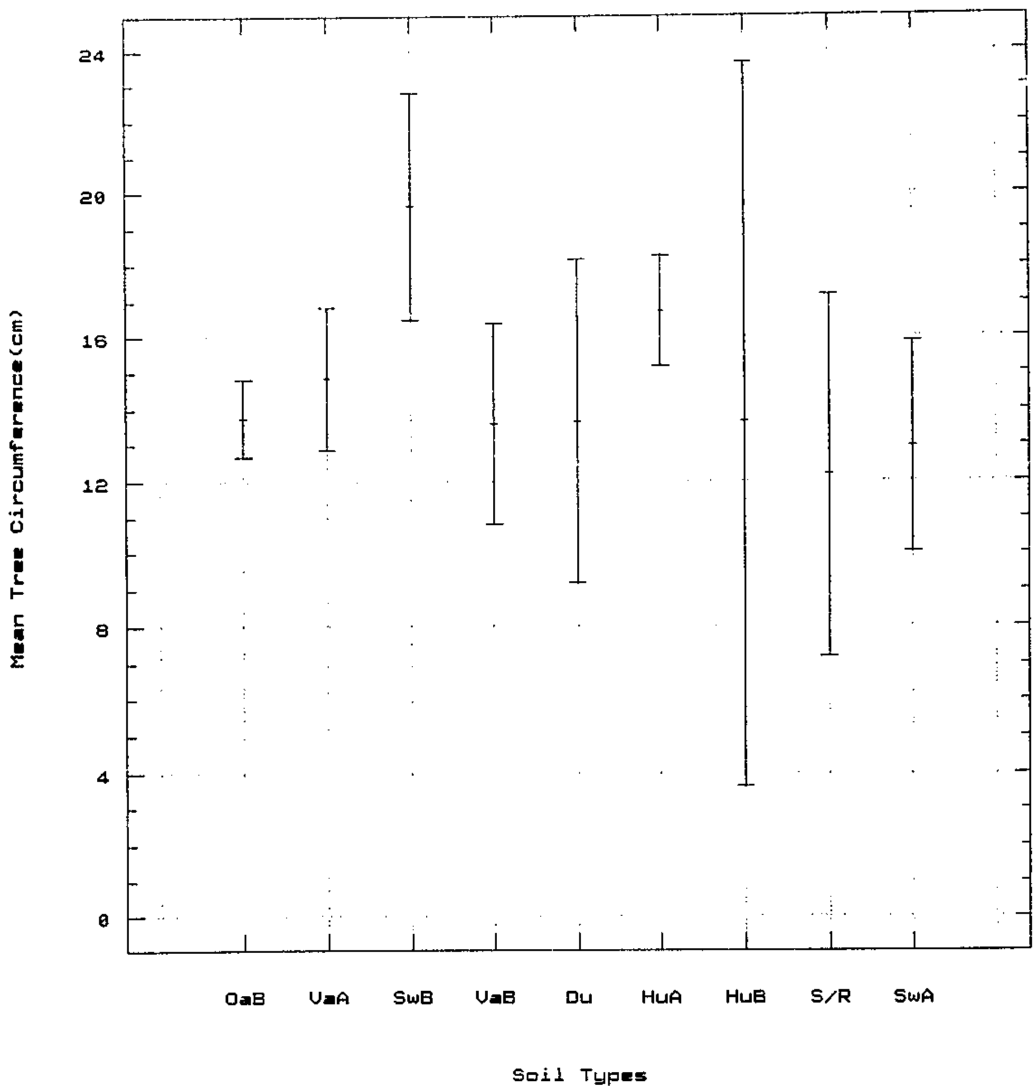
Height: There were significant differences in mean height between soil types VaA, SwA and S/R and the rest (Figure 25). These soil types had a mean tree height of below 2m and were found in association with *C.mopane* shrubland, thus indicating an association between soil type, vegetation type and height. Although VaA soils were also found in association with *C.mopane* woodland, mean heights differ from the rest. This can be attributed to the effect mean heights of *C.mopane* shrubland had on total mean heights for this specific soil type.

Circumference: There were no overall significant differences in circumference between soils associated with different vegetation types (Figure 26). Although there were significant differences in circumference between certain soils, they cannot be attributed to differences in vegetation type. Highest mean circumferences were on SwB soils, in association with *C.mopane* woodland and lowest on S/R soils, in association with *C.mopane* shrubland.



Soil types:
OaB = Oakleaf
VaA/VaB = Valsrivier
SwA/SwB = Swartland
Du = Dundee
HuA/HuB = Hutton
S/R = Shallow & Rocky

Figure 25: Mean tree height(m) per soil type.



Soil types:
OaB = Oakleaf
VaA/VaB = Valsrivier
SwA/SwB = Swartland
Du = Dundee
HuA/HuB = Hutton
S/R = Shallow & Rocky

Figure 26: Mean tree circumference(cm) per soil type.

7.2.3. Senility

Figure 27 illustrates average senility (number of trees dead per plot) for different soil types.

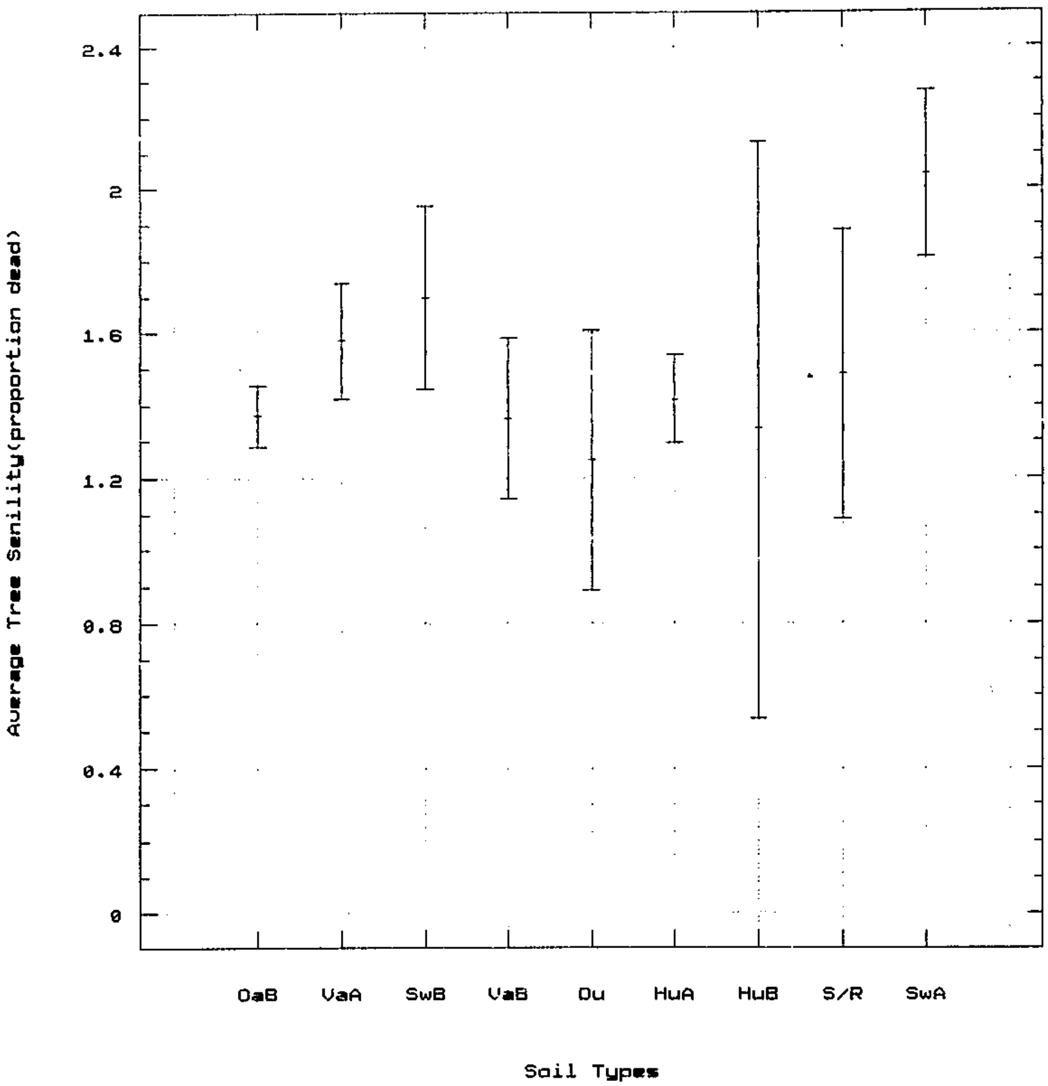
Highest average senility proportion per plot occurred on Swartland (SwA & SwB) and Valsrivier (VaA) soils with averages of 2.25 ±0.17, 1.70 ±0.13 and 1.58 ±0.10 dead trees per plot, respectively. SwA soils were found exclusively in association with *C.mopane* shrubland, while the majority of VaA soils were also associated with this vegetation type (Table 7).

There were significant differences in senility proportion between SwA soils and the rest as well as between SwB soils and most other soils found in association with *C.mopane* woodland (Figure 27). Swartland (SwA) soils were found in association with *C.mopane* shrubland and have shallow topsoils over dense clay. This dense subsoil clay factor seems to be positively linked to higher senility proportion of trees. SwB (calcrete origin), OaA (red, well drained), VaA (better soils under clay than SwA), VaB (lime soils-sweetveld soils), Du (deep/sandy/young stratified alluvium) and HuA (well drained/deep/red/sandy) were better types of soils (Ellis, *pers.comm.*), with lower senility proportions. They were also associated with *C.mopane* woodland and *C.mopane/C.apiculatum* open woodland. There were no significant differences in senility proportion between the majority of other soils.

7.2.4. Age and growth rate

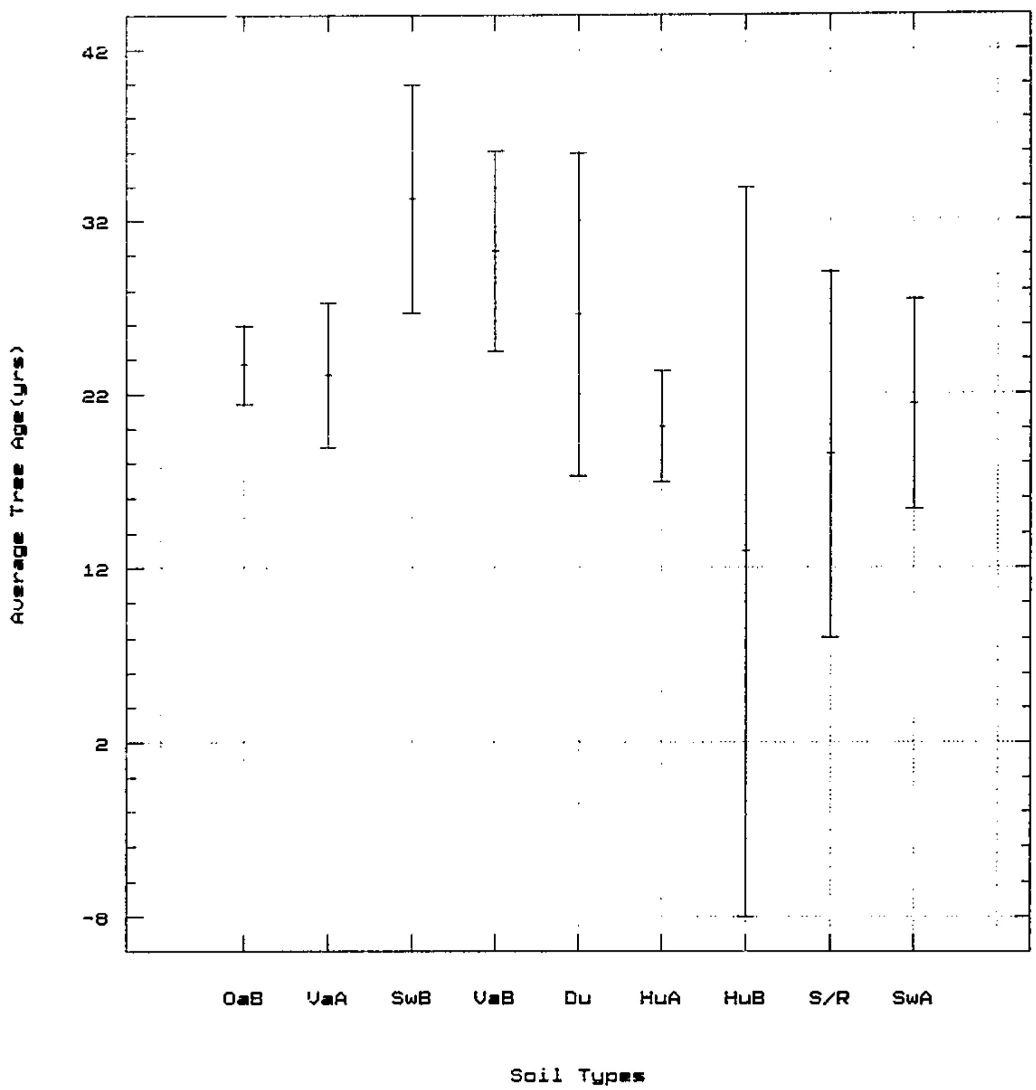
Average age and mean annual growth rate for different soils are illustrated in Figures 28 & 29.

Oldest trees on average were found in *C.mopane* woodland on Swartland (SwB), Valsrivier (VaB) and Dundee (Du) soils, with ages of 33 ±4yrs, 30 ±5yrs and 27 ±3yrs, respectively.



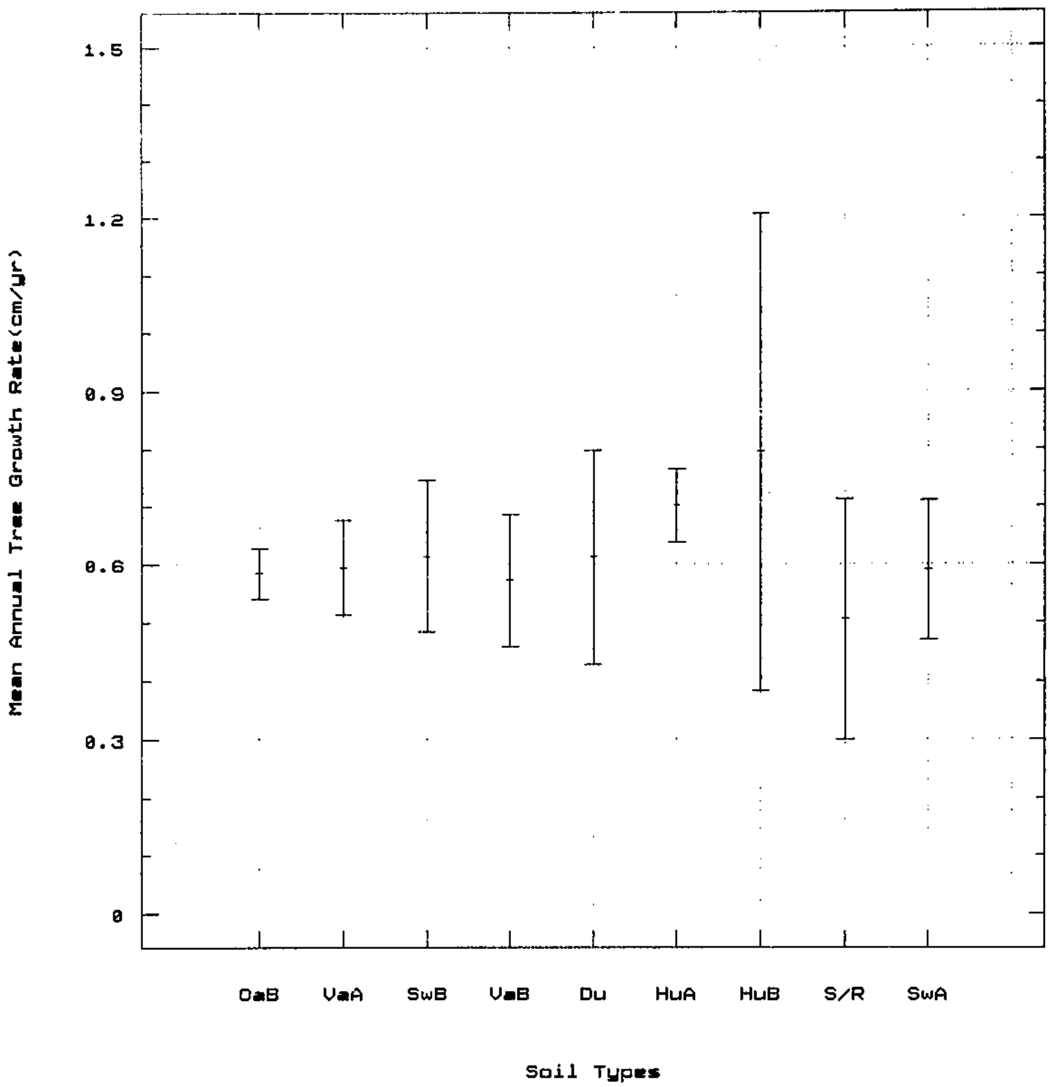
Soil types:
OaB = Oakleaf
VaA/VaB = Valsrivier
SwA/SwB = Swartland
Du = Dundee
HuA/HuB = Hutton
S/R = Shallow & Rocky

Figure 27: Average tree senility(proportion of trees dead) per soil type.



Soil types:
OaB = Oakleaf
VaA/VaB = Valsrivier
SwA/SwB = Swartland
Du = Dundee
HuA/HuB = Hutton
S/R = Shallow & Rocky

Figure 28: Average tree age(yrs) per soil type.



Soil types:
OaB = Oakleaf
VaA/VaB = Valsrivier
SwA/SwB = Swartland
Du = Dundee
HuA/HuB = Hutton
S/R = Shallow & Rocky

Figure 29: Mean annual tree growth rate(cm/yr) per soil type.

Shallow/Rocky (S/R) soils in *C.mopane* shrubland, had the lowest average tree age of 19 ±4yrs while Hutton (HuA) soils in *C.mopane/C.apiculatum* open woodland also had a low average age of 20 ±1yr per tree. The average age per tree for all soils is 24 ±1yr.

Hutton (HuA) soils had the fastest annual tree growth rate of 0.70 ±0.03cm/yr while those trees associated with shallow/rocky (S/R) and Valsrivier (VaB) soils, had the slowest growth rates of 0.51 ±0.11cm/yr and 0.57 ±0.06cm/yr, respectively (Figure 29).

Age: There was a significant difference in tree age between SwB and VaB soils associated with *C.mopane* woodland, and those of HuA, S/R and SwA soils associated with the other two vegetation types. There was no significant difference between average ages of trees on Hutton (HuA & HuB) soils (which support *C.mopane/C.apiculatum* open woodland), and those of Swartland (SwA = 21 ±3yrs) and shallow/rocky (S/R) soils (which support *C.mopane* shrubland).

Growth rate: The only significant difference in mean annual growth rate between soil types, was between mopane growing on Hutton (HuA = 0.70 ±0.03cm/yr) and Oakleaf (OaB = 0.59 ±0.02) and Valsrivier (VaA = 0.60 ±0.05cm/yr) soils (Figure 29). No significant differences in annual growth rate were found between mopane growing on any of the other soil types. HuA soils with the fastest annual growth rate, occur in *C.mopane/C.apiculatum* open woodland. This indicates an association between soil type, vegetation type and growth rate of mopane.

7.2.5. Biomass

Mean total weight/tree and charcoal weight/tree for each soil type are illustrated in Figures 30 & 31.

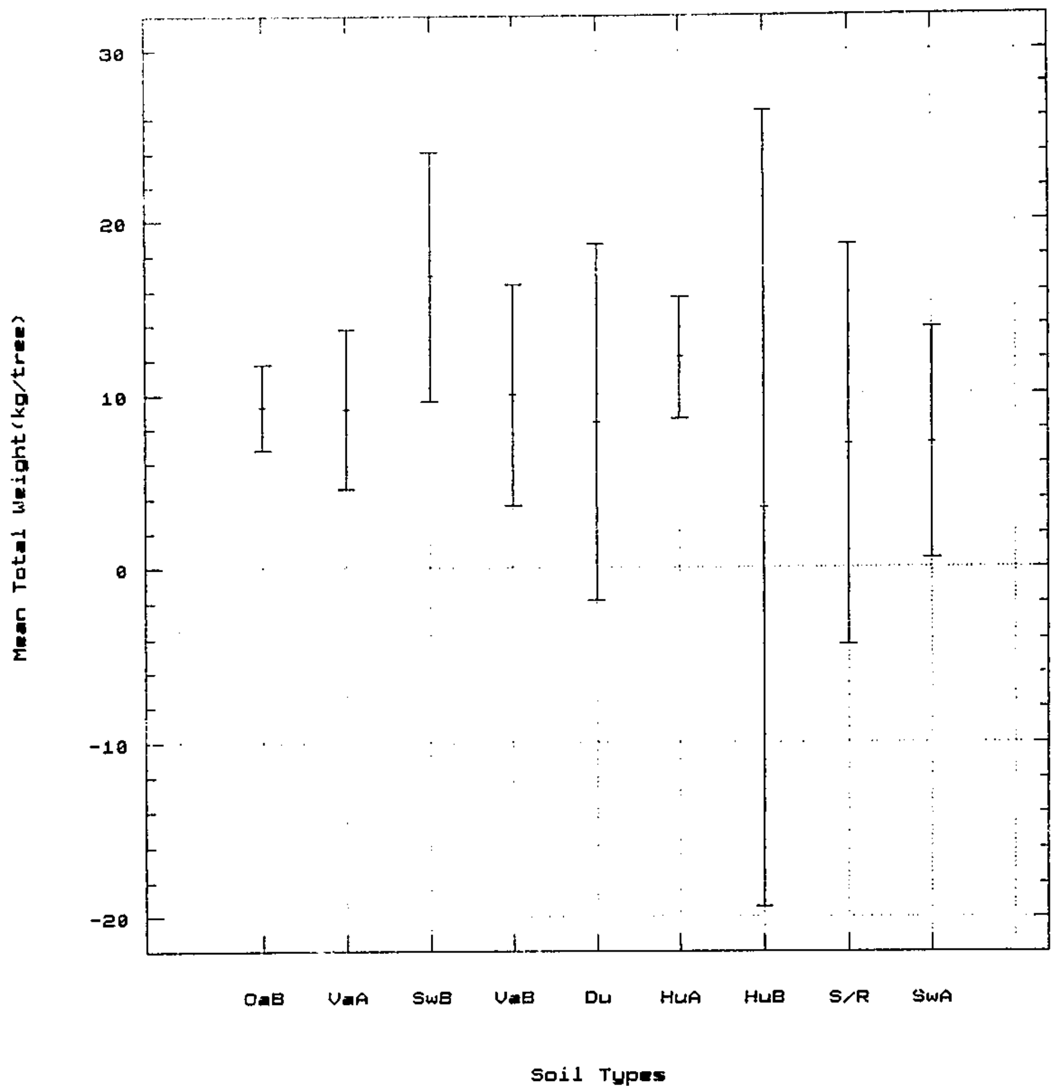
Soil types with highest mean total weights per tree were Swartland (SwB)(16.80 ±4.75kg), Hutton (HuA)(12.09 ±2.28kg) and Valsrivier (VaB)(10.00 ±2.74kg)(Figure 30). SwB and VaB soils support *C.mopane* woodland, while Huttons support *C.mopane/C.apiculatum* open woodland. Only 10 of 126 plots were on Swartland (SwB) soils, compared to 43 of 44 plots on Hutton (HuA) soils (Table 7). Soils with lowest mean total weights per tree were shallow/rocky (S/R)(7.00 ±6.18kg) and Swartland (SwA) (7.00 ±2.45kg).

Since there is a very strong positive correlation between total weight and available charcoal weight per tree (Figure 32), soils with highest mean total weights per tree also had highest mean charcoal weights. Highest charcoal weights were found on Swartland (SwB)(13.00 ±4.32kg) soils followed by Hutton (7.90 ±1.66kg) and Valsrivier (6.77 ±2.13kg)(Figure 31). Lowest values were found on Shallow/rocky (S/R) and Swartland (SwA) soils, with 3.50 ±3.34kg and 5.08 ±2.28kg, respectively.

Total Weight: Although SwB, HuA and VaB soils supported trees with the highest mean total weights, there were no significant differences in mean total weights per tree and different soil types (Figure 30). As SwB soils support trees with greatest mean circumferences (See 7.2.2) and HuA soils supported trees with the second greatest mean heights (See 7.2.2), it was expected of them to produce high mean weights per tree. Mopane associated specifically with these soil types could result in trees with a harvesting potential.

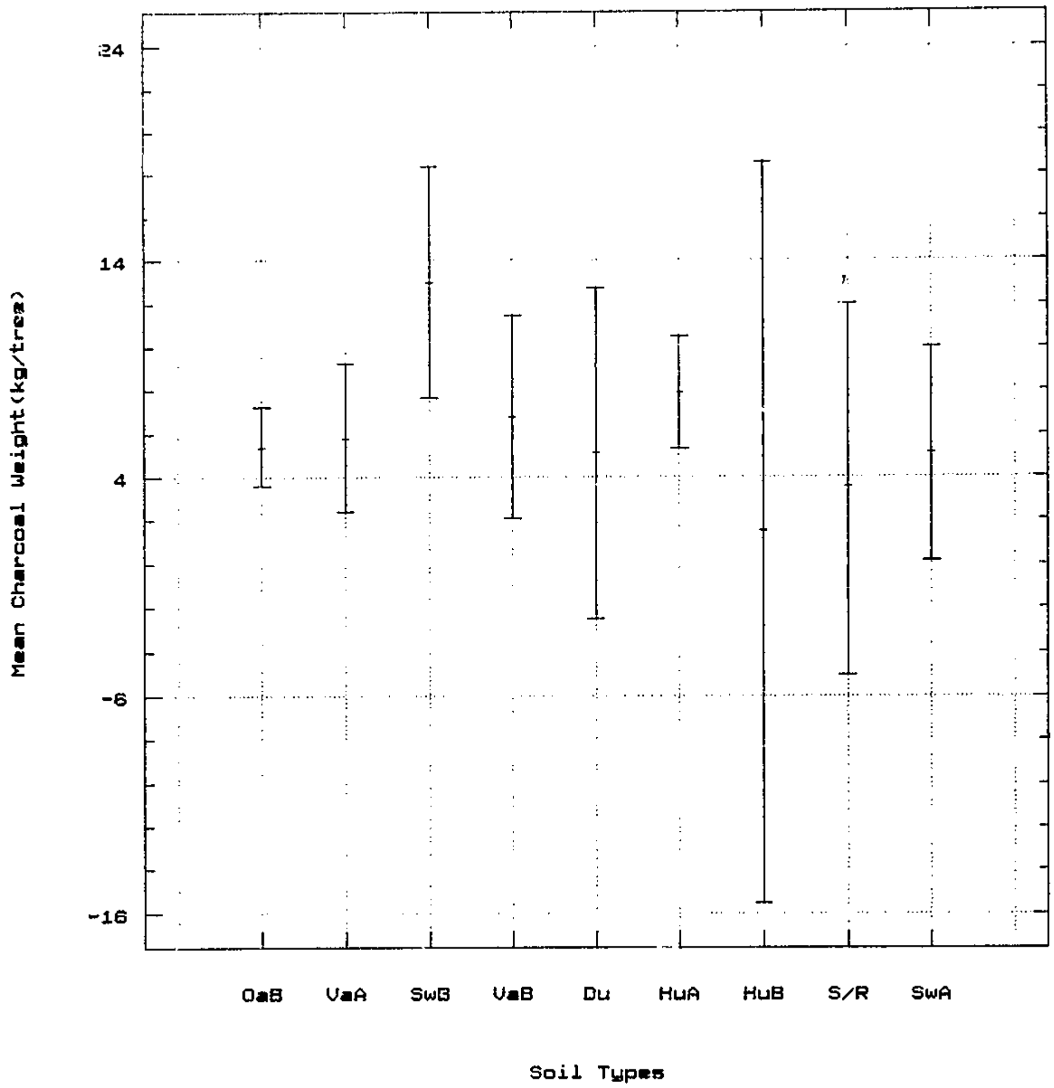
Charcoal Weight: Significant differences in mean charcoal weight per tree, occured between SwB (13.00 ±4.32kg) soils and OaB (5.37 ±0.73kg), VaA (5.80 ±1.82kg) and SwA (5.08 ±2.28kg)

(Figure 31). No significant differences in mean charcoal weights occured between any other soils. SwB soils were associated with *C.mopane* woodland, while SwA was associated exclusively with shrubland and VaA predominantly with shrubland (See Table 7). Mopane associated with SwB soils should result in high charcoal yields and be important from a harvesting point of view.



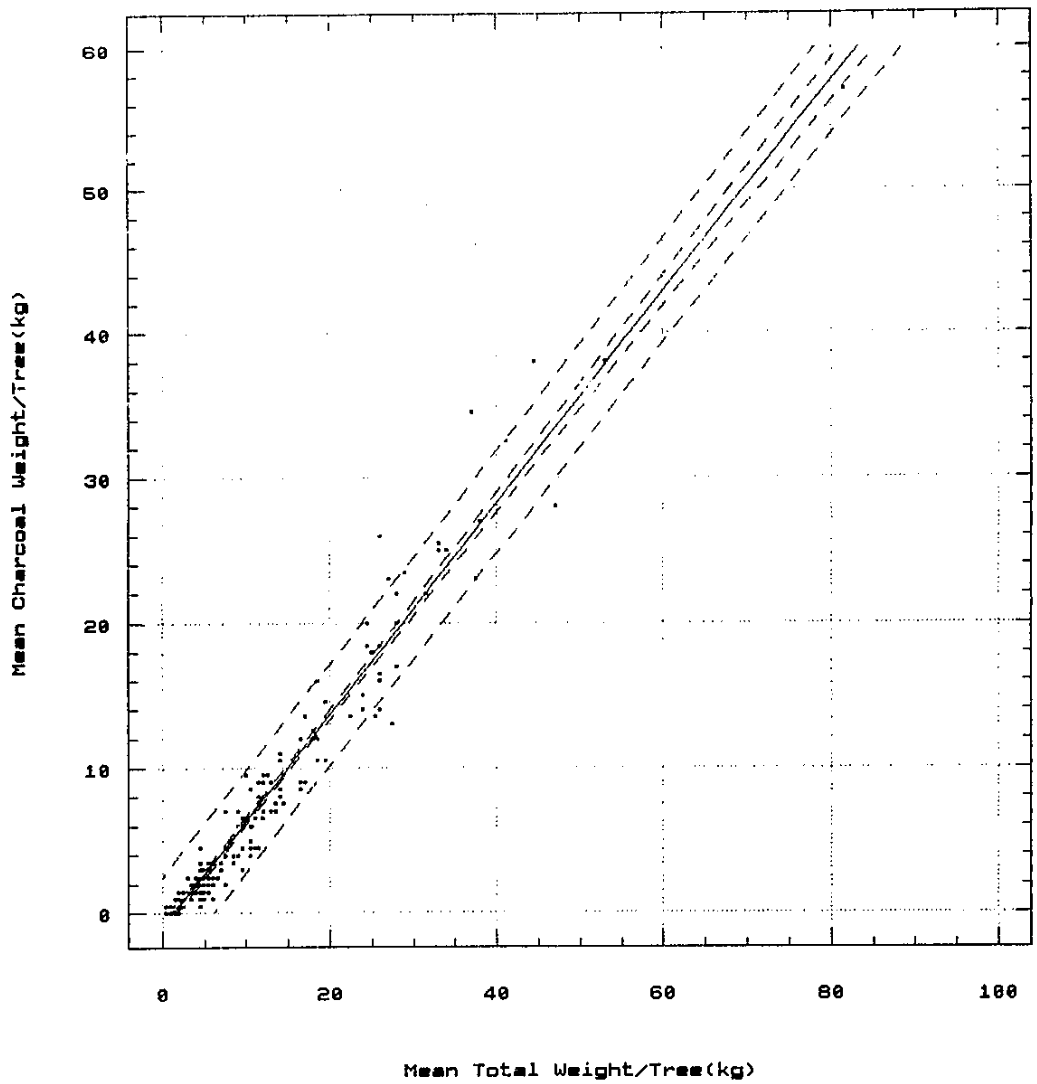
Soil types:
OaB = Oakleaf
VaA/VaB = Valsrivier
SwA/SwB = Swartland
Du = Dundee
HuA/HuB = Hutton
S/R = Shallow & Rocky

Figure 30: Mean total weight per tree per soil type.



Soil types:
OaB = Oakleaf
VaA/VaB = Valsrivier
SwA/SwB = Swartland
Du = Dundee
HuA/HuB = Hutton
S/R = Shallow & Rocky

Figure 31: Mean charcoal weight per tree per soil type.



r = 0.98
DF = 198
$p < 0.05$
$r^2 = 0.95$

Figure 32: Correlation between mean total weight/tree and mean charcoal weight/tree.

CHAPTER 8

CHAPTER 8: HARVESTING STRATEGY

8.1. Introduction

The fact that mopane makes a good firewood as well as charcoal and has become so dense that it dominates most vegetation types where it occurs, on VLNR (See Chapter 4), makes it a prime candidate for utilization. Mopane has achieved harvestable proportions on VLNR due to a number of natural and human-induced factors. Low rainfall and high temperatures (drought conditions) favour the survival of mopane over grass and other tree species due to the hardiness of mopane (Obermeijer, 1933; Palmer & Pitman, 1961; Von Breitenbach, 1965; De Winter *et al.*, 1966; Ayensu *et al.*, 1980). Incorrect farming practices such as using only grazers and not browsers as well as incorrect veld management have led to vast areas being overgrazed. Lack of competition from grass, which favours mopane growth, in time led to the formation of very dense stands, enhanced by mopane's ability to coppice vigorously.

Potential consequences of harvesting are severe and it should not be implemented without careful ecological, aesthetic and economic consideration. Harvesting objectives should be consistent with overall management objectives for VLNR. The prime ecological objectives are to reduce bush density and to utilize mopane on a sustainable basis. The economic objective is to do so while achieving economic viability. Aesthetic objectives are to improve visibility for game viewing and hunting.

Population dynamics of mopane on VLNR have been discussed in Chapters 6 & 7 and now questions such as where to harvest, what portion to harvest, when to harvest and what harvesting methods to implement, will be dealt with. Results of a preliminary harvesting model are discussed in section 10.2.

8.2. Harvesting model

8.2.1. Description of model

A preliminary harvesting model was developed using a Quattro Pro spreadsheet and optimizer functions. Results are presented in Appendix 3.

Circumference data (independent variables) for all stems in *C.mopane* woodland (126 plots), were placed into 1cm classes from 3cm-30cm (as most stems occur in this circumference range), and into 2cm classes from 30cm-72cm. The number of stems in each class was calculated and entered into the model.

A 5 year harvesting interval was implemented up to 60 years. The dependant variables: initial population (Popinit), trees to be harvested (Harvest), trees remaining after harvesting (Post Harvest), yield (Yield) and promotion proportion (Promotion) were calculated for all circumference classes (See Appendix 3, p:1/11). Trees harvested and yields are only applicable to stems with a circumference >13cm, a strategy to ensure good size and quality charcoal.

Average growth rate for *C.mopane* woodland of 0.59cm/yr (See 6.4.) was used to determine promotion between circumference classes. Regression of circumference on total weight was used to determine the volume parameter (0.01897). After all relevant data was entered into the harvesting model, total population (Totpop), population above 13cm circumference (Oldpop), old population harvested (Oldpop Harvest) and harvestable yield (Harvest Yield) were determined at 5 year intervals (See Appendix 3, p:9/10/19/20). The optimizer facility of Quatro Pro was used to determine best harvesting rate over time (60yrs). The assumptions made for the model were: - Populations of harvestable stems (circumferences) would decrease over time.

- Harvestable yields would decrease over time.
- Promotion from one circumference class to another would increase initially due to initial promotions and then decrease with time.

8.2.2. Results

An optimum harvesting rate of 27% (0.2686) every 5 years would ensure best harvestable yields for up to 60 years. Other advantages of harvesting 25-50% of mopane are discussed below (See 8.4, 9.2 & 9.3).

The total population of 11 069stems, was left constant for the duration of the model. An old population (>13cm circ.) of 4 248 stems initially, decreased to 1 657 stems after 60yrs.

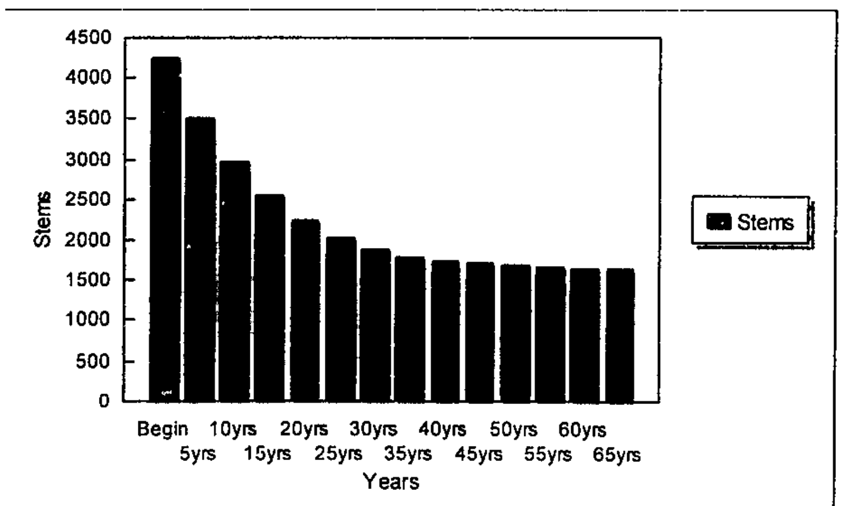


Figure 33: The decrease of old population stems (>13cm) over time (5yr intervals).

At a harvesting rate of 27%, 1 141stems (Oldpop) could be harvested initially. The harvest decreased to 444 stems after 60yrs (Figure 34 & Appendix 3).

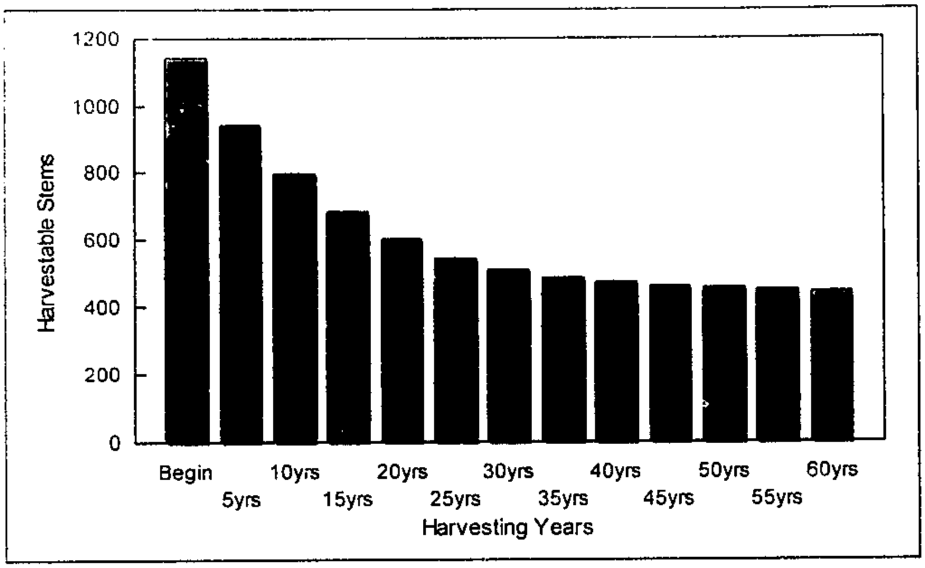


Figure 34: The decrease of harvestable stems over time.

Initial total harvestable yield is ±8 000kg/ha. This slowly declines to ±1 500kg/ha after 60yrs for the same hectare (Figure 35 & Appendix 3).

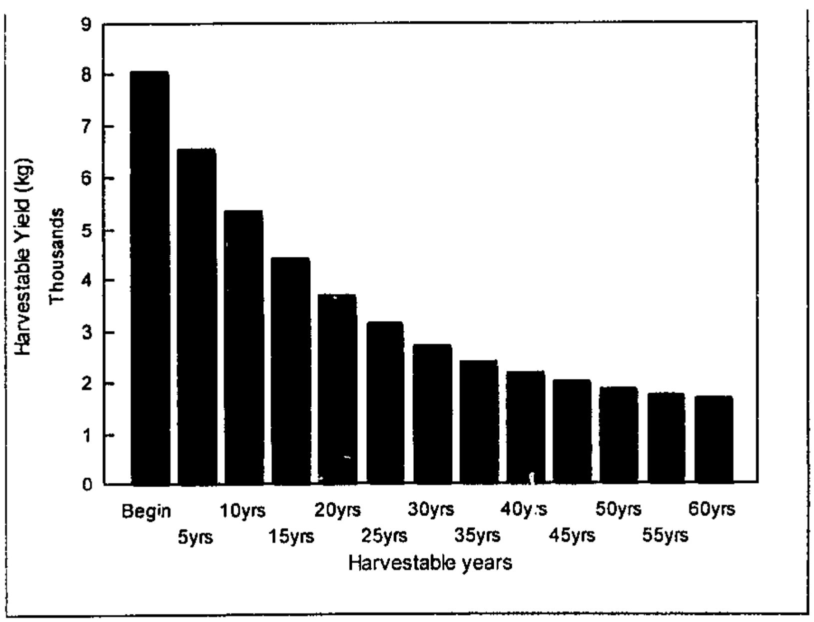


Figure 35: Decrease of potential total harvestable yield (kg) over time.

Total yield after 60yrs is ±45 000kg/ha or ±37 000kg/ha if the first year's harvest is excluded. An alternative harvesting model with a harvesting rate of 19% would have initial yields of ±6 000kg/ha, decreasing to ±2 000kg/ha after 60 years. Total yield after 60 years is also ±45 000kg/ha, but 39 000kg/ha if the first year's harvest is excluded. This model results in slightly higher yields over time.

8.2.3. Discussion

A harvesting strategy of 25% should be implemented to ensure best sustainable yields on a 5 year rotation. This would mean harvesting every fourth tree with a circumference >13cm every 5 years on a specific hectare.

C.mopane woodland has a charcoal potential of 62.5% (6.2.5.) and a total mean charcoal weight of ±14 500kg/ha (10.4), calculated using a minimum circumference of 7-8cm as utilisable. A mean charcoal weight of ±3 500kg/ha is obtainable at a harvesting rate of 25% (8.4). A minimum circumference of 13cm was used for the harvesting model. Total harvestable yield of ±8 000kg/ha would have an initial charcoal potential of ±5 000kg/ha and at a harvesting rate of 25%, would yield ±1 200kg/ha. Because a minimum circumference of 13cm was used for the model, it has lower yields than the mean charcoal weight of ±3 500kg/ha as calculated in 8.4. After 60 years the charcoal potential would be ±900kg/ha.

The charcoal making procedure used (retort vs kiln), would determine the absolute charcoal yields obtainable per hectare as well as the economic feasibility of harvesting mopane.

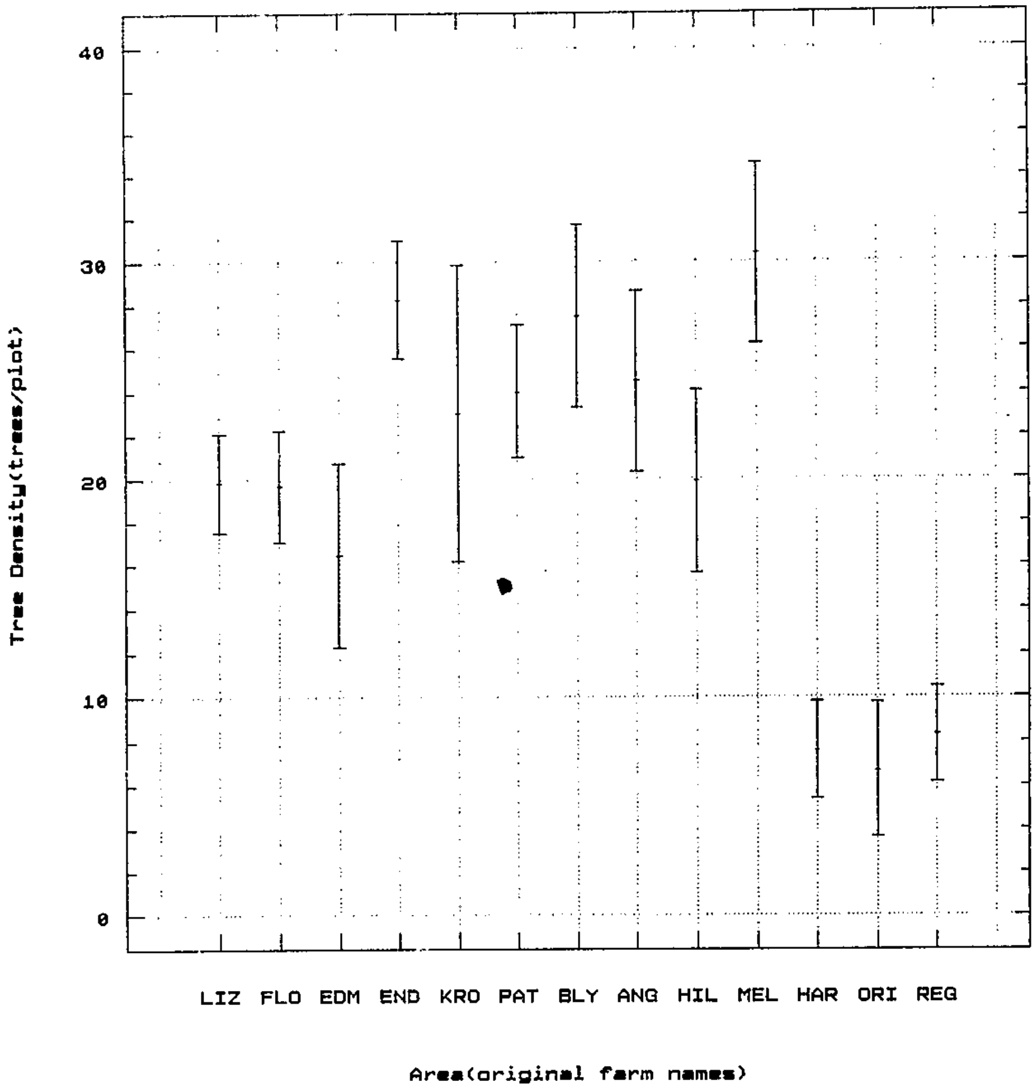
According to a Gaylard & Associates report on the Gaylard charcoal retort (Appendix 2), wood with an initial moisture content of 20% and a final carbon content of 80%, would yield approximately 30% charcoal by mass. Higher yields are possible at lower carbon contents. This suggests that wood with a charcoal potential of between ±1 200kg/ha and 3 500kg/ha (8.4 & harvest model results) would yield between ±350-1 000kg/ha charcoal at 30% of raw material. At the current price of approximately R2/kg for charcoal, it would mean that economic yields of between R700-R2 000/ha could be obtained. More research is however needed to determine economic yields of harvesting mopane for charcoal purposes.

8.3. Where to harvest?

Harvesting should commence in *C.mopane* woodland as this area poses the biggest problem as a result of the density of the bush. Economic viability of harvesting mopane would also be ensured as the highest potential harvestable yield occurs in this area (See 6.3.5.). Other advantages would be the fact that harvesting would open up the area, which would be beneficial for grazing species and game bird populations. It would also be better from a game viewing and hunting point of view due to better visibility.

Areas (previous farm names used) with the highest mopane densities are illustrated in Figure 36. Melisande, Endora and Blyklip with average densities of 3 038, 2 826 and 2 750 trees/ha are most densely populated. However it is not necessarily so that areas with highest mopane densities provide most wood available for charcoal (See Table 8). Dense stands tend to be dominated by shrubby growth forms with lower available total and charcoal weights per hectare.

It is important to know which areas have highest potential for charcoal production in order to implement an effective harvesting strategy. Farms with the highest mean charcoal weights per tree were Hilda (9.00 ±2.87kg), Edmonsburg (8.94 ±2.82kg), Lizulea (8.64 ±2.00kg) and Endora (7.63 ±2.20kg)(Figure 37). Highest mean charcoal weights were found



Areas: Original farm names used
See Chapter 5 & Table 1.

Figure 36: Mean tree density(trees/plot) per area.

on Endora (21 562kg/ha), Hilda (17 892kg/ha) and Lizulea (17 124kg/ha)(Table 8).

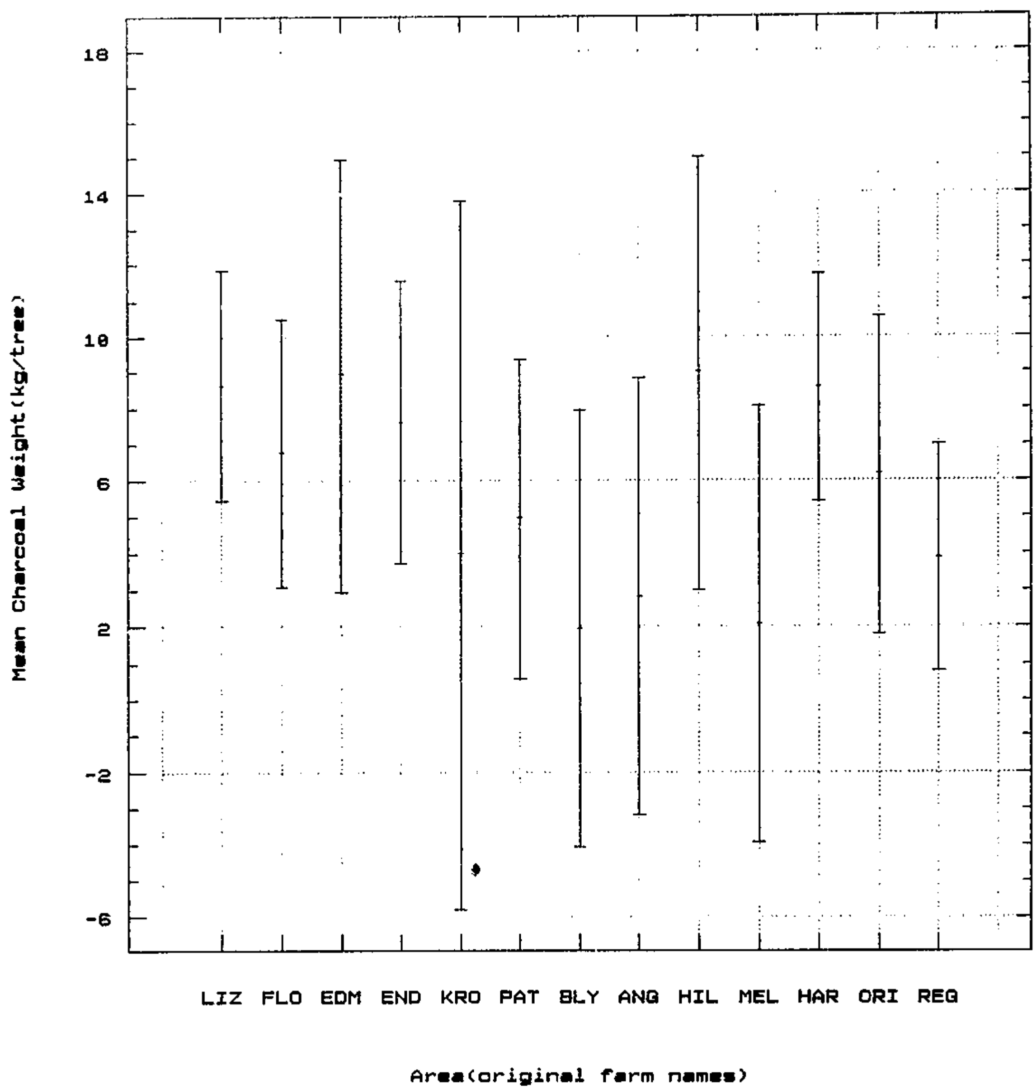
Table 8. Potential mean charcoal weights (kg/ha) and mean annual growth rates (cm/yr) for different areas in the *C.mopane* woodland. Weights given are in kg/tree or kg/ha and are total available charcoal weights.

Area	Plots	Density Trees/ha	Mean weight/tree & SD*	Mean weight/ha	Growth rate (cm/yr) & SD*
Liz	28	1 982	8.64 ±2.00	17 125	0.60 ±0.04
Flo	21	1 967	6.79 ±1.66	13 356	0.65 ±0.04
Edm	8	1 650	8.94 ±2.82	14 751	0.60 ±0.05
End	19	2 826	7.63 ±2.20	21 562	0.59 ±0.05
Kro	3	2 300	4.00 ±2.84	9 200	0.59 ±0.12
Pat	15	2 400	4.97 ±1.66	11 832	0.58 ±0.04
Bly	8	2 750	1.94 ±0.86	5 335	0.51 ±0.04
Ang	8	2 450	2.81 ±1.46	6 885	0.69 ±0.10
Hil	8	1 988	9.00 ±2.87	17 892	0.59 ±0.04
Mel	8	3 038	2.06 ±0.93	6 258	0.42 ±0.05

*SD= Standard deviation at 95% Confidence Interval.

Endora, Hilda, Lizulea, Edmonsburg, Flora and Patricia, all have a potential mean charcoal weight (at 100% harvesting) of over 10 tons/ha. It is suggested that harvesting should take place in these areas, rather than those with low mean charcoal weights per tree and hectare: Blyklip (1.94 ±0.86), Melisande (2.06 ±0.93) and Anglican (2.81 ±1.45).

Clear cutting should be avoided as it is unsightly and could cause ecological problems such as erosion and habitat destruction. Soil degradation, rainfall infiltration and grass quality would also be affected (Smit & Swart, 1991), with an increase in size of the harvested area. Rate of regeneration and economical viability would be in the balance



Areas: Original farm names used
See Chapter 5 & Table 1.

Figure 37: Mean charcoal weight per tree per area.

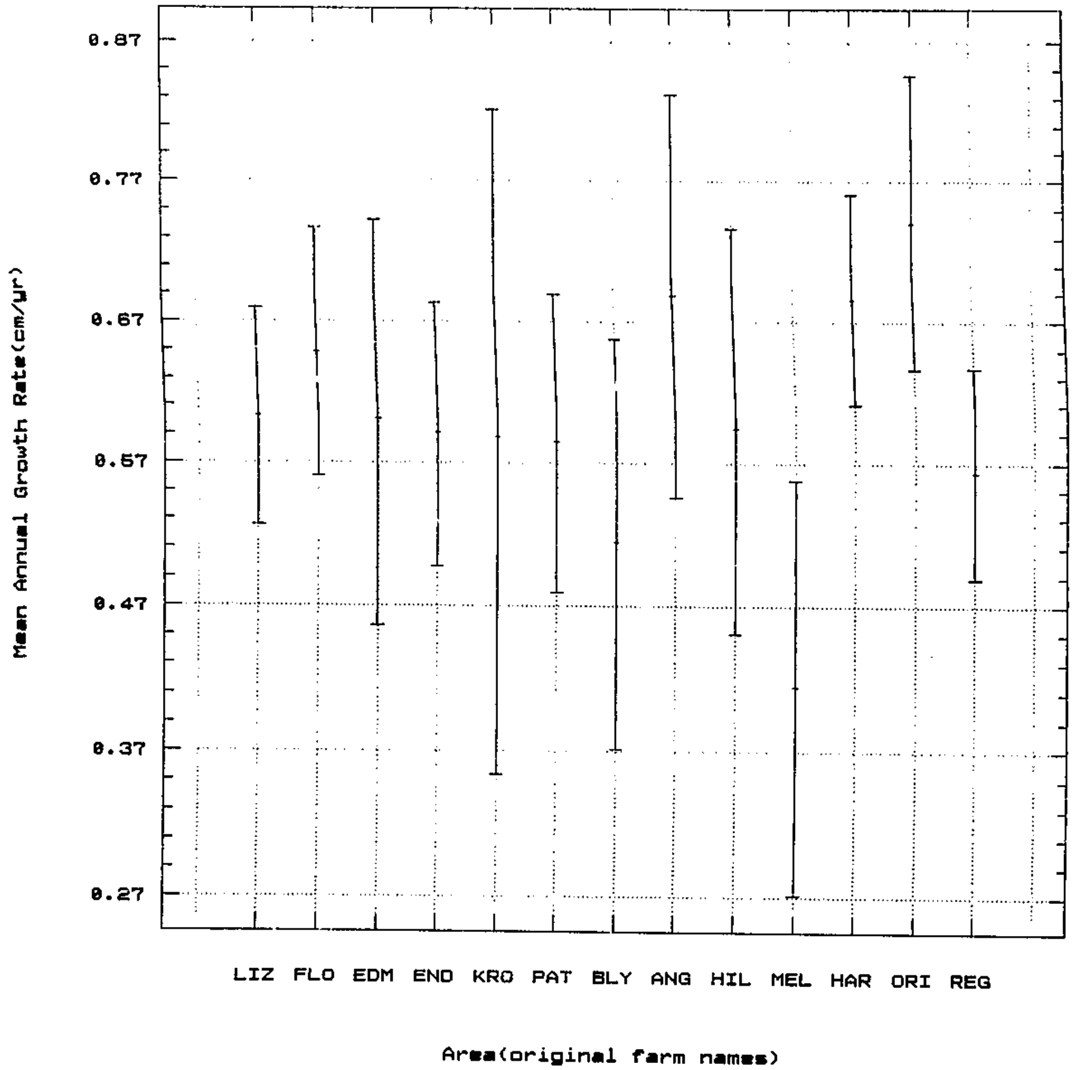
if grassland were to replace the existing woodland.

Annual mean growth rates do not differ much between the different farm areas (Figure 38). The only area with a significantly slower growth rate than the rest, is Melisande with 0.42 ±0.05cm/yr)(Table 8 & Figure 38). The reason is not known, but high tree density could be a contributing factor.

Areas with the highest insect presence were Flora and Endora (Figure 39), while there was no significant difference in insect presence between other areas of *C.mopane* woodland.

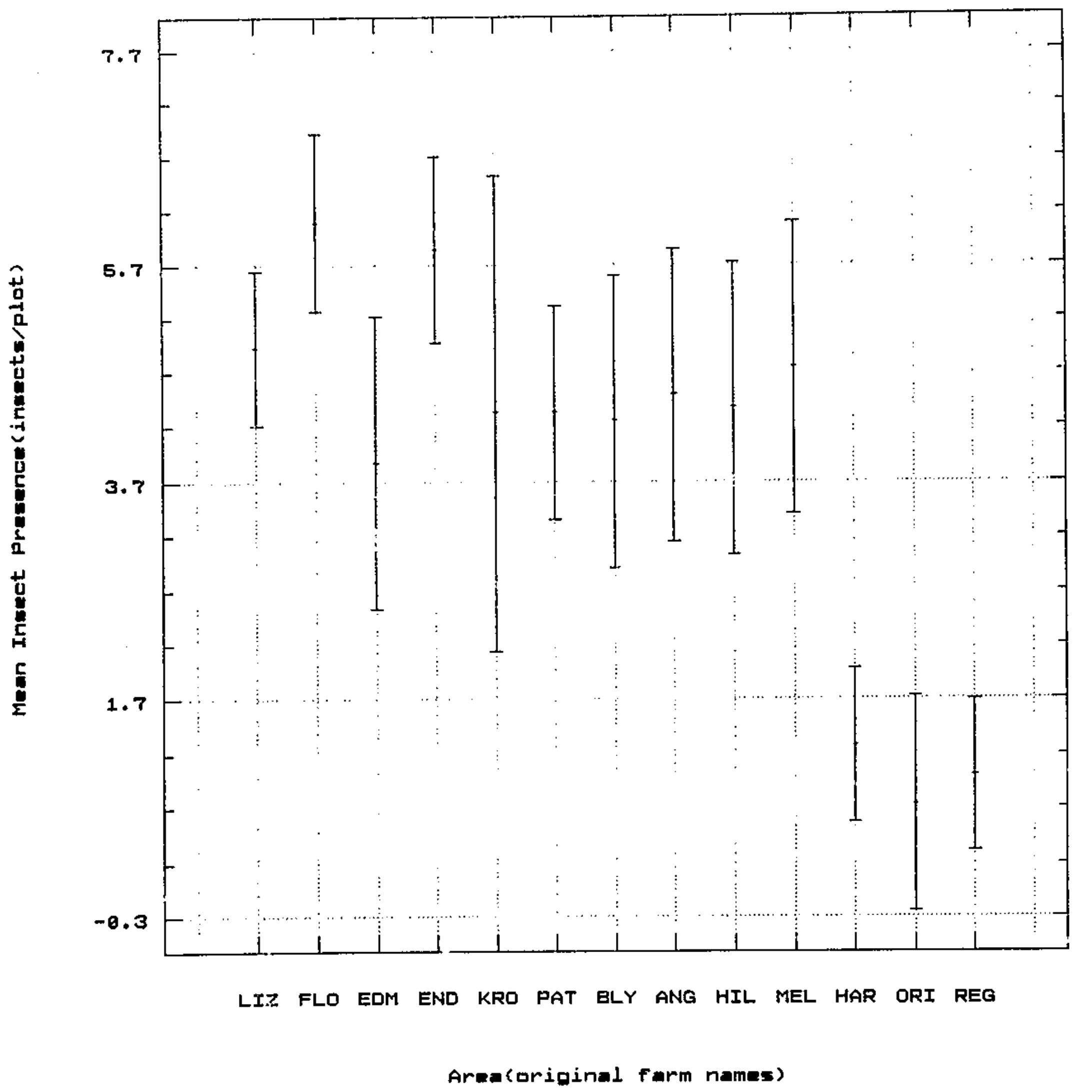
The presence of browse damage (browse damaged trees compared to total) was also significantly higher on Melisande (Figure 40). This could be due to the close proximity of water (Melisande dam) as well as the fact that mean height and circumference was lowest for this area. Elephants prefer smaller mopane as browse (Garai, *pers.comm.*). There is not much difference in browse damage between other areas in this vegetation type (Figure 40). Another reason for elephants frequenting the Melisande and adjacent areas, could be to avoid contact with humans by sheltering in dense mopane stands (Table 8). It must be taken into consideration that the elephants are Kruger National Park orphans as well as recently introduced family units. The effect of human disturbance is not known.

Harvesting should be limited or avoided on Melisande, Anglican and Blyklip where yields are too low (Table 8). Other areas that should also be avoided are those with sodic or duplex soils (sandy loam topsoil with a dense clay subsoil), very sandy sites and areas with a high erosion risk. Marginal sites include alluvium fringes of rivers and clay and loam soils (Scholes, 1988). There are many factors that have to be



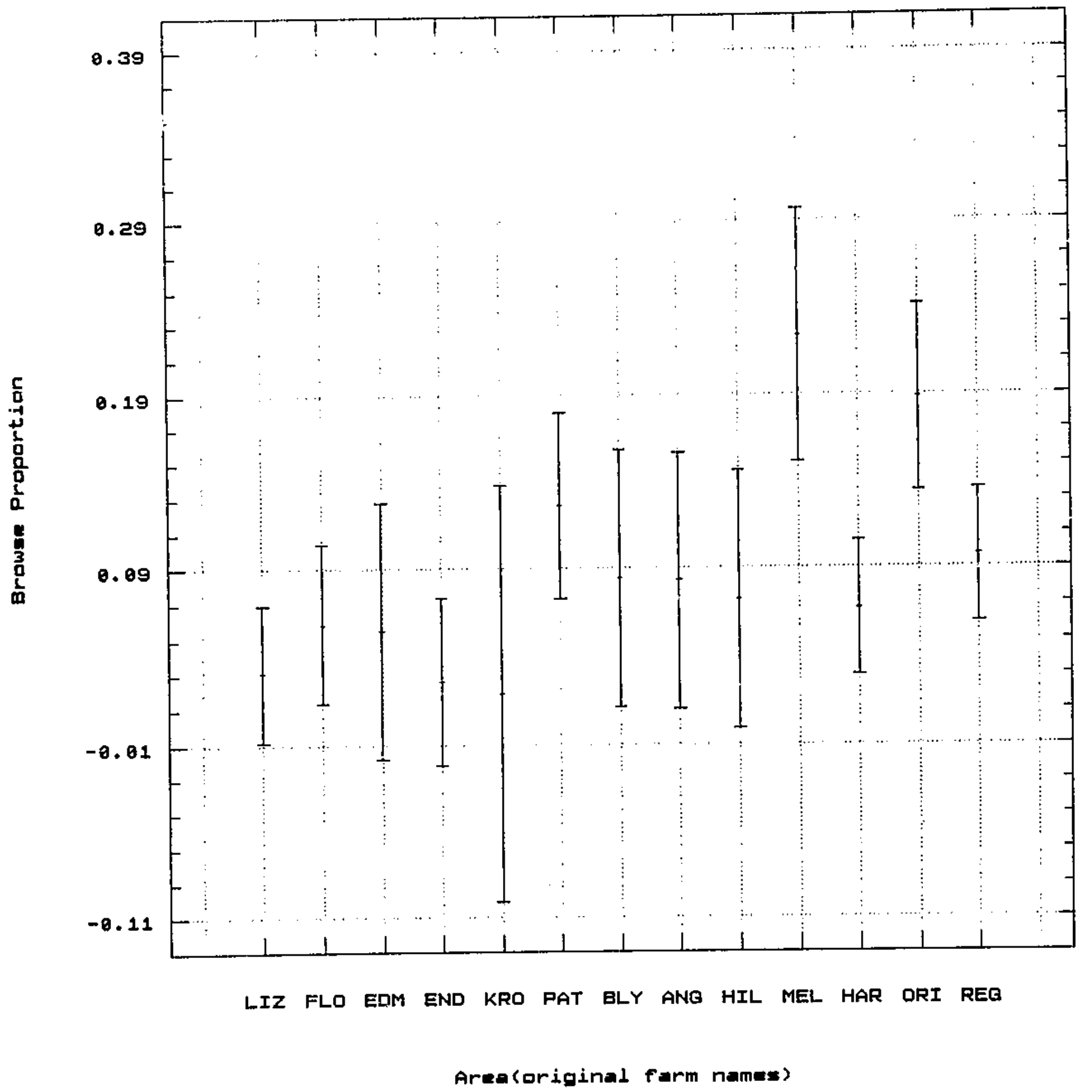
Areas: Original farm names used
See Chapter 5 & Table 1.

Figure 38: Mean annual tree growth rate(cm/yr) per area.



Areas: **Original farm names used**
See Chapter 5 & Table 1.

Figure 39: Mean insect presence(insect/plot) per area.



Areas: Original farm names used
See Chapter 5 & Table 1.

Figure 40: Browse proportion per area.

taken into consideration before harvesting is commenced.

8.4. What portion to harvest?

As already discussed, clear cutting is not ecologically acceptable. In wildlife conservation areas 30% clearing would be manageable and 80% a reasonable maximum (Scholes, 1988). Stromgaard (1985) states that members of a certain tribe in Zambia do not clear fell trees, but only lop branches off, leaving the stems to ensure faster regrowth and an early recovery of the original form. Smit & Swart (1991) investigated responses of mopane following clearing at various levels on the farm Halcyon, adjacent to VLNR. The levels of harvesting were: 0% = no harvesting and 6 other levels thinned to an equivalent of 75%, 50%, 35%, 10% and 100% of the leaf biomass of the 0% level. Attention was given mainly to grass growth and grass species composition after clearing, but some interesting tree data were also collected.

Total available leaf biomass was highest when no harvesting was done, although only a small portion was below 1.5m, the utilization range for most domestic stock. Most wild browsing ungulates on VLNR would utilize a greater vertical range. Best available leaf biomass/ha was attained after harvesting between 25% and 50% of mopane. Leaf biomass, flower and seed production increased after harvesting, especially in areas with lower densities (80% harvest), because of lack of inter species competition.

There were more perennial grass species present in the *Salvadora angustifolia* associated areas at a harvesting level of 50%. Only slight differences in perennial grass species composition were found in non-Salvadora areas at any harvesting level. Grass production between trees was highest at a 50% (50-60 kg/ha) harvesting level and under trees at a

90% (80-100 kg/ha) harvesting level. Highest grass production occurred at the 100% & 80% harvesting levels (300-350kg/ha), where trees were before being harvested. Total grass production (DM), including annual and perennial grass species, was higher at 100% (140-150 kg/ha), 80% (90-100 kg/ha) and 50% (60-70 kg/ha) harvesting levels than those at other levels. Carrying capacity for grazers was enhanced, being computed as follows: at harvesting levels of 100% (43.2 ha/LAU), 80% (71.3 ha/LAU) and 50% (95.9 ha/LAU) compared to 243.3 ha/LAU for areas not harvested.

These findings indicate that a harvesting strategy of between 25% and 50% of mopane would ensure best availability of leaf and grass biomass. The harvesting model (8.2. & Appendix 3) suggests that an optimum harvesting strategy of 27% would yield best potential harvesting results and be sustainable at 5 year intervals. Available wood for charcoal production per hectare (kg/ha) at 25% and 50% harvesting levels is presented in Table 9.

Table 9. Potential wood available for charcoal production (kg/ha) in areas with the highest potential charcoal yields at different harvesting levels (25%/50%/100%).

		Harvesting levels	
Mean weights/area	**25%**	**50%**	**Total**
Endora	5 391	10 781	21 562
Hilda	4 473	8 946	17 892
Lizulea	4 281	8 562	17 125
Edmonsburg	3 688	7 376	14 751
Flora	3 339	6 678	13 356
Patricia	2 958	5 916	11 832
Mean weights/veg.type			
C.mopane woodland	3 697	394	14 787
C.mopane/C.apiculatum	1 409	2 817	5 634
C.mopane shrubland	809	1 619	3 237

Although a 25% harvesting strategy would ensure the highest sustained yields of wood for charcoal, other levels of harvesting could result in better grass and browse production. Table 9 compares these results to 50% and 100% harvesting strategies. Harvesting strategies take complete trees (all stems included) into account and not portions of trees due to the growth form of mopane.

8.5. When to harvest?

Season of harvesting is important as it could have a lasting effect on population dynamics of mopane and especially of dependant browsing ungulate populations. The fact that browsers select for mopane during adverse environmental conditions has led to the perception that it is a less palatable browse species than those species normally preferred under favourable conditions. In fact, mopane compares favourably in palatability to other species (Styles, 1993) and its importance for browsing ungulates has been undervalued. According to Styles (1993), the chemical content of mature mopane leaves varies seasonally to make them most palatable during summer and autumn and least palatable during spring. Crude protein levels are highest while the energy value (kJ/g) is lowest during summer (15.92%) and autumn (12.90%). Senescent, fallen and old leaves are also an important source of food for many browsers and mixed feeders during these seasons (Guy *et al.*, 1979). Palatability of mature leaves decreases in winter due to an increase in condensed tannins and phenolics and a decrease in moisture, crude protein (9.31%) and nitrogen. It is lowest during spring due to high condensed tannin and fibre contents. An ecological advantage that mopane has over other species is that new leaf flush occurs during spring, independent of rainfall. Browsers benefit as new leaves are highly palatable with a high crude protein content (17.5%) and come at a time when most other species have shed their leaves (Guy *et al.*, 1979; Styles, 1993). Browsers utilize mature mopane leaves extensively during summer and autumn (most palatable) and their importance increases when other trees have lost their leaves.

Importance of season depends on the size of harvested area decided upon. For small localized areas (1-3ha) it is not important, but as soon as harvesting is commenced on a large regional scale, it would be important.

Best season to harvest mopane is during winter when the palatability of mature leaves is at its lowest. Months suitable to harvest mopane are from April to September, with best months being May, June, July and August. Other advantages of harvesting during winter are mild mean temperatures of between 7.2°C and 24.7°C compared to summer mean temperatures of between 20.3°C and 32.0°C (O'Connor, 1992). Although rainfall is low and unpredictable in summer

(November to March), it occurs in the form of thundershowers which could be dangerous due to lightning, while hardly any rainfall occurs during winter. A disadvantage of harvesting during winter is the fact that hunting is then at its peak. This problem could be avoided by effective co-ordination of hunting and harvesting activities.

Harvesting should be avoided during spring when the palatable new leaf flush provides a very important source of food for browsers.

Although VLNR is large and not all areas and all mopane will be affected by harvesting, other smaller areas (should harvesting of mopane become common practice to other farmers in the region) could be adversely affected by incorrect harvesting strategies.

8.6. Harvesting methods

Techniques used for bush clearing are mechanical, chemical and natural methods. Because the prime objective for harvesting mopane on VLNR is to utilize it on a sustainable and economically viable basis, chemical and natural bush clearing methods are not applicable.

Mechanical methods such as hand felling are recommended where labour is cheap while chainsaws should improve labour efficiency. These mechanical methods cause minimal disturbance to grass and soil surface, provided harvest debris is not dragged excessively. Heavy mechanised methods such as bulldozing, chaining, root-ploughing and bush-breaking by roller, cause widespread disruption of grass and soil and are not recommended.

Two ways of harvesting mopane proportionally involve either removing portions of trees randomly over designated areas (even harvesting) or clear felling a portion of the land surface (patch harvesting). Even harvesting in elongated patches should be done as this maximises ecotonal boundary and maintains available browse while improving visibility.

Even harvesting (25%, See 8.3.) should commence adjacent to roads as this would ensure easy access and avoid vehicles entering and disturbing the environment. Visibility for hunting and game viewing would improve. Areas further from roads could be utilized later.

Harvesting should commence immediately adjacent to roads in 1 to 4ha blocks (100x100m or 200x200m) or in elongated strips of 100x200m. A length of 200m would also be the maximum effective hunting range. Between harvested blocks or strips, patches (300m wide) should be left undisturbed to provide corridors of dense bush to enable shy animal species to cross roads. Ecotonal boundaries would also be increased in this way.

A balance must be struck between harvesting small and large trees. Small trees provide most available browse while large trees provide browse, shade and a source of regeneration through seed production. Biomass needed to make harvesting viable would more readily be obtained by harvesting larger trees. This could have an effect on the growth rate of the smaller trees as competition for resources diminishes.

Disadvantages of bush clearing are: dominance by less productive grass species after harvesting (See 9.1.1.), soil compaction, erosion, susceptibility of the system to over exploitation and severe coppicing of harvested species. In the absence of effective management, coppiced plants could become more dense than original stands. If planned and executed with care there need be no adverse ecological consequences as a result of harvesting mopane.

8.7. Frequency of harvesting

Mopane is a slow growing tree species (Van Wyk, 1972; Ayensu *et al.*, 1980; Prior & Cutler, 1992; Van Wyk, 1994). Return frequency to harvested areas depends on average growth rate for each area. This would also depend on growth form (extent of coppice) after harvesting. Seedling regeneration is slow (Scholes, 1990) and unpredictable, due to animal predation (Jarman & Thomas, 1969). Early dieoff of mopane seedlings is also a well known fact (Von Breitenbach, 1965; De Winter *et al.*, 1966; Ayensu *et al.*, 1980). This means that regeneration would be mainly by coppicing.

Growth rates (See 8.4) for Endora (0.59cm/yr), Hilda (0.59cm/yr) and Lizulea (0.60cm/yr) do not vary much from the average growth rate for *C.mopane* woodland (0.59 ±0.02cm/yr). Regeneration time to reach minimum cut-off circumference of 7cm is 12yrs. Regeneration time to reach present mean circumference (14.24cm) is 24yrs (This study). Return frequency to harvested areas, according to mean circumferences at present, would be between 12 and 25 years (Von Breitenbach, 1965; Ayensu *et al.*, 1980; Scholes, 1990; Present study - See 8.4).

As indicated above, the harvesting model suggests an optimal strategy of harvesting every 5 years at a level of 27%. Initial yields of ±8 000kg/ha total weight would decrease to ±1 500kg/ha over a 60 year period (See Appendix 3). It must also be kept in mind that only stems with a circumference >13cm were used in this harvesting model.

Regeneration time would primarily be determined by climatic and edaphic factors as well as the reduction of intra specific competition after harvesting. Long term research is needed to determine exact regeneration time, growth rate and growth form.

CHAPTER 9

CHAPTER 9: ECOLOGICAL IMPLICATIONS

9.1. Effects on grass and browse production

9.1.1. Grass production

Grass cover under mopane woodland is generally sparse and discontinuous (Henkel, 1930; Miller, 1938; Bawden & Stobbs, 1963; Louw, 1970; Weare & Yalala, 1971; Kennan, 1972). According to Van der Schijff (1969), grass cover under mopane does not differ significantly from that under other woodland types. In certain areas of Botswana and Zimbabwe, grass growth is often dense under mopane (Tinley, 1966; West, 1967). According to O'Connor (1991), grass cover on VLNR varies from less than 10% median cover in *C.mopane* shrubland to 70% median cover in mixed *C.mopane/C.apiculatum* open woodland.

Yearly grass yields are highly correlated with annual rainfall in both cleared and bushed conditions. Any factor which negatively affects the woody component results in higher herbaceous productivity and vice versa (Teague & Smit, 1992). Scholes (1988) states that there is an increase in grass production following complete clearing with an average of 350 kg/ha/yr in mopane veld in the Eastern Transvaal. Grass yields in Botswana (Tuli lowveld) after clearing vary between 581 and 3862 kg/ha compared to 173 and 1346 kg/ha under trees if not cleared (Dye & Spear, 1982). Total grass production (kg/ha) for all grass species as determined by Smit & Swart (1991) was highest in clear cut areas (140-150kg/ha), followed by a 80% harvesting level (90-100kg/ha) and 50% harvesting level (60-70kg/ha)(Harvesting levels: 100% = no harvesting and 6 other levels harvested to the equivalent of 75%, 50%, 35%, 20%, 10%, 0% of the leaf biomass of the 100% level). Although there is an increase in total grass production under clear cut conditions, grass production as a whole is still low in

C.mopane woodland (Smit & Swart, 1991).

Grass production is higher beneath trees than between trees, because of shade and leaf litter (Stuart-Hill *et al.*, 1987). Although above mentioned grass production results were valid for *Acacia karroo*, Smit & Swart (1991) confirm similar results for mopane. Crude protein content of grass is also higher beneath trees than between trees (Grossman *et al.*, 1980). Kennard & Walker (1973) state that soils beneath trees have a higher infiltration rate, better water retention capacity and are richer in organic minerals. Grass production is highest beneath trees, with 200-250kg/ha (90% harvesting level), compared to between trees with 80-90kg/ha (100% harvested), 50-60kg/ha (80% harvested) and 50-60kg/ha (50% harvested) (Smit & Swart, 1991). Grass yields after harvesting mopane on VLNR would also be low, as work by Smit & Swart (1991) was done in similar vegetation on a neighbouring farm.

As a general rule quality of grass decreases following bush clearing, especially on sandy soils (Scholes, 1988). This is due to loss of high quality sub-canopy grass and, if soil disturbance takes place, an increase in low quality opportunistic species. Work by Smit & Swart (1991) show huge differences in total grass species composition between *Salvadora angustifolia* and non-*S.angustifolia* habitats in *C.mopane* woodland. Small differences in perennial grass species composition was encountered in non-*S.angustifolia* habitats. An increase of 30-35% perennial grass species was encountered in *S.angustifolia* habitats (50% harvesting level). A disturbing fact was the lack of perennial grass species in areas with low tree densities.

A clear reaction to harvesting is an increase of 60-70% annual grass species encountered (100% harvesting level) in non-*S.angustifolia* habitats. This increase was primarily encountered on bare patches of soil usually associated with non-*S.angustifolia* habitats. Annual grass species composition was lower at lower harvesting intensities (30% species increase at 50% harvesting). This same increase in annual grass species was not witnessed in *S.angustifolia* habitats as there was less bare soil to colonise. Similar grass species composition (perennial & annual) would be expected in harvested areas on VLNR as well.

Changes in primary determinants (rainfall and soil composition) and secondary determinants (fire and herbivores), influence bush-grass competition enormously. An increase in tree biomass leads to a decrease in grass biomass. This is enhanced by lack of rainfall in arid areas. Although there is an increase in total grass production with a decrease in tree density, it is low for mopane woodland (Smit & Swart, 1991). Reasons therefor are large bare open spaces between trees that produce lower grass yields. Effects of harvesting mopane on total grass production is low but should however be taken into account when deciding carrying capacities for grazers as bush clearing increases grazer carrying capacity (See 9.3).

Harvesting 25% of *C.mopane* woodland trees, should result in a total grass production of ± 20kg/ha and less than 5% increase in grass species composition (Smit & Swart, 1991).

9.1.2. Browse production

Smit and Swart (1991) state that the browsing capacity of mopane is often overestimated as most available leaf biomass is above 1.5m, the height not readily available for most browsers. Mopane is ubiquitous for VLNR and is predominantly utilised by elephants as a source of food (Garai, *pers.comm.*). *C.mopane* woodland has a mean height of 2.3m while 68.2% of mopane is below 2.5m (Parent study). This suggests that the importance of mopane as browse species, cannot be overestimated for VLNR. Styles (1993) suggests that the value of mopane has always been underestimated, especially its nutritive value and value during the dry season for most browsers. The fact that it undergoes leaf flush independent of rainfall, and maintains leaf development under adverse conditions, confirms its importance for herbivores.

Research done by Smit and Swart (1991), show that there is an increase in mopane leaf biomass, flower and seed production at lower tree densities as a result of decreased competition. A total dry leaf biomass of 1 500kg/ha was calculated for areas not harvested. Dry leaf biomass below 1.5m was as low as 250kg/ha, in areas not harvested. A 30% increase in total leaf biomass was observed at a 80% harvesting level. Although leaf biomass increases were low, the highest increases were observed at lower tree densities. Flower and seed production increased between 10%-20% at harvesting levels above 50%.

Dense stands of mopane may even be detrimental to browsers as trees at lower densities become deciduous later in autumn and show earlier leaf development in spring than at higher tree densities (Smit & Swart, 1991). This is important for browsers such as kudu who regularly die during the dry, leafless season due to lack of available browse. Less dense stands do not have the same total available leaf biomass as dense stands, but that which is present, is better distributed over the season.

Browse production should increase (although not substantially) at a suggested harvesting level of 25-50% for VLNR. The amount with which it would increase is not known (further research needed), but what is important is a better seasonal distribution of browse and an increase in flower and seed production as determined by Smit & Swart (1991).

Harvesting 25% of *C.mopane* woodland trees, would result in between 750kg/ha and 1 000kg/ha total dry leaf biomass available, while dry leaf biomass below 1.5m would be less than 250kg/ha (Smit & Swart, 1991).

Harvesting mopane not only has economic advantages but could also benefit browsers by creating a better browser orientated habitat. By correct management of the browse resource, a more effective browsing capacity could be envisaged. It should be clear that the amount of harvesting/thinning of mopane could influence carrying capacity for browsers and grazers enormously. The balance between a harvesting strategy, qualitative and quantitative browse and grass biomass and carrying capacity for ungulates is very important and careful planning should be done before decisions are made on harvesting.

Other ecological implications of harvesting not discussed in this study are hydrological cycle changes, changes in nutrient cycle which are closely linked to hydrological changes and habitat changes if harvesting is done on a very large scale (thousands of hectares).

9.2. Browsers

9.2.1. Elephants

Browsers most likely to be affected by harvesting mopane on VLNR are elephants, as mopane constitutes the largest proportion of their diet (Garai, *pers.comm.*). Because mopane is usually ubiquitous in vegetation types where it occurs, it is a large component in elephants diet (Lawton, 1968; Van Wyk & Fairall, 1969; Jarman, 1971; Anderson & Walker, 1974; Caughley, 1976; Guy, 1976; Lewis, 1986 & 1987; de Villiers & Kok, 1988; Viljoen, 1989; Funston, 1993; Van Wyk, 1994).

Mopane is an important source of food for elephants, during the dry season (Bell & Jachmann, 1984; Lewis, 1986; Styles, 1993) and they have even been observed to utilize burned mopane (Van Wyk & Fairall, 1969; Lewis, 1987). Under exceptional drought conditions harvesting should be avoided to minimize elephant stress. As already stated, harvesting should also be avoided during early spring, when new leaf flush occurs independently of rainfall, as mopane is then virtually the sole provider of browse. Other seasonal problems are not envisioned as harvesting would be limited to specific areas (Endora, Hilda and Lizulea) to ensure best potential charcoal yields, leaving the remainder of the entire reserve unaffected.

Although elephants are destructive feeders, it appears that they prefer to browse on new regrowth from previously damaged mopane trees, forming a "hedge" (Anderson & Walker, 1974; Styles, 1993; Pers.obs.). This "hedge" as described by Styles (1993), is maintained in height and shape by browsing elephants. Most of their feeding is on vegetation below 2m (Caughley, 1976; Guy, 1976; Pellew, 1983) or at mouth height (Garai, *pers.comm.*). Mopane is relatively resistant to browsing and although elephants do not prevent regeneration, they prevent recruitment of mopane into taller height classes (Caughley, 1976). *C.mopane* woodland on VLNR has a mean height (2.30m) and mean circumference (14.24cm) which is within elephant browsing range. However, 31.8% of mopane trees are in height classes above 2.5m (Table 3). Implementation of a 25% even harvesting strategy could easily be accommodated without utilizing trees below 2.5m. Charcoal potential weights of 5 391kg/ha (Endora), 4 473kg/ha (Hilda) and 4 281kg/ha (Lizulea) would be expected under this harvesting strategy (Table 9). Even a 50%, even harvesting strategy should not influence available elephant browse, as harvesting would occur in small localized areas. Height classes could also effectively be managed by harvesting strategies so as to create specific elephant browse heights if needed.

Human disturbance, such as frequency and proximity of gunshots, may be sufficient to disrupt elephant movements and normal patterns of utilization and cause stress (Lewis, 1986). Effects of harvesting mopane by chainsaw or any other methods should be negligible as hunting is already allowed as part of a game management strategy. Elephants are likely to become accustomed to additional noise and human activity. Harvesting activities should however be avoided in Melisande, Anglican and Blyklip as elephants utilize these areas extensively and potential charcoal yields are lowest here. However, elephant movements must at all times be taken into account to ensure the safety of workers.

Work by Smit and Swart (1991) indicates that effects of harvesting (thinning) mopane could also be advantageous for browsers such as elephant. They show that mopane trees on plots thinned to certain percentages, become senescent later in autumn and regrowth of new leaves takes place earlier in spring than on plots not thinned. This means a better leaf distribution over all seasons (Smit, 1992). This effect could be manipulated by management to create a greater carrying capacity for browsers. Increased grass growth after harvesting mopane, would provide an additional source of food for elephant on VLNR.

It would be expected that the long term effect of elephants on mopane for the VLNR would be to thin the bush naturally. They could also create a certain browsed "hedge" as indicated by Styles (1993) in the Tuli Block, Botswana. The vertical distribution of mopane could also change in heavily utilized areas. At present the elephants number about 50, but increased numbers should increase the effect on the environment.

9.2.2. Eland

Evidence on diet selection by eland, indicate a preference for browse (Smithers, 1983; Kenmuir & Williams, 1992). Eland together with elephant, are two species that are almost exclusively dependant on mopane for food on the VLNR. Lightfoot and Posselt (1950) show that eland spend only 6-7% of feeding time, grazing. The species is thus important as it utilizes mopane browse and provides an economic return (Lightfoot & Posselt, 1950). Harvesting would also facilitate sightings and improve hunting opportunities for this species. Proposals made above in reference to elephants, also apply to eland.

9.2.3. Giraffe

Giraffe are essentially browsers of trees and shrubs (Smithers, 1983; Kenmuir & Williams, 1992). Oates (1972), indicates that mopane is a species that is avoided by giraffe on the Hans Merensky Nature Reserve in the Transvaal Lowveld Mopane Woodland. Sauer *et al.*(1982) state that mopane is utilized to a certain extent, especially during the dry season when browse from other species is less ready available. Lightfoot & Posselt (1950) state that giraffe browse much the same woody species as eland. According to Hall-Martin (1974), mopane is the second most important browse species utilized by giraffe in the Transvaal lowveld. Giraffe were seen to utilize mopane near water on VLNR (Pers.obs.). The species should thus be no more or less affected by harvesting mopane than others, except during the dry season. Giraffe also seem to avoid very dense *C.mopane* woodland stands (Pers.obs.), thus harvesting in woodland areas should not influence their behaviour.

9.2.4. Kudu/Impala/Other species

Kudu are almost entirely browsers (Novellie, 1983) but according to Jarman (1971) mopane forms less than 1.5% of their diet in woodlands around Lake Kariba in Zimbabwe. Emergence of new green mopane foliage in spring, triggers utilization by kudu (Styles, 1993). Harvesting in *C.mopane* woodland areas, especially during early spring and under drought conditions, should affect kudu in the same way as elephant and giraffe.

Impala utilize fewer tree species than kudu but feed on fallen leaves and seeds of mopane throughout the year (Jarman, 1971; Smithers, 1983; Kenmuir & Williams, 1992). Foliage discarded during harvesting (<8cm circumference) can serve as a source of food for impala if left in harvested areas or used as surface cover for erosion control in other areas. As impala are ubiquitous on VLNR, harvesting in *C.mopane* woodland areas should not influence impala behaviour.

Klipspringer, bushbuck, steenbok and duiker are other browsing species found on the reserve. New mopane spring foliage is utilized by duiker and steenbok in Botswana (Styles, 1993). Duiker were seen to browse on mature mopane leaves on VLNR (Pers.obs) and are even recorded eating mopane caterpillars (Kenmuir & Williams, 1992). These species should not be affected by harvesting *C.mopane* woodland, unless it includes their territories.

Species requiring browse as a food source, or dense cover for breeding or predator evasion are kudu, giraffe, bushbuck, and sable. These species would only be affected if harvesting were to take place on the entire reserve. Its limitation to *C.woodland* areas, should have negligible impacts. Research on the distribution of browsers in time and space, would enable more precise predictions to be made of the influence of harvesting.

O'Connor (1991) advocates maintenance of a browser orientated community on VLNR. He suggests that browse production is more reliable in a semi-arid system, and greater economic return is likely to accrue from browsers than from grazers.

9.3. Grazers

Grazing species such as zebra, buffalo, wildebeest and domestic stock, especially cattle, are known to browse mopane (Irvine, 1937; Lawton, 1968; Jarman, 1971; Taylor & Walker, 1978; Donaldson, 1979; Styles, 1993).

Very few studies have used animals to evaluate a response to harvesting. Indications are that increases in animal performance with clearing are much less than the increases of grass production (Grossman *et al.*, 1980; Pieterse & Grunow, 1985). Increased grass production and changes in species composition after harvesting are discussed in Chapter 11.1.1.

Carrying capacity for grazers increases with a decrease in mopane density (Smit & Swart, 1991). Clear cutting (100% mopane harvested) produces best carrying capacity results (43.2ha/LAU) followed by 80% (71.3ha/LAU) and 50% (95.9ha/LAU) harvested. Areas not harvested had a carrying capacity of 243.3ha/LAU. This indicates that mopane is not suited to an exclusively grazer orientated system. A harvesting strategy of between 25%-50% would definitely benefit grazers due to an increased carrying capacity from 243.3ha/LAU to 95.9ha/LAU (50%).

Advantages of visibility after harvesting for grazing species that rely on detection and flight from predators (wildebeest, zebra, warthog and tsessebe), are ensured. Habitats could be created by thinning mopane in certain areas to specific species requirements and needs, such as for roan and sable (Kenmuir & Williams, 1992).

Changes in distribution and movement patterns of grazers could be expected due to habitat changes and increased grass production. Grazer population numbers could be expected to increase after the first few seasons due to habitat creation and food availability. Game bird population numbers would also be expected to increase as a result of habitat expansion. Grass species composition colonizing harvested areas would determine the quality, palatability and nutritious value of grass, thus directly influence grazer carrying capacity. Environmental factors, especially rainfall, would determine rate of grass biomass increase as well as grazer population responses to harvesting.

Harvesting mopane in *C.mopane* wōodland areas, should make this area more accessible for grazers as a result of an expected grass biomass increase and increased visibility. Grazer carrying capacity should also increase

CHAPTER 10

CHAPTER 10: CONCLUSION

The main conclusions derived from this study are summarised and itemized below.

1: Mopane is ubiquitous on the VLNR with *C.mopane* woodland (vegetation types following O'Connor, 1991) dominating large areas of the central, southern and north western parts of the reserve. This vegetation type is found predominantly in association with Oakleaf (OaB) soils, which are well drained, deep alluviums, sandy loams or sandy clays. *C.mopane* shrubland is found mainly in the south western part of the reserve in association with Valsrivier (VaA) and Swartland (SwA) soils which have sodic and dense clay subsoil's, respectively. *C.mopane/C.apiculatum* open woodland is found on the eastern boundary in association with Hutton (HuA) soils which are deep and sandy.

2: *C.mopane* woodland has the highest average density of 2 289 trees/ha compared to 727 trees/ha for *C.mopane* shrubland and 830 trees/ha for *C.mopane/C.apiculatum* open woodland. Specific areas of VLNR with highest average densities are Melisande with 3 038 trees/ha followed by Endora with 2 826 trees/ha, both found in *C.mopane* woodland. A median herbaceous cover of only 20% indicates lack of grass in this dense woodland. Its dense structure is a result of overgrazing, incorrect farming practices and environmental factors. There seems to be a correlation between soil type and density as dense mopane woodland is found predominantly in association with Oakleaf (OaB) soils, while mopane on other soil types is not as dense.

3: Observations suggest that mopane in *C.mopane* woodland is essentially a reasonably small, slow growing tree. 48.1% of *C.mopane* woodland is found in a height-class of 1-2.5m, while altogether 89.3% is below 3.5m in height. 49.2% of mopane is [illegible] and [illegible] circumference-class less than 10cm, while [illegible]% is below [illegible]cm. This indicates a reasonably small height and circumference distribution for this vegetation type. Average age per tree of 25 years and a diameter growth rate of 0.59cm/yr indicate a slow growing tree species which should regenerate to its present average circumference in 24 years. It should take an average of 12 years to regenerate to a minimum size of 7-8cm in circumference required for good quality charcoal.

4: Biomass estimations indicate a significant difference in total and charcoal available weights per hectare between the three vegetation types, although not much difference between mean weights per tree. *C.mopane* woodland has the highest mean total weight of 23 668kg/ha and charcoal weight of 14 787kg/ha. This indicates that 62.5% of mopane is utilizable for charcoal production in this specific vegetation type. Amounts of charcoal actually derived from wood with a charcoal potential depends on proportion of trees harvested and effectiveness of the charcoal making procedure implemented.

5: Harvesting should take place during winter when the mean daily temperatures are mild compared to summer. Palatability of mature mopane leaves is lowest then and harvesting would have the least effect on browsers. Manual harvesting with hand saws would be best where labour is cheap, while chainsaws should increase productivity. Harvesting should be done in elongated patches so as to increase the ecotone boundary and make it more ecologically acceptable. A strategy of harvesting between 25-50% of mopane trees should be economically and ecologically viable. Harvesting levels of 25% and 50% would yield mean weights of 3 697kg/ha and 7 394kg/ha of wood with charcoal potential. Endora (25% = 5 391kg/ha & 50% = 10 781kg/ha), Hilda (25% = 4 473kg/ha & 50%

5 946kg/ha) and Lisulea (25% = 4 281kg/ha & 50% = 8 562kg/ha) areas, have best potential charcoal yields and harvesting should be implemented here first. An optimum harvesting rate of 27%, with an initial total yield of ±8 000kg/ha (±5 000kg/ha charcoal yield) is suggested by a harvest model developed specifically from the mopane data. Actual charcoal yields would depend on the charcoal making technique used.

6: Most important ecological effects that harvesting should have on mopane, would be to delay the onset of leaf senescence until later in autumn and to stimulate leaf flush earlier in spring. This would mean a more even spread of available browse over the year. It still has to be determined what effect harvesting will have on growth rate and biomass increase of mopane due to a decrease in intra-specific competition.

7: Decreased woody biomass due to harvesting would mean an increase in herbaceous biomass. Grass production should increase, although quality of the grass biomass would depend on species colonizing cleared areas. The fact that grass quality is usually best below trees and that areas cleared would be more susceptible to environmental factors, should influence the quality of grass. As a rule of thumb however, an increase in grass biomass should mean an increase in available habitat and carrying capacity for grazers. Depending on harvesting intensity, there should be a decrease in total browse production but a better distribution of available browse over the year. This should be advantageous for browsers especially during the critical dry period before the rainy season begins.

8: Responses of elephants to chainsaw harvesting cannot be predicted with any certainty. They should adapt to harvesting activities, especially if areas which they utilize extensively are avoided and their movements are taken into consideration. It is expected that elephants should have a natural thinning effect on mopane, especially with an increase in their numbers. They could also be responsible for creating a specific mopane "hedge" in areas heavily utilized. Both total herbivore densities and species proportions can be expected to change following bush clearing. There should be an increase in habitat for grazers especially in dense *C.mopane* woodland after harvesting. This should lead to different distribution and movement patterns of grazers. The effect should decrease as size of cleared areas relative to uncleared areas increases. Resistance of mopane to a wide spectrum of environmental stresses together with its importance as a source of browse for animals, source of food for humans (mopane worms) and potential utilization for firewood and charcoal production, suggests that this species plays an indispensable role in the functioning of ecosystems in which it occurs in Southern Africa.

SUMMARY

SUMMARY

Principle objectives of this study were to investigate the ecological feasibility of sustained utilization of mopane, using Venetia Limpopo Nature Reserve as a pilot study area. The study was limited to three different mopane dominated vegetation types on the reserve with most research being conducted in *C.mopane* woodland.

Results can be summarized as follows:

1. *Colophospermum mopane* is ubiquitous on VLNR.
2. *C.mopane* woodland has the densest mopane growth of the three vegetation types and highest densities are found on soils (OaB, VaB, Du, SwB & VaA) in association with *C.mopane* woodland. There seems to be a correlation between mopane density and soil type.
3. Largest mopane trees according to height and circumference were found in *C.mopane/C.apiculatum* open woodland. There is no significant difference between height and circumference on different soil types.
4. Most senility occurs in *C.mopane* shrubland and there is a significant difference in senility between mopane associated with different soils on which this vegetation type occurs.
5. Oldest average ages per tree were found in *C.mopane* woodland while growth rates were fastest in *C.mopane/C.apiculatum* open woodland.
6. There is a significant positive correlation between total and charcoal weights for mopane. Total and charcoal weights per tree were highest for *C.mopane/C.apiculatum* open woodland, while weights per hectare were highest for *C.mopane* woodland. Soils could not positively be associated with this trend.
7. Mopane lends itself to harvesting, especially *C.mopane* woodland in the Endora, Lizzulea and Hilda areas.

Winter months seem to be most desirable for harvesting activities. Hand felling in elongated patches (increases ecotone boundary) is recommended where labour is cheap. A harvesting strategy of between 25% and 50% would make the operation economically viable and ecologically acceptable. An optimum harvesting rate of 27% is suggested by a harvesting model developed specifically for this mopane data.

8. Total herbivore densities, distribution and species proportions can be expected to change following bush clearing. Habitat for grazers should increase due to an increased grass production. Habitat for browsers should not be influenced much. Effect of noise and human disturbance during harvesting, especially for elephants is negligible, as hunting activities already take place on VLNR.
9. Grass production would increase but quality should decrease after harvesting, due to an increase in low quality opportunistic species, especially if soil disturbance takes place. Grass quality is best in association with herbaceous species such as Salvadora angustifolia. Carrying capacity for grazers should increase after harvesting as a result of habitat change and grass biomass increase.
10. Total browse production would decrease but leaf biomass should increase on remaining trees as they have improved water availability due to a lack of intra-specific competition. Higher seed production and more flowering takes place at lower tree densities. Greatest advantages for browsers after harvesting, is the fact that leaves become senescent later in autumn and that spring leaf flush takes place earlier thus prolonging browse availability.

OPSOMMING

OPSOMMING

Die hoof doelwitte van hierdie studie was om te bepaal wat die invloed van die oes van mopanie op die ekologie sou wees as dit op 'n volgehoue basis plaasvind en tot watter mate mopanie geskik is vir houtskoolvervaardiging. Die navorsing is op die Venetia Limpopo Natuureservaat in slegs drie van die belangrikste mopanie veldtipes uitgevoer met die oorgrote meerderheid van die navorsing in die *C.mopane* bosveld.

Die resultate van die studie kan soos volg opgesom word:

1. *Colophospermum mopane* is alomteenwoordig op die VLNR.
2. Die *C.mopane* bosveld het die hoogste digtheid van al drie veldtipes en word ook geassosieer met sekere grondtipes (OaB, VaB, Du, SwB & VaA) wat eie is aan hierdie spesifieke veldtipe. Daar blyk 'n korrelasie te wees tussen die digthede van mopanie en grondtipes.
3. Die grootste mopanie bome, ten opsigte van hoogte en omtrek, word in die *C.mopane/C.apiculatum* oop bosveld aangetref. Daar is nie 'n beduidende verskil tussen die hoogte en omtrek van mopanie op die verskillende grondtipes nie.
4. Die *C.mopane* struikveld toon die meeste seniliteit ten opsigte van die persentasie kruin dood. Daar is 'n definitiewe aanduiding dat seniliteit ooreenstem met sekere grondtipes veral met betrekking tot die mopanie struikveld.
5. Die *C.mopane* bosveld het gemiddeld die oudste bome terwyl die *C.mopane/C.apiculatum* oop bosveld die vinnigste groeikoers toon. Die bogenoemde feite het 'n verband met die grondtipes.
6. Daar is 'n positiewe korrelasie tussen die totale gewig en die houtskoolgewig van mopanie. Die

swaarste bome is in die *C.mopane/C.apiculatum* oop bosveld aangetref, terwyl die swaarste gewig per hektaar in die *C.mopane* bosveld aangetref is. Gewig kon nie met grondtipes gekorreleer word nie.

7. Die mopanie in die *C.mopane* bosveld is geskik vir die oes vir houtskool, veral in die Endora, Lizzulea en Hilda gebiede. Dit is raadsaam om die bome in verlengde stroke per hand af te kap (vergroot die ekotoongebied), veral waar arbeid goedkoop is. 'n Oesstrategie van tussen 25% en 50% vir mopanie word aanbeveel om dit ekonomies en ekologies aanvaarbaar te maak. 'n Optimum oesstrategie van 27% word aanbeveel deur 'n oes model wat spesifiek vir hierdie mopane data opgestel is.

8. Daar kan verwag word dat na die oes van mopanie die getalle asook verspreidingspatrone van alle hoefdierspesies kan verander. 'n Voordeel van lae mopanie digthede is dat die verspreiding van die blaarbiomassa ewerediger oor die seisoene sal geskied. Grasvreters word bevoordeel vanweë die verandering in habitat. Die effek van geraas en ander oesbedrywighede op olifante behoort klein te wees aangesien jagaktiwiteite alreeds op diereservaat toegepas word en hulle redelik gewoond daaraan behoort te wees.

9. Grasproduksie behoort toe te neem terwyl die kwaliteit daarvan afneem as gevolg van opportunistiese lae kwaliteit grasspesies wat toeneem na die oes van mopanie, veral as die grond tydens oesaktiwiteite versteur word. Die beste kwaliteit gras word in assosiasie met kruidagtige spesies, veral *Salvadora angustifolia*, gevind. As gevolg van die verandering in habitat asook die toename in grasbiomassa neem die drakrag vir

grasvreters na die oes van mopanie toe.

10. Die totale blaarbiomassa behoort na die oes van mopanie af te neem, maar behoort terselfdertyd op die oorblywende bome as gevolg van die afname in kompetisie vir water en ander natuurlike hulpbronne toe te neem. Hoër persentasies blomvorming en saadproduksie vind by laer boomdigthede plaas. Die grootste enkele voordeel vir blaarvreters, na die oes van mopanie, is die feit dat die blare later in die herfs afval en vroeër in die lente uitbot en dus die voedselbeskikbaarheid vir blaarvreters verleng.

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APPENDICES

APPENDIX 1: Common tree names
2: Gaylard Batch Charcoal Retort
3: Harvesting model - 27%
4: Statistical results for Vegetation types

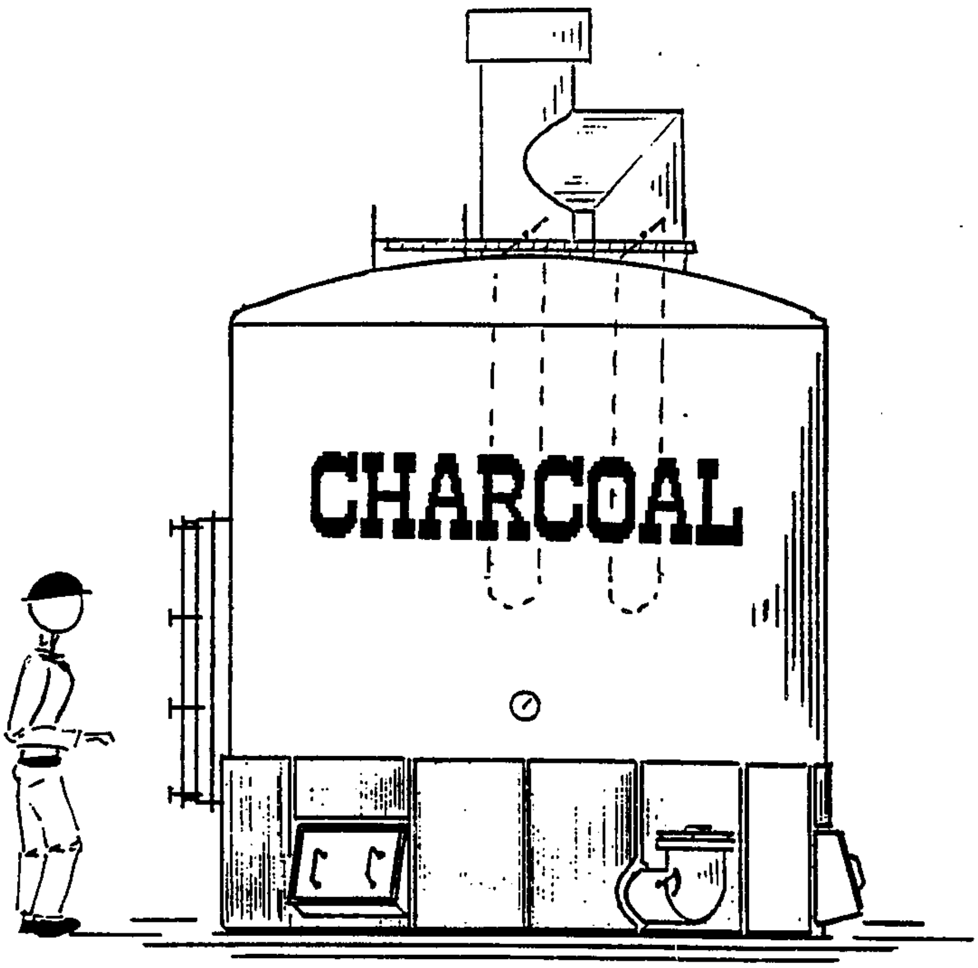
APPENDIX 1

APPENDIX 1.

List of common names for tree species encountered during this study:

Acacia stuhlmannii	-	Vlei Thorn
Adansonia digitata	-	Boabab
Adenium obesum	-	Impala lily spp.
" *oleifolium*		"
Aloe littoralis	-	Mopane aloe
Boscia albitrunca	-	Shepherd's tree
" *foetida*		Smelly shepherd's tree
Cadaba termitaria	-	Pink cadaba
Colophospermum mopane	-	Mopane
Combretum apiculatum	-	Red bushwillow
Commiphora glandulosa	-	Common commiphora
" *mollis*		Velvet commiphora
Grewia bicolor	-	Bastard brandybush
Lanea scweinfurthii	-	False marula spp.
Maerua parvifolia	-	Bush-cherry spp.
Salvadora angustifolia	-	Transvaal mustard tree
Sesamothamnus lugardii	-	Transvaal sesame tree
Terminalia prunioides	-	Purple-pod terminalia
Ximenia americana	-	Small sourplum

APPENDIX 2



GAYLARD CHARCOAL RETORT

SA patent 84/8488

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THE GAYLARD BATCH CHARCOAL RETORT

The GAYLARD BATCH CHARCOAL RETORT has been developed to produce high quality charcoal from a range of raw materials. It features a number of advantages over more traditional means of charcoal manufacture, and this brochure gives a general description of the unit and its features.

WHAT IS A RETORT ?

Charcoal has traditionally been prepared in kilns. These consist essentially of enclosures (made of metal, brick or mud) in which wood is burnt in a limited supply of air. Approximately half of the wood is burnt completely to ash, and the heat given off by this combustion is sufficient to carbonise the remaining wood and thereby form charcoal. While this is happening, the volatile tars and gases (which are given off by the wood during carbonisation) leave the kiln in the form of large volumes of polluting smoke.

Besides causing a great deal of pollution, this method is extremely wasteful in that it uses the raw material (the wood) as its source of energy. The tars and gases are unused, despite the fact that they contain about half of the total available energy of the wood in its uncarbonised form.

In a charcoal retort, these tars and gases are utilised as the principal source of energy. By recycling them and burning them, it is possible to avoid burning the solid raw material. This results in a very much higher yield of charcoal product from a given quantity of raw material.

The retort principle has been recognised for many years, and charcoal retorts have been in operation for half a century. The earlier retorts have had the disadvantage, however, of being complex units designed for the production of large volumes of charcoal at fixed sites. They are extremely expensive to construct and require complex operating procedures.

The GAYLARD unit was developed to overcome these disadvantages, and to offer retorts to charcoal manufacturers in the form of relatively inexpensive units which are easy to operate.

GENERAL DESCRIPTION

The GAYLARD retort is a self-contained, transportable unit which is designed for the production of charcoal from such raw materials as wood, nut shells and other carbonaceous materials.

In exterior appearance the retort is a cylindrical vessel approximately five metres high with a domed top, on top of which is a chimney and duct arrangement. The diameter of the vessel is approximately 3,3 metres and it rests on the ground without any need for foundations.

The unit has a double wall, and on the inside is a carbonising chamber into which the raw material is loaded by means of a hatch in the top. The volume of raw material which can be loaded is 24 cubic metres.

Underneath the carbonising chamber is a combustion chamber. In the first phase of processing a batch this chamber is used for burning waste material such as bark or twigs. The purpose of this initial combustion is to raise the temperature of the raw material to the point where it emits combustible gases. These gases are burnt in the combustion chamber during the subsequent phase of the operation and this provides the energy for completion of the carbonisation process.

The unit is designed in such a way that hot gases are routed in differing directions at various stages in the process. This is achieved by means of chain-operated dampers.

Control of the process is achieved by means of the adjustment of air dampers in order to maintain correct temperatures. These temperatures are monitored and recorded electronically on a control panel, and this provides the operator with a clear understanding of the state of the process at all times as well as providing a permanent record of the operation.

The unit is delivered in fully assembled form, with the exception of the chimney assembly which is mounted on site. Site erection consists of offloading the unit onto a flat piece of ground, mounting the chimney, and connecting the instrument panel to the retort. The offloading can be achieved by means of a crane or by erecting a lifting frame, either of which should have a minimum of a 10 tonne carrying capacity.

The unit requires the following services to be supplied to it:

(a) Handling equipment (conveyor or other) to bring raw material to the loading hatch at 5 metre elevation.

(b) A supply of electricity to the control panel (220v)

(c) A supply of water for cooling purposes.

FEATURES

The main features favouring the use of the GAYLARD retort are as follows:

* Raw Material Savings

  The high yield of product in relation to raw material input means that savings of up to 50% can be achieved when compared to kiln production. Since raw materials usually constitute the largest single production cost of charcoal, this is highly significant.

* Reduced Labour Cost

  Because of lower raw material requirements the amount of labour required is reduced significantly.

* Quality of Product

  Because of the fact that temperatures are controlled throughout the process, and because no combustion of raw material takes place, the quality of retort charcoal is significantly improved. This has been borne out by its acceptability to buyers in Europe and elsewhere in preference to kiln charcoal.

* Long Equipment Life

  The units are designed such that suitable construction materials are used in locations where the unit is subjected to high temperatures. The expected life of a unit is expected to be in excess of 10 years with suitable maintenance, and units have already been in continuous operation for more than 7 years. This compares with an average life of four years or less for a kiln.

* Transportability

  The units are readily transportable and can therefore be relocated if the supply of raw materials becomes exhausted.

* Ease of Operation

  The operation of the unit is relatively simple and can be handled by any reasonably competent person.

* Pollution

  Whilst the units are not completely smoke free, the amount of pollution is very much less than that experienced when operating charcoal kilns, and only occurs for a limited period during each cycle.

OPERATIONAL REQUIREMENTS

The operational requirements of the retort are as follows:

* Raw Materials

  The raw materials may be supplied in log or lump form. The largest practical size of each log is 200 mm diameter and 2,4 metre length, but operation is improved if logs are reduced in size. It is recommended that all logs be cut to 500 mm maximum lengths, and that all logs larger than 200 mm diameter be split or cut to 200 mm lengths.

  As for all charcoal making processes, the moisture content of the raw material should be as low as possible for good product quality. The maximum allowable moisture content is 25% but it is recommended that it be restricted to 20% or lower.

* Raw Material Handling

  Raw material must be loaded into the hatch at 5 metre elevation, and a conveyor or other lifting equipment is required. It has been found convenient in some cases to position the retort close to the bank of a hill so that the raw material can be delivered at the correct elevation to avoid lifting.

* Starting Material

  The unit requires initial fueling in order to raise the temperature to the point where the combustible gases can take over. Examples of suitable fuels are bark, small branches and twigs. The quantity required will depend on the moisture content of the raw material, but can be expected to be about 10 percent of the mass of the raw material.

* Electricity

  A 220v electrical supply is required for the instrument panel, and it is also advisable to install electric lighting around the production site.

* Water

  The retort requires a water supply for cooling, and water must also be available for fire fighting in the event that charcoal product catches fire after offloading from the retort.

* Labour

  Labour is required for the following:

  (a) Loading of the retort with raw material - quantity of labour to be determined depending on the type of handling equipment installed.

  (b) Operating - one operator can handle up to four retorts simultaneously.

(c) **Stoking of starting fire - one fireman required for each two retorts.**

(d) **Charcoal unloading - each retort requires three labourers for one to two hours per batch.**

DESCRIPTION OF OPERATION

The phases of manufacturing each batch of charcoal are as follows:

1. Loading

   The raw material is loaded through the top hatch.

2. Preheating

   Starting material is burnt in the combustion chamber until the raw material is emitting sufficient combustible gas to take over the heating process.

3. Carbonisation

   The combustible gases are burnt in the combustion chamber and the temperature of the raw material continues to rise until the desired temperature is reached, indicating that carbonisation is completed to the desired level. The higher this temperature, the higher the carbon content of the charcoal.

4. Cooling

   Water is injected in the form of a spray to assist with cooling of the unit.

5. Unloading

   The charcoal is unloaded through a side access door just above ground level.

Times for these operations depend on certain factors, but generally fall into the following ranges:

Loading	-	2 to 3 hours (depending on equipment)
Preheating	-	4 to 8 hours (depending on log sizes, raw material density and moisture content)
Carbonisation	-	4 to 6 hours (depending on log sizes and raw material density)
Cooling	-	6 to 10 hours (depending on charcoal volume and ambient conditions)
Unloading	-	1 to 3 hours (depending on labour efficiency)

PRODUCT DATA

1. Yield as Percentage of Raw Material

Product yield as a mass percentage of raw material input varies depending on the following:

(a) The moisture content of the raw material, and
(b) The final carbonising temperature.

The higher the final temperature the lower will be the yield, since volatile matter is driven off to enhance the fixed carbon content.

Typically, with an initial moisture content of 20% and with a final carbon content of 80%, the yield will be approximately 30% by mass. Higher yields are possible at lower carbon contents, and the decision as to what level of carbon content is desirable will depend on customer requirements.

2. Product Mass

The volume of raw material which can be loaded is 24 cubic metres. The mass of raw material will therefore depend on its density and on packing efficiency, with the latter being dependent on the average size and straightness of the individual pieces. Depending on species and on cutting, therefore, up to 8 tonnes or more may be loaded if relatively dense material is used (eg. black wattle).

Depending on the degree of carbonisation therefore (see 1. above) it can be expected that up to 2,6 tonnes of carbon may be produced in a single batch.

3. Product Quality

* Carbon Content

Fixed carbon contents of up to 87% have been achieved. The limit will depend somewhat on the ash content of the carbon and in some cases (eg with indigenous timbers containing large amounts of ash) it may not be possible to exceed 80%.

* Fines Content

Formation of fines is largely a function of high moisture content in the raw material and careless handling. It is possible to reduce fines to 5% of the total.

* Moisture

Moisture content is generally below 2%.

General Appearance

Retort charcoal has a significantly better appearance than kiln charcoal, a factor which is often important when selling the product, especially on the export market.

APPENDIX 3

			Circ. Class(cm)	3	4
			Year		
		Popinit	0	697	455
Harvest Rate	0.268638854	Harvest	0		
		Post Harvest	0	697	455
Tot Yield	45712.86192	Yield	0		
Tot not yr 1	37661.4792	Promotion	0	411.23	268.45
VolumeParm	0.01897	Popinit	5	1426.94785	597.78
		Harvest	5		
Prom Propn	0.59	Post Harvest	5	1426.94785	597.78
		Yield	5		
Tot Yield	39490.65476	Promotion	5	841.8992317	352.6902
		Popinit	10	1528.86614	1086.989032
		Harvest	10		
		Post Harvest	10	1528.86614	1086.989032
		Yield	10		
		Promotion	10	902.0310225	641.3235287
		Popinit	15	1422.944487	1347.696526
		Harvest	15		
		Post Harvest	15	1422.944487	1347.696526
		Yield	15		
		Promotion	15	839.5372475	795.1409501
		Popinit	20	1267.68075	1392.092823
		Harvest	20		
		Post Harvest	20	1267.68075	1392.092823
		Yield	20		
		Promotion	20	747.931[illegible]426	821.3347656
		Popinit	25	1122.342936	1318.6897
		Harvest	25		
		Post Harvest	25	1122.342936	1318.6897
		Yield	25		
		Promotion	25	662.1823323	778.026923
		Popinit	30	1004.920837	1202.845109
		Harvest	30		
		Post Harvest	30	1004.920837	1202.845109
		Yield	30		
		Promotion	30	592.903294	709.6786145
		Popinit	35	918.4380199	1086.069789
		Harvest	35		
		Post Harvest	35	918.4380199	1086.069789
		Yield	35		
		Promotion	35	541.8784317	640.7811754
		Popinit	40	859.9411508	987.1670451
		Harvest	40		
		Post Harvest	40	859.9411508	987.1670451
		Yield	40		
		Promotion	40	507.365279	582.4285566
		Popinit	45	823.321898	912.1037675
		Harvest	45		
		Post Harvest	45	823.321898	912.1037675
		Yield	45		
		Promotion	45	485.7599198	538.1412228
		Popinit	50	800.7963687	859.7224645
		Harvest	50		
		Post Harvest	50	800.7963687	859.7224645

5	6	7	8	9	10
679	790	863	695	691	609
679	790	863	695	691	609
400.61	466.1	509.17	410.05	407.69	359.31
546.84	724.51	819.93	794.12	693.36	657.38
546.84	724.51	819.93	794.12	693.36	657.38
322.6356	427.4609	483.7587	468.5308	409.0824	387.8542
576.8946	619.6847	763.6322	809.3479	752.8084	678.6082
576.8946	619.6847	763.6322	809.3479	752.8084	678.6082
340.367814	365.613973	450.542998	477.515261	444.156956	400.378838
877.8503147	594.438541	678.703175	782.375637	786.166705	722.386318
877.8503147	594.438541	678.703175	782.375637	786.166705	722.386318
517.9316857	350.7187392	400.4348733	461.6016258	463.838356	426.2079276
1155.059579	761.6514875	628.9870409	721.2088844	783.9299749	760.0167463
1155.059579	761.6514875	628.9870409	721.2088844	783.9299749	760.0167463
681.4851517	449.3743776	371.1023542	425.5132418	462.5186852	448.4098803
1294.909193	993.7622615	707.2590644	666.7979968	746.9245315	774.1255512
1294.909193	993.7622615	707.2590644	666.7979968	746.9245315	774.1255512
763.9964239	586.3197343	417.282848	393.4108181	440.6854736	456.7340752
1308.939692	1171.438951	876.2959507	690.6700267	699.649876	758.0769496
1308.939692	1171.438951	876.2959507	690.6700267	699.649876	758.0769496
772.2744184	691.1489811	517.0146109	407.4953157	412.7934268	447.2654002
1246.343888	1252.564388	1050.430321	800.1893219	694.3517649	723.6049762
1246.343888	1252.564388	1050.430321	800.1893219	694.3517649	723.6049762
735.3428941	739.0129891	619.7538894	472.1116999	409.6675413	426.9269359
1151.78217	1248.894293	1169.689421	947.8315113	756.7959235	706.3455815
1151.78217	1248.894293	1169.689421	947.8315113	756.7959235	706.3455815
679.55148	736.847633	690.1167582	559.2205917	446.5095949	416.7438931
1054.659246	1191.59814	1216.420296	1078.727678	869.5069203	736.1112833
1054.659246	1191.59814	1216.420296	1078.727678	869.5069203	736.1112833
622.2489552	703.0429028	717.6879743	636.4493299	513.009083	434.3056571
970.5515137	1110.804193	1201.775224	1159.966322	992.9471673	814.8147091
970.5515137	1110.804193	1201.775224	1159.966322	992.9471673	814.8147091

11	12	13	14	15	16
653	689	478	456	383	312
		128.4093721	122.4993173	102.888681	83.81532234
653	689	349.5906279	333.5006827	280.111319	228.1846777
		323.3260071	357.7230722	344.9112261	319.6837766
385.27	406.51	206.2584705	196.7654028	165.2656782	134.6289598
627.04	667.76	549.8421575	342.9937504	311.6110436	258.8213961
		147.7089669	92.14144792	83.71083355	69.52948315
627.04	667.76	402.1331906	250.8523025	227.9002101	189.2919129
		371.9210655	269.0718819	280.621794	265.1955172
369.9536	393.9784	237.2585824	148.0028585	134.4611239	111.6822286
644.9406	643.7352	558.8530081	340.1080265	241.4419446	212.0708082
		150.1296315	91.36623035	64.86068722	56.97045882
644.9406	643.7352	408.7233767	248.7417961	176.5812574	155.1003494
		378.0161333	266.8080879	217.4309064	217.2935798
380.514954	379.803768	241.1467922	146.7576597	104.1829419	91.50920616
664.804484	644.446386	547.3803524	343.1309286	219.1559752	167.7740851
		147.0476304	92.17829933	58.87380996	45.0706379
664.804484	644.446386	400.332722	250.9526293	160.2821653	122.7034472
		370.2558656	269.1794955	197.3612431	171.9059396
392.2346456	380.2233677	236.196306	148.0620513	94.56647751	72.39503386
698.7777661	656.4576638	544.3597838	339.086884	213.7777391	144.8748909
		146.2361883	91.09191182	57.42900676	38.91902461
698.7777661	656.4576638	398.1235955	247.9949722	156.3487323	105.9558663
		368.2127099	266.0070217	192.5178645	148.4427957
412.278882	387.3100217	234.8929213	146.3170336	92.24575206	62.51396109
734.9087644	681.4265241	550.5406958	336.5708599	210.4200138	135.6876572
		147.8966214	90.41600999	56.52699131	36.45097669
734.9087644	681.4265241	402.6440744	246.1548499	153.8930225	99.23668053
		372.3935668	264.03325	189.49406	139.0293035
433.596171	402.0416492	237.5600039	145.2313615	90.7968833	58.54964151
758.0466686	712.9810459	567.1257197	338.4834924	208.3275007	131.4839223
		152.3520032	90.92981737	55.96486098	35.32169017
758.0466686	712.9810459	414.7737165	247.553675	152.3626397	96.16223215
		383.6119132	265.5336727	187.6096441	134.7220412
447.2475345	420.6588171	244.7164927	146.0566682	89.89395744	56.73571697
758.0645344	739.5697633	590.7160409	346.2134995	208.5253505	129.3204726
		158.6892801	93.00639762	56.01801113	34.74050352
758.0645344	739.5697633	432.0267608	253.2071019	152.5073394	94.5799691
		399.5687424	271.597712	187.7878181	132.5053112
447.2580753	436.3461603	254.8957889	149.3921901	89.97933025	55.80218177
737.733395	750.4816782	613.4771323	358.7107006	211.9201993	128.7571176
		164.8037936	96.36363141	56.9299994	34.58916447
737.733395	750.4816782	448.6733387	262.3470692	154.9901999	94.16795312
		414.9646687	281.4015216	190.8450542	131.9280821
435.2627031	442.7841902	264.7172698	154.7847708	91.44421792	55.55909234
719.2145851	742.9601911	626.740259	372.2795682	218.3307528	130.0530787
		168.3667847	100.0087564	58.65212315	34.93730998
719.2145851	742.9601911	458.3734743	272.2708118	159.6786296	95.11576872
		423.9360365	292.0460326	196.6180878	133.2559595
424.3366052	438.3465128	270.4403498	160.6397789	94.21039149	56.11830354
729.183637	728.9502836	626.2796372	382.0713827	226.1080171	133.2078567
		168.2430438	102.6392183	60.74139852	35.78480591
729.183637	728.9502836	458.0365934	279.4321644	165.3666186	97.42305075

17	18	19	20	21	22
313	284	248	216	202	195
84.0839612	76.29343444	66.62243571	58.02599239	54.26504844	52.38457646
228.9160388	207.7065656	181.3775643	157.9740076	147.7349516	142.6154235
362.0497218	368.2895431	353.3314447	345.8117776	356.5463515	377.7513376
135.0604629	122.5468737	107.0127629	93.20466449	87.16362142	84.14309989
228.4845357	220.2201548	196.911675	171.7821061	153.7759946	145.6359451
61.37982376	59.15968993	52.89812666	46.14734805	41.31020692	39.12347334
167.104712	161.0604648	144.0135484	125.634758	112.4657877	106.5124717
264.2899764	285.5802119	284.5146976	275.0197938	271.4270784	282.1239644
98.59178006	95.02567426	84.96799355	74.12450722	66.35481475	62.84235832
180.1951605	164.6265706	154.0712291	136.4782443	120.2354802	110.0249282
48.40742136	44.22509322	41.38951837	36.66335911	32.29992157	29.55697058
131.7877392	120.4014774	112.6817107	99.81488522	87.93555862	80.46795759
208.4332516	213.4867764	222.6151859	218.4990013	212.2253554	213.1387886
77.75476611	71.03687168	66.48220933	58.89078228	51.88197958	47.47609498
145.5421792	127.1193719	117.2363731	107.4063123	94.94436131	84.87384219
39.09828419	34.14920233	31.49424487	28.8535086	25.50574439	22.80041167
106.443895	92.97016952	85.74212821	78.55280367	69.43861693	62.07343052
168.3498578	164.8476598	169.3930602	171.9554063	167.5844833	164.4164483
62.80189807	54.85240002	50.58785564	46.34615416	40.96878399	36.62332401
116.0370308	100.9196676	90.00667258	82.79450515	74.8159871	66.4188905
31.17205494	27.11094381	24.17928935	22.24182095	20.09848101	17.84269461
84.86497588	73.80872377	65.82738324	60.55268419	54.71750609	48.5761959
134.2210055	130.8720361	130.0492783	132.5523843	132.0562735	128.6657678
50.07033577	43.54714702	38.83815611	35.72608367	32.28332859	28.65995558
97.3086012	80.33191251	70.53637415	63.66475663	58.16026117	52.19956891
26.14087108	21.58027289	18.94881069	17.10282724	15.62410589	14.02283235
71.16773013	58.75163962	51.58756346	46.56192939	42.53615528	38.17673656
112.5576741	104.1739555	101.9169389	101.9260308	102.6575689	101.1202922
41.98896077	34.66346738	30.43666244	27.47153834	25.09633162	22.52427457
87.72841086	66.07713302	55.8143684	49.52705349	44.91136201	40.74879361
23.56725973	17.75088527	14.99390794	13.30489087	12.06493681	10.9467092
64.16115114	48.32624775	40.82046045	36.22216262	32.8464252	29.8020844
101.4761877	85.6884406	80.64533574	79.29184447	79.27218943	78.93800662
37.85507917	28.51248617	24.08407167	21.37107594	19.37939087	17.5832298
83.04178893	57.66884075	45.24887496	38.93515834	34.83811028	31.59824547
22.30825099	15.49209127	12.1556059	10.4594963	9.358870008	8.488516442
60.73353795	42.17674948	33.09326906	28.47566204	25.47924027	23.10972903
96.05513285	74.78461624	65.37941426	62.33442739	61.49208472	61.21168971
35.83278739	24.88428219	19.52502875	16.8006406	15.03275176	13.63474013
80.70293233	53.12525468	38.45252251	31.20005018	27.24712911	24.50774066
21.67994323	14.27150752	10.32984157	8.381545715	7.31963753	6.583731357
59.0229891	38.85374716	28.12268094	22.81850447	19.92749158	17.9240093
93.34975783	68.89252033	55.55946751	49.95067043	48.09338848	47.4760606
34.82356357	22.92371082	16.59238175	13.46291763	11.75722003	10.57516549
79.75851787	50.75359991	34.45401001	25.94796859	21.63318918	19.10606385
21.42623681	13.6343889	9.255685753	6.970632536	5.811515143	5.13263109
58.33228106	37.11921101	25.19832426	18.97733605	15.82167404	13.97343276
92.25734571	65.81697226	49.78207735	41.54219047	38.18433007	37.01200602
34.41604583	21.90033449	14.86701131	11.19662827	9.334787683	8.244325327
80.03453878	49.63492234	32.23164744	22.64771909	17.68351463	15.06389511
21.50038675	13.33386864	8.65867282	6.084057295	4.750479098	4.046747515
58.53415203	36.3010537	23.57297462	16.5636618	12.93303553	11.0171476

23	24	25	26	27	28
142	145	112	107	72	87
38.14671722	38.95263378	30.08755161	28.74435734	19.34199746	23.37158027
103.8532828	106.0473662	81.91244839	78.25564266	52.65800254	63.62841973
300.6561239	334.2847183	280.1715791	289.5052951	210.0806549	272.9991866
61.27343684	62.56794607	48.32834455	46.17082917	31.0682215	37.54076764
126.7229458	104.752857	96.15204991	80.41315804	67.76061021	57.15587359
34.0427069	28.14068742	25.83017646	21.6020986	18.20313265	15.35428836
92.68023893	76.61216957	70.32187344	58.81105944	49.55747756	41.80158523
268.3100684	241.4984779	240.5274255	217.570421	197.711019	179.3506552
54.68134097	45.20118005	41.48990533	34.69852507	29.23891176	24.66293528
100.8412563	86.09233049	74.03314816	65.6024397	55.01709087	46.3775617
27.08987949	23.12774497	19.88818005	17.6233642	14.77972822	12.45881501
73.75137679	62.96458552	54.1449681	47.9790755	40.23736265	33.91874669
213.5108539	198.478279	185.1962859	177.4976978	160.5281456	145.5291566
43.51331231	37.14910546	31.94553118	28.30765455	23.74004396	20.01206055
77.71415946	69.32879237	59.34854238	51.61695214	44.80497323	37.64673011
20.87704271	18.62440731	15.94332439	13.86631885	12.03635665	10.11337442
56.83711675	50.70438506	43.40521799	37.75063329	32.76861659	27.53335569
164.5439293	159.8314195	148.4622753	139.657766	130.7313628	118.1324908
33.53389888	29.91558719	25.60907861	22.27287364	19.33348379	16.24467985
59.92654188	54.32269676	47.71172656	41.08683826	35.70800644	30.62215962
16.09859751	14.59318698	12.81722353	11.03752113	9.592557916	8.226301856
43.82794436	39.72950977	34.89450303	30.04931713	26.11544852	22.39585776
126.8822662	125.2361889	119.3524087	111.16689	104.1883525	96.08993872
25.85848717	23.44041077	20.58775679	17.72909711	15.40811463	13.21355608
46.62941277	42.14758618	37.74715701	32.90797681	28.436431	24.59041631
12.52647199	11.32247924	10.14035299	8.840361167	7.639130226	6.605941249
34.10294077	30.82510694	27.60680402	24.06761564	20.79730077	17.98447506
98.72829933	97.16754465	94.4257195	89.03769662	82.9714451	77.1628006
20.12073506	18.1868131	16.28801437	14.19989323	12.27040746	10.61084029
36.50648029	32.7590289	29.50560275	26.15573679	22.72678655	19.64404223
9.807059015	8.800347972	7.926351298	7.026447147	6.105297886	5.277152987
26.69942127	23.95868093	21.57925145	19.12928964	16.62148866	14.36688925
77.29504832	75.52305345	73.80920815	70.76845137	66.31191946	61.64146611
15.75265855	14.13562175	12.73175835	11.28628089	9.806678311	8.476464655
28.52999252	25.57571773	22.98311484	20.57476711	18.10109124	15.6971029
7.664264485	6.870631493	6.174157625	5.52718185	4.8626564	4.216851729
20.86572803	18.70508624	16.80895722	15.04758526	13.23843484	11.48025117
60.40645751	58.96256275	57.49299623	55.6682619	52.81512641	49.25627959
12.31077954	11.03600088	9.917284759	8.878075301	7.810676555	6.773348192
22.18968862	19.9798649	17.92767334	16.08679471	14.30583359	12.51757954
5.961012515	5.367368003	4.816069615	4.321538091	3.843102735	3.362708217
16.22867611	14.6124969	13.11160373	11.76525662	10.46273085	9.154871318
46.98215333	46.06181731	44.84664776	43.52534814	41.74137345	39.27918427
9.574918904	8.621373168	7.735846198	6.941501408	6.173011202	5.401374078
17.22892269	15.56604263	13.9971307	12.55960141	11.23122106	9.926508442
4.628358042	4.181643848	3.760173145	3.373996926	3.01714235	2.666645849
12.60056465	11.38439878	10.23695755	9.185604487	8.214078706	7.259862593
36.47874026	35.88613915	35.01426973	33.98197302	32.77030937	31.1486061
7.434333144	6.716795282	6.039804955	5.419506648	4.846306437	4.28331893
13.41055683	12.10193665	10.91394788	9.805902795	8.787278917	7.8228501
3.602596615	3.251050387	2.931910447	2.634246486	2.360604535	2.101521483
9.807960219	8.850886258	7.982037431	7.171656309	6.426674382	5.721328617

29	30	32	34	36	38
67	45	72	70	53	44
17.9988032	12.08874841	19.34199746	18.80471976	14.23785924	11.82010956
49.0011968	32.91125159	52.65800254	51.19528024	38.76214076	32.17989044
225.5261138	162.0992707	295.0927169	323.8783454	274.9203632	254.299735
28.91070611	19.41763844	31.0682215	30.20521534	22.86966305	18.98613536
57.63125833	42.40431926	41.00741948	52.0582864	46.09769305	36.06341813
15.48199517	11.39144772	11.01618616	13.98487838	12.38363142	9.688035304
42.14926316	31.01287155	29.99123332	38.07340802	33.71406164	26.37538282
193.9903541	152.749094	168.069317	240.8650237	233.1168777	208.4299471
24.86806526	18.29759421	17.69482766	22.46331073	19.89129636	15.56147586
41.94413318	37.5833426	30.59399987	33.30492494	36.286076	30.70520332
11.26782385	10.09634607	8.218737055	8.946996858	9.74784986	8.248610622
30.67630932	27.48699653	22.37526282	24.35792808	26.53822614	22.4565927
141.1865276	135.3829428	125.3898131	154.0963426	188.2222866	177.4619333
18.0990225	16.21732795	13.20140506	14.37117757	15.65755342	13.24938969
32.58934737	29.36869108	25.39118571	23.18815558	25.25185029	24.86475643
8.754764919	7.889571504	6.821059021	6.229239533	6.783628114	6.679639664
23.83458245	21.47911957	18.57012668	16.95891604	18.46822217	18.18511677
109.6977442	105.7920757	104.0660274	107.2877352	130.9858085	143.7068402
14.06240365	12.67268055	10.95637474	10.00576047	10.89625108	10.72921889
26.01685866	22.86884267	20.28643249	17.90953032	17.57773156	18.35214896
6.989139086	6.14345968	5.449723968	4.811195695	4.722061655	4.930100258
19.02771957	16.72538299	14.83670852	13.09833463	12.8556699	13.4220487
87.57434368	82.37828266	83.14414554	82.86441497	91.17879894	106.0669685
11.22635455	9.867975965	8.753658027	7.72801743	7.584845242	7.919008732
21.0149211	18.08376157	15.95102646	14.12397522	12.99884209	13.08788521
5.645424315	4.858000979	4.285065462	3.794248513	3.491994038	3.515914479
15.36949679	13.2257606	11.665961	10.32972671	9.506848052	9.571970729
70.73751475	65.14143475	65.37544076	65.3492818	67.42729034	75.64194863
9.068003105	7.803193751	6.882916987	6.094538759	5.60904035	5.64746273
16.91233397	14.49[illegible]6495	12.58624276	11.11810494	9.99234646	9.533548349
4.54331001	3.892728757	3.381153627	2.986754966	2.684332498	2.5610815
12.36902396	10.59783619	9.205088933	8.131349973	7.308013962	6.972466849
56.92795456	52.19800024	51.58484127	51.44162045	51.83206638	55.0995186
7.297724136	6.252723354	5.43100247	4.797496484	4.311728237	4.113755441
13.54776448	11.64283697	10.02680982	8.764855959	7.793782208	7.170439646
3.639455919	3.127718378	2.693590695	2.354580857	2.093712718	1.926258687
9.908308559	8.515118597	7.333219121	6.410275102	5.70006949	5.244180959
45.60260707	41.9398974	41.09497986	40.55352922	40.42772519	41.44183867
5.84590205	5.023919972	4.326599281	3.78206231	3.363040999	3.094066766
10.8357547	9.337100675	8.030539812	6.954812073	6.119090801	5.513155192
2.910904721	2.508308022	2.157315009	1.868332743	1.643825538	1.481047691
7.924849979	6.828792653	5.873224802	5.08647933	4.475265263	4.032107501
36.47381564	33.63416023	32.91324738	32.17875753	31.74080501	31.86349782
4.675661488	4.028987665	3.465202633	3.001022805	2.640406505	2.378943426
8.650562569	7.475466476	6.437009834	5.550659159	4.835881563	4.293570581
2.323877212	2.008200745	1.729230943	1.491122714	1.299105679	1.153419879
6.326685357	5.467265731	4.707778891	4.059536445	3.536775883	3.140150702
29.11832475	26.92817031	26.3821489	25.68197578	25.08457199	24.81486047
3.732744361	3.225686781	2.777589546	2.395126503	2.086697771	1.852688914
6.877259927	5.97432331	5.155876127	4.441999488	3.845204615	3.374159559
1.847499223	1.604935366	1.385068652	1.193293651	1.03297136	0.906430356
5.029760704	4.369387945	3.770807474	3.248705838	2.812233255	2.467729203

40	42	44	46	48	50
29	31	18	11	11	9
7.790526756	8.327804464	4.835499366	2.95502739	2.95502739	2.417749683
21.20947324	22.67219554	13.16450063	8.04497261	8.04497261	6.582250317
185.7137324	218.8700376	139.477417	93.16105249	101.4381214	90.05515041
12.51358921	13.37659537	7.767055374	4.74653384	4.74653384	3.883527687
27.68201939	21.80918938	18.77404063	11.06549414	8.04497261	7.44525647
7.436465956	5.858795635	5.043436753	2.972621662	2.16119222	2.000065163
20.24555343	15.95039375	13.73060387	8.092872462	5.88378039	5.445171306
177.2734876	153.9799387	145.4752607	93.71573462	74.18790077	74.49618792
11.94487653	9.410732312	8.101056286	4.774794764	3.47143043	3.212651071
23.86215277	18.48453796	15.0402799	11.419134	7.187144724	5.703950666
6.410301367	4.965665089	4.040403551	3.067623068	1.93074632	1.532302768
17.45185141	13.51887287	10.99987635	8.351610935	5.256396404	4.171647896
152.8113605	130.5068232	116.5432995	96.71077657	66.27731448	57.07445946
10.29659233	7.976134996	6.489927046	4.927391452	3.101275059	2.46127226
20.40464877	15.83933021	12.4860843	9.914048529	7.082514797	4.811650697
5.481481455	4.25505951	3.354247373	2.663298095	1.902638656	1.292596327
14.92316731	11.5842707	9.131836926	7.250748434	5.179876141	3.519054369
130.6697752	111.8307999	96.75148811	83.96390992	65.31245418	48.14599191
8.804668716	6.834719712	5.387783786	4.277941576	3.056126923	2.076242078
16.84771749	13.5542197	10.57877285	8.360590644	6.401690794	4.496939215
4.525951513	3.641190043	2.841869412	2.245979487	1.719742876	1.208589873
12.32176598	9.913029659	7.736903439	6.114611158	4.681947918	3.290349341
107.8914654	95.69717985	81.97221733	70.80740217	59.03413528	45.01696085
7.269841926	5.848687499	4.564773029	3.607620583	2.762349271	1.941306111
12.97093278	11.33418409	9.020817909	7.071763604	5.527219229	4.111392501
3.484496514	3.04480222	2.423342182	1.899750468	1.484825838	1.104479769
9.486436269	8.289381866	6.597475727	5.172013136	4.042393392	3.006912733
83.06483931	80.02300957	69.90002116	59.89208548	50.97006685	41.1391189
5.596997399	4.890735301	3.892510679	3.05148775	2.385012101	1.774078512
9.5369016	8.995643964	7.595700349	6.013036065	4.708869041	3.617846322
2.561962313	2.416579482	2.040500235	1.615335115	1.264965181	0.971894089
6.974919287	6.579064481	5.555200115	4.397700949	3.44388386	2.645952233
61.07357213	63.51215911	58.85714804	50.9255244	43.42352996	36.20063274
4.115202379	3.881648044	3.277568068	2.59464356	2.031891477	1.561111817
6.973472349	6.812618817	6.159230091	5.080625457	4.006635942	3.116731893
1.873345618	1.830134109	1.654621943	1.364853399	1.076338087	0.837275283
5.100126731	4.982484707	4.504658148	3.715772058	2.930297856	2.27945661
44.65757165	48.09929472	47.72669319	43.02876499	36.94778393	31.18641771
3.009074771	2.939665977	2.657748307	2.192305514	1.728875735	1.3448794
5.185118726	5.051893501	4.786575818	4.181214851	3.393727635	2.663452945
1.392924351	1.357134879	1.285860241	1.123236765	0.911687102	0.715506946
3.792194375	3.694758622	3.500715577	3.057978087	2.482040534	1.947945999
33.20509488	35.66800388	37.08995729	35.41148875	31.29575963	26.65085062
2.237394681	2.179907587	2.065422191	1.804207071	1.464403915	1.149288139
3.93374312	3.752245716	3.615200974	3.319193206	2.82184369	2.263061774
1.056756242	1.007998988	0.971183445	0.891664258	0.758056854	0.607946321
2.876986877	2.744246728	2.644017528	2.427528948	2.063786836	1.655115454
25.19138335	26.49206971	28.01327187	28.11086659	26.02204753	22.64448539
1.697422258	1.61910557	1.559970342	1.432242079	1.217634233	0.976518118
3.032253534	2.822563416	2.703152756	2.555257211	2.278394682	1.896231569
0.814581113	0.758250201	0.726171858	0.686441368	0.612065336	0.509401475
2.21767242	2.064313216	1.976980899	1.868815843	1.666329347	1.386830094

52	54	56	58	60	62
6	2	8	9	5	3
1.611833122	0.537277707	2.149110829	2.417749683	1.343194268	0.805916561
4.388166878	1.462722293	5.850889171	6.582250317	3.656805732	2.194083439
64.93576713	23.34229499	100.4134939	121.1782104	72.04412033	46.15626643
2.589018458	0.863006153	3.452024611	3.883527687	2.157515382	1.294509229
5.682676107	3.188734598	3.261870713	6.150747241	5.382818037	3.057089592
1.526587595	0.856618007	0.876265209	1.652329688	1.446034067	0.821253043
4.156088512	2.332116591	2.385605504	4.498417553	3.93678397	2.235836548
61.50148872	37.21619181	40.94197938	82.81517147	77.56007808	47.03461389
2.452092222	1.375948789	1.407507247	2.654066356	2.322702542	1.319143563
4.916647361	3.408260024	2.354047045	3.251858444	4.268147784	3.239395527
1.320802511	0.915591066	0.5323885	0.873575525	1.146590328	0.870227501
3.59584485	2.492668958	1.721658545	2.378282919	3.121557456	2.369168026
53.21104468	39.77830544	29.54726109	43.78382074	61.49899051	49.83946767
2.121548461	1.470674685	1.015778542	1.403186922	1.841718899	1.397809135
3.935568648	3.143542734	2.176554689	1.990874539	2.683025479	2.81307779
1.05724665	0.844477717	0.584707157	0.534826254	0.720764889	0.755701993
2.878321998	2.299065018	1.591847533	1.456048285	1.96226059	2.057375797
42.59319487	36.68875091	27.31943263	26.80562375	38.6592421	43.28038931
1.698209979	1.35644836	0.939190044	0.859068488	1.157733748	1.21385172
3.256354097	2.640826636	2.009105849	1.536169841	1.66359533	2.001257825
0.874783232	0.70942864	0.539723892	0.412674905	0.446906342	0.537615608
2.381570865	1.931397996	1.469381957	1.123494936	1.216688988	1.463642217
35.24230855	30.82147717	25.21766725	20.68336802	23.97045243	30.79019645
1.405126811	1.139524818	0.866935354	0.662862012	0.717846503	0.863548908
2.917750166	2.196999989	1.74197142	1.327568278	1.161704497	1.317939812
0.78382106	0.590199558	0.467961205	0.35663642	0.312078964	0.35404984
2.133929106	1.60680043	1.274010214	0.970931858	0.849625533	0.963889971
31.57772422	25.64151091	21.86467957	17.87470535	16.73879572	20.27706036
1.259018173	0.948012254	0.751666027	0.572849796	0.501279064	0.568695083
2.648989446	1.917806349	1.470356442	1.149748088	0.921196264	0.896473953
0.711621488	0.515197299	0.394994869	0.308867008	0.247469108	0.240827735
1.937367958	1.40260905	1.075361573	0.84088108	0.673727156	0.655646218
28.66902696	22.38300076	18.45545346	15.48049064	13.27335491	13.7926302
1.143047095	0.827539339	0.634463328	0.496119837	0.397499022	0.386831268
2.35543268	1.718116806	1.268437584	0.979224571	0.772347971	0.666313971
0.632760735	0.461552929	0.340751619	0.263057766	0.207482674	0.178997821
1.722671945	1.256563876	0.927685966	0.716166805	0.564865297	0.48731615
25.49197133	20.05239465	15.92103121	13.18452012	11.12862603	10.25152173
1.016376448	0.741372687	0.54733472	0.422538415	0.333270526	0.287516528
2.051174897	1.531567637	1.121723933	0.84096311	0.654133187	0.533070147
0.551025273	0.411438574	0.301338632	0.225915366	0.175725589	0.143203353
1.500149624	1.120129063	0.820385302	0.615047744	0.478407597	0.389866794
22.19910258	17.87515179	14.07952742	11.32293385	9.425290002	8.201509242
0.885088278	0.660876147	0.484027328	0.362878169	0.282260482	0.230021408
1.764349485	1.344341194	0.997234121	0.736196903	0.559025284	0.442105868
0.473972823	0.361142277	0.267895831	0.197771092	0.150175911	0.118766814
1.290376662	0.983198917	0.72933829	0.538425811	0.408849372	0.323339054
19.09489789	15.69000436	12.51697029	9.912335911	8.054896962	6.801985408
0.761322231	0.580087361	0.430309591	0.317671228	0.24122113	0.190770042
1.505572549	1.164433787	0.87911606	0.651064173	0.485299471	0.373790142
0.404455284	0.312812158	0.23616473	0.174901133	0.130370294	0.100414555
1.101117265	0.851621629	0.642951329	0.47616304	0.354929177	0.273375587

64	66	68	70	72		Harvest
						Yield
0	1	0	2	0		
0	0.268638854	0	0.537277707	0		
0	0.731361146	0	1.462722293	0		
0	17.43467712	0	39.22402107	0		8051.382724
0	0.431503076	0	0.863006153	0		
1.294509229	0.29985807	0.431503076	0.59971614	0.863006153		
0.347755475	0.080553528	0.115918492	0.161107056	0.231836984		
0.946753754	0.219304542	0.315584585	0.438609084	0.631169169		
21.22223586	5.227928632	7.985971566	11.76163926	17.9062615		6528.258732
0.558584715	0.12938968	0.186194905	0.258779359	0		
1.707312602	0.648499577	0.258779359	0.366024629	0.889948528		
0.4586505	0.174212183	0.06951819	0.098328437	0.239074753		
1.248662102	0.474287394	0.189261169	0.267696192	0.650873776		
27.9897508	11.30638073	4.789316042	7.178478883	18.46528096		5337.739463
0.73671064	0.279829562	0.11166409	0.157940754	0		
1.909760597	0.931168472	0.357426642	0.221419529	0.808814529		
0.513035898	0.250148031	0.096018683	0.059481888	0.217279008		
1.3967247	0.681020441	0.261407958	0.16193764	0.591535521		
31.30669129	16.23462165	6.615014246	4.342482126	16.78185541		4405.448652
0.824067573	0.40180206	0.154230695	0.095543208	0		
1.786508847	1.103285954	0.508979323	0.220625128	0.687078729		
0.479925689	0.296385474	0.136731622	0.059268481	0.184576042		
1.306583158	0.80690048	0.372247701	0.161356646	0.502502687		
29.28809719	19.23543437	9.419850343	4.326902333	14.255995		3683.391247
0.770884063	0.476071283	0.219626144	0.095200421	0		
1.399248003	1.10171326	0.628692841	0.285782369	0.597703108		
0.37589238	0.295962987	0.168891324	0.076772248	0.160566278		
1.023355623	0.805750273	0.459801517	0.209010121	0.437136831		
22.93932749	19.20801497	11.6354284	5.604766827	12.40156646		3129.221779
0.603779818	0.475392661	0.271282895	0.123315971	0		
0.988270889	0.93413743	0.663911283	0.356977044	0.560452802		
0.265487959	0.250945608	0.178352366	0.095897904	0.150559398		
0.72278293	0.683191821	0.485558917	0.26107914	0.409893404		
16.20175231	16.28638447	12.28722787	7.001037553	11.62867078		2710.67402
0.426441929	0.403083175	0.286479761	0.154036693	0		
0.68317227	0.706550576	0.602162331	0.393522208	0.563930096		
0.183526615	0.189806937	0.161764198	0.105715355	0.151493535		
0.499645654	0.516743639	0.440398132	0.287806854	0.412436562		
11.1999534	12.31848115	11.14441939	7.717761698	11.70082014		2400.137238
0.294790936	0.304878747	0.259834898	0.169806044	0		
0.492371247	0.506655828	0.485441981	0.377835708	0.582242605		
0.132270047	0.136107441	0.130408577	0.101501351	0.156412986		
0.360101199	0.370548387	0.355033404	0.276334357	0.425829619		
8.071953828	8.833380772	8.984236895	7.410117886	12.08078102		2171.50714
0.212459708	0.218623548	0.209469708	0.16303727	0		
0.3776629	0.364384546	0.364167244	0.322766794	0.58886689		
0.101454929	0.097887847	0.097834844	0.086707702	0.158192526		
0.276207972	0.2664967	0.2663524	0.236059093	0.430674363		
6.191420625	6.352926914	6.740134972	6.330105773	12.21822635		2000.119158
0.162962703	0.157233053	0.157147916	0.139274865	0		
0.30401531	0.27222635	0.266437537	0.253932144	0.569949228		
0.081670324	0.073130575	0.071575474	0.06821604	0.153110507		
0.222344986	0.199095775	0.194862062	0.185716104	0.416838721		

Oldpop		
Harvest	Totpop	Oldpop
	11069	4248
1141.17785		
	11069	3513.33215
943.8175212		
	11069	2963.493028
796.10937		
	11069	2547.187426
684.2735103		
	11069	2243.137284
602.5938285		
	11069	2027.853477
544.7602335		
	11069	1885.134893
506.4204766		
	11069	1799.373233
483.3815627		
	11069	1752.337831
470.7460261		
	11069	1724.375995
463.2343906		
	11069	1699.488117
456.5485396		

		Yield	50		
		Promotion	50	472.4698576	507.236254
		Popinit	55	784.8750508	824.956068
		Harvest	55		
		Post Harvest	55	784.8750508	824.956068
		Yield	55		
		Promotion	55	463.07628	486.7240801
		Popinit	60	771.2370116	801.3082678
		Harvest	60		
		Post Harvest	60	771.2370116	801.3082678
		Yield	60		
		Promotion	60	455.0298368	472.771878
		Popinit	65	760.4670408	783.5662266

572.6253931	655.3744737	709.0473821	684.3801301	585.8388287	480.7406784
905.1623747	1028.055112	1148.102316	1184.633574	1091.488469	919.9128594
905.1623747	1028.055112	1148.102316	1184.633574	1091.488469	919.9128594
534.0458011	606.5525162	677.3803662	698.9338088	643.9781965	542.7485871
857.8406537	955.548397	1077.274466	1163.080132	1146.444081	1021.142469
857.8406537	955.548397	1077.274466	1163.080132	1146.444081	1021.142469
506.1259857	563.7735542	635.5919347	686.2172776	676.4020078	602.4740567
824.4865461	897.9008285	1005.456085	1112.454789	1156.259351	1095.07042

		423.6244654	299.7275193	203.6219149	136.4884317
430.2183458	430.0806673	270.2415901	164.864977	97.56630496	57.47959994
779.7059696	729.0879621	617.8756706	384.8087775	232.6652906	137.5097558
		165.9854119	103.3745889	62.50293696	36.94046316
779.7059696	729.0879621	451.8902587	281.4341887	170.1623537	100.5692926
		417.9399027	301.8749519	209.5270774	140.8962758
460.026522	430.1618976	266.6152527	166.0461713	100.3957887	59.33588264
862.4280346	758.9525865	615.4369037	382.00327	235.8127363	141.6291986
		165.3302643	102.6209205	63.34846316	38.04710557
862.4280346	758.9525865	450.1066394	279.3823495	172.4642731	103.5820931
		416.290286	299.6740862	212.3615144	145.1171702
508.8325404	447.782026	265.5629172	164.8355862	101.7539212	61.11343491
956.0695508	820.0031009	632.3257482	380.1096805	235.5459382	144.2225793

92.57662141	64.36627772	46.57101933	36.25855554	31.21283476	29.18157194
34.5351497	21.41762168	13.90805503	9.77256046	7.630490962	6.500117083
81.47860227	49.41858171	31.08254128	20.69915636	15.07510503	12.14752148
21.88831831	13.27575114	8.349978258	5.560597637	4.049758933	3.263296244
59.59028396	36.14283057	22.73256302	15.13855873	11.02534609	8.884225233
94.24698175	64.08572846	44.91069323	33.13894471	26.60878067	23.53201275
35.15826754	21.32427004	13.41221218	8.931749648	6.504954195	5.241692887
83.76789906	49.97682807	30.64462088	19.61902126	13.45214155	10.14748654
22.50331238	13.4257178	8.232335823	5.270431381	3.613767884	2.726009152
61.26458669	36.55111027	22.41228505	14.34858988	9.838373662	7.421477389
96.89503052	64.80965908	44.27794867	31.40966952	23.74411875	19.65757238
36.14610615	21.56515506	13.22324818	8.465668028	5.804640461	4.378671659
86.23191545	51.13206136	30.75419193	19.10617003	12.49940123	8.84744619

28.39412703	27.89994816	27.30158938	26.53140918	25.63940708	24.54749097
5.786696529	5.222022892	4.709402084	4.231277222	3.791737885	3.375583884
10.52138077	9.415559695	8.494658239	7.649781171	6.866213719	6.137482618
2.82645167	2.529385217	2.281995251	2.055028445	1.844531782	1.648766295
7.694929103	6.886174678	6.212662987	5.594752726	5.021681937	4.488716323
22.27688424	21.70674336	21.24965904	20.69768369	20.03414826	19.2589398
4.540008171	4.06284306	3.665471162	3.300904109	2.962792343	2.648342631
8.39661382	7.363339789	6.610034885	5.95931978	5.359793703	4.803166035
2.255656711	1.97807916	1.775712194	1.600904834	1.439648836	1.290317018
6.140957108	5.385260629	4.834322691	4.358414946	3.919944866	3.512849017
17.77812229	16.97553081	16.53521349	16.12387506	15.63873571	15.07195886
3.623164694	3.177303771	2.852250388	2.571464818	2.312767471	2.07258092
6.896464074	5.831121552	5.159376074	4.639200515	4.178642213	3.753035568

23.14927918	21.52074337	21.13140964	20.55239207	19.94575565	19.50108822
2.967558815	2.577938888	2.22477641	1.916736444	1.65921762	1.45596023
5.437785772	4.759007873	4.123969952	3.556745803	3.069752079	2.670986594
1.460800536	1.278454419	1.10785856	0.955480115	0.82465468	0.717530777
3.976985236	3.480553453	3.016111392	2.601265688	2.245097399	1.953455817
18.30392079	17.14292679	16.90213191	16.45647065	15.92334635	15.43707234
2.346421289	2.053526537	1.779505721	1.534746756	1.324607466	1.152538932
4.278906578	3.773448205	3.290132208	2.846024653	2.45523669	2.125524351
1.149480558	1.0136848	0.883857345	0.7645528	0.65957197	0.570998425
3.12942602	2.759753405	2.406274863	2.081471853	1.79566472	1.554525926
14.40306226	13.59273783	13.48463961	13.16808222	12.73574646	12.2845518
1.846361352	1.628254509	1.419702169	1.228068393	1.059442185	0.917170296
3.355645588	2.977860248	2.614827203	2.273105629	1.964290928	1.696797814

19.41831453	19.92821164	20.94604245	21.6409501	21.0105524	18.97393546
1.308426728	1.217944797	1.16641873	1.102601347	0.983134314	0.818229756
2.365205922	2.154795147	2.028506966	1.932633226	1.785796379	1.551734653
0.635386208	0.578861698	0.544935786	0.519180374	0.479734292	0.416856218
1.729819714	1.575933448	1.48357118	1.413452851	1.306062087	1.134878435
15.14659378	15.21355144	15.71838399	16.3678314	16.46798454	15.52685529
1.020593632	0.929800735	0.875306996	0.833937182	0.770576631	0.669578276
1.861765015	1.666726345	1.538064918	1.454822665	1.369422638	1.23587679
0.500142419	0.447747455	0.413183997	0.390821893	0.367880128	0.332004524
1.361622596	1.218978891	1.124880922	1.064000772	1.00154251	0.903872266
11.92259758	11.76762767	11.91807344	12.32116461	12.62833271	12.36634113
0.803357331	0.719197545	0.663679744	0.627760456	0.590910081	0.533284637
1.47543556	1.303138677	1.180398723	1.09992006	1.038392885	0.96149771

16.29425141	13.59027847	11.03438939	8.766087931	6.992594698	5.750919126
0.649659187	0.502456761	0.379341284	0.280936194	0.209408215	0.161291596
1.269687834	0.998824054	0.766066806	0.574568131	0.426457156	0.321492205
0.341087484	0.268322949	0.205795309	0.154351324	0.114562962	0.086365297
0.92860035	0.730501105	0.560271497	0.420216807	0.311894195	0.235126908
13.74135892	11.65742286	9.615430573	7.736126425	6.144746139	4.946293293
0.547874207	0.430995652	0.330560183	0.247927916	0.184017575	0.138724876
1.05030442	0.84737966	0.660706966	0.502849074	0.375804536	0.280419607
0.282152575	0.2276391	0.177491562	0.135064799	0.1009557	0.075331602
0.768151845	0.619740559	0.483215404	0.367764275	0.274848836	0.205068005
11.36705387	9.889692992	8.292966868	6.770483435	5.41490144	4.314374033
0.453209588	0.36564693	0.285097088	0.216980922	0.162160813	0.121001923
0.848226893	0.707303218	0.563765246	0.435880441	0.329668945	0.246246895

4.984039106	4.746178516	4.931048491	4.980119887	11.82570934		1865.557475
0.131183542	0.117466507	0.114968617	0.109572501	0		
0.25245304	0.21281281	0.197359953	0.191112219	0.526411222		
0.067818695	0.057169789	0.053018552	0.051340168	0.141414507		
0.184634345	0.15564302	0.144341402	0.139772052	0.384996715		
4.138725198	3.710322622	3.652606574	3.748094862	10.9[illegible]235203		1756.605957
0.108934264	0.091829382	0.085161427	0.082465511	0		
0.214424957	0.172747902	0.151009357	0.142467968	0.467462226		
0.057602875	0.046406798	0.04056698	0.038272432	0.125578516		
0.156822062	0.126341104	0.110442376	0.104195537	0.341883709		
3.515291296	3.011803893	2.794780604	2.794083293	9.699236592		1672.818338
0.092525029	0.074541251	0.065161002	0.061475367	0		
0.185296977	0.144324881	0.119822625	0.107881172	0.403359076		
					Tot Yield	45712.86192
					Tot Not 1	37661.4792

	11069	1673.020245
449.4382407		
	11069	1653.743902
444.259666		
	11069	1657.266062

APPENDIX 4

APPENDIX 4

Results of statistical tests for significance of differences between vegetation types in regard to various factors:

Veg.Type		**Mean**	**Homogeneous Grps.**			**Sig.diff.**
	1.Density:					
3	(trees/ha)	2 289		X		3-4 *
4		830	X			3-5 *
5		727	X			4-5
	2.Height:					
3	(m)	2.3	X			3-4 *
4		1.4		X		3-5 *
5		2.6			X	4-5 *
	3.Circ:					
3	(cm)	14.3	X			3-4
4		13.9	X			3-5 *
5		16.6		X		4-5 *
	4.Senility:					
3	(Prop.trees dead)	1.39	X			3-4 *
4		1.84		X		3-5
5		1.41	X			4-5 *
	5.Age:					
3	(Years)	25		X		3-4
4		21	X	X		3-5 *
5		19	X			4-5
	6.Growth Rate:					
3	(cm/yr)	0.59	X			3-4
4		0.56	X			3-5 *
5		0.71		X		4-5 *
	7.Total Wgt:					
3	(kg/tree)	10.4	X	X		3-4
4		6.1	X			3-5
5		11.9		X		4-5 *

8.Charcoal Wgt:

3	(kg/tree)	6.5	X	3-4
4		3.9	X	3-5
5		7.8	X	4-5

* Denotes a statistically significant difference

3- *C.mopane* woodland

4- *C.mopane* shrubland

5- *C.mopane/C.apiculatum* open woodland