Population dynamics of Marula, *Sclerocarya birrea* sub sp. c*affra* in Mwenezi, Zimbabwe

By

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ABSTRACT

This study, conducted in Ward 3, Mwenezi, determined the abundance, distribution and size structure of Marula, *Sclerocarya birrea* subsp. *caffra.* The relationship between incidence of debarked stems and size structure was investigated. The study also aimed at establishing whether the current *S. birrea* population will be able to sustain continued extraction. Results indicate that communities vary spatially and cannot, therefore, be extrapolated from one site to another. Marula stem densities varied from transect to transect, with a pooled density of 7 stems/ ha, but distance from processing centre to each of the belt transects could not be related to the distribution of Marula ($r^2 < 0.025$, $p>0.05$). There were no significant differences, at transect level in total stem counts ($F = 1.16$, $df = 10$, $p>0.05$), number of debarked stems ($F = 1.65$, $df = 10$, $p>0.05$) and fruiting stems ($F = 1.87$, $df = 10$, $p>0.05$). Differences were only significant at size class level. The most debarked stems were those with basal diameters of 40.1 to 60 cm, which coincidentally, had the high fruiting incidence. The population size structure in the various transects differed significantly. Frequency of size classes in Belts 6 and 10 indicated that younger trees (saplings and seedlings) are relatively scarce and that mortality of seedlings and saplings may be sufficiently high to prevent recruitment. Inverse J-shaped distribution of Marula in Belts 2, 4, 5, 7 and 9, across the size classes however, indicates that the population is normal (recruitment into upper size classes is occurring) with no previous record of overexploitation. Marula tree variables: height, basal diameter, basal area and canopy cover were positively correlated, and the relationships could be described by simple linear regression model. Marula population projections carried out using the Leslie matrices seem to show that there may be a gradual decrease in stem numbers on a per size class basis and the overall stem counts.

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DEDICATION

In memory of my father, Stanislaus, and to my mother, Christine

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1. INTRODUCTION

1.1 Timber and Non timber forest resources

Forest resources sustain a number of important ecological and human functions that are demanded and supplied at various levels. Non-timber forest products (NTFPs), for example, are an integral part of the survival and development strategy for the continuing well-being of humans, livestock and native flora (Wickens, 1994). People from different parts of the world use forest products such as fruits, nuts, fibre, wood and oils. These products contribute to daily requirements for food, medicine, energy and construction (Sunderland & Ndoye, 2004).

In a bid to improve rural livelihoods, forest products are being commercialized in their raw state or semi-processed or processed products, depending on local and/or external initiatives. Like other forest resource species, *S. birrea* forms an integral part of the diet, tradition and culture of rural communities in southern Africa (Wynberg *et al*., 2002). It also comprises the basis for various commercial enterprises. Southern Alliance for Indigenous Resources (SAFIRE) has, among other nongovernmental agencies, taken an initiative in promoting the commercialization of indigenous resources in Zimbabwe (Madzara & Siamachira, 2003).

1.2 Marula species

The indigenous African Marula (*Sclerocarya birrea* (A.Rich.) Hochst) belongs to Anacardiaceae, a plant family of some 70 genera and 650 species (Hall *et al.*, 2002; Holtzhausen, 1991; Palgrave, 1983; Shackleton *et al.*, 2002; von Teichman, 1982). Other members of Anacardiaceae include the mango (*Mangifera indica*), cashew nut (*Anacardium occidentale*) and pistachio (*Pistacia vera*). *S. birrea* is one of the two species of *Sclerocarya*, the other being *Sclerocarya gillettii*. The latter is endemic to a small area of arid Eastern Kenya (Hall *et al*., 2002). The Marula is a large, mostly single stemmed, dioecious tree that grows to more than 15m in height (Gadd, 2002; Palgrave, 1983; Shackleton *et al*., 2002; von Teichman, 1982; Wild *et al*., 1972). Although *S. birrea* is considered a dioecious species (single tree with either male flowers or female flowers only), occasional monoecious individuals (bearing both male and female flowers) may occur (Baijnath, 1983; Lewis, 1987; Shackleton *et al.,* 2002; van Wyk & Gericke, 2000).

Three subspecies of *S. birrea* are recognized. These are: *Sclerocarya birrea* (A. Rich.) Hochst. subsp. *birrea*, *Sclerocarya birrea* (A. Rich.) Hochst. subsp. *caffra* (Sond.) Kokwaro, and *Sclerocarya birrea* (A. Rich.) Hochst. subsp *multifoliolata* (Engl.) Kokwaro (Hall *et al*., 2002; Shackleton *et al*., 2002). The subspecies are separated on the basis of gross inflorescence and foliar characteristics (Hall *et al*., 2002). Subsp. *caffra* has long (typically 0.5–3.0 cm) petiolules of the lower pairs of leaflets, acuminate or cuspidate leaflet apices, and frequently longer (up to 22 cm) inflorescences on male plants. Unlike subspecies *caffra,* subspecies *birrea* and *multifoliolata* share characteristics of very short petiolulate lower leaflets, blunter leaflet apices (which are obtuse or abovate) and male inflorescences that are not more than 9cm long. The latter two subspecies, however, differ in leaflet shape, size and number. Subsp. *caffra* was the main focus of the present study. The subspecies extends into southern Africa, and has a high commercialization potential (Hall *et al*., 2002; van Wyk & Gericke, 2000).

In its vegetative stage, *S. birrea,* can be confused with two other members of the Anacardiaceae family namely: *Lannea discolor* (Sond.) Engl. and *L. schweinfurthii* (Engl.) (Hall *et al*., 2002; Shackleton *et al*., 2002). *S. birrea* also resembles *Kirkia acuminata* Oliv., a woodland species, often found on rocky areas. Like *S. birrea*, *K. acuminata* is deciduous (Hall *et al*., 2002).

In recent years, products from *S. birrea* have gained importance as components of many commercial enterprises (SAFIRE, 2003; Shackleton *et al*., 2002; von Teichman, 1993; Wynberg *et al*., 2002). During the long period of Marula exploitation in Zimbabwe, the impact of fruit/seed harvesting on the long term fate of *S. birrea* populations was apparently never studied. According to local informants, however, the Marula tree has never appeared to decline in density. In his study on the impact of seed harvesting on the populations of the Tagua Palm (vegetable ivory - *Phytelephas seemannii*) in Colombia, Bernal (1998) found that over 80% of the seed could be harvested without negative impact on the palm populations. Vegetable ivory is mostly used for button manufacture. In contrast to Tagua Palm, Marula generally exists in lower stocking levels (Khonje *et* *al*., 1999; Hall *et al.*, 2002). On the other hand, research on other species have indicated declines in recruitment and altered population size structures under high exploitation levels (Boot & Gullison, 1995; Cunningham & Milton, 1987). This, therefore, necessitates the need to further examine the *S. birrea* population to ensure sustainable exploitation. Besides providing a history of population change in the past, projecting the current Marula population would attempt to forecast population dynamics.

1.3 Study area

1.3.1 Location

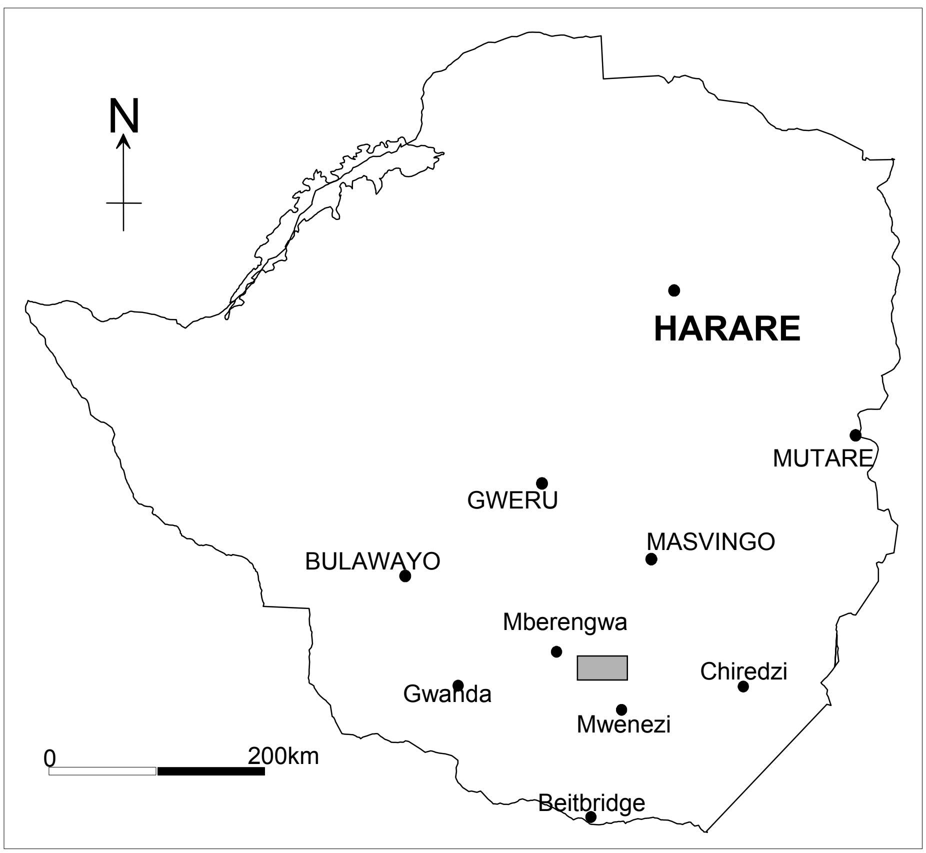

Figure 1.1 Approximate location of Mwenezi Ward 3

The study was carried out in Ward 3 of Mwenezi District in the South- eastern Lowveld of Zimbabwe. Mwenezi is about 478 m above sea level, and lies in the South-eastern part of Masvingo province with Chivi to the North, Chiredzi to the East, Gwanda to the South and Mberengwa to the West (Figure 1.1). Ward 3 approximately extends to the East from 30^{o} 15'E to 30^{o} 45' E. The southern range is approximately 20^{o} 40' S to 20^{o} 55' S.

1.3.2 Geology and soils

The geology of the area is associated with the Zambezi geological mobile belt and the northern zone of the Limpopo geological mobile belt. Parent rocks include magmatitic gneisses, paragneiss and mafic granulites (Anderson *et al*., 1993). The granites (gneisses) generally give rise to light to medium - textured soils which are characterized by the presence of significant amounts of course sand. The mafic rocks (other than basalt) are relatively rich in ferromagnesian minerals. These, therefore, give rise to clayey soils that are red, reddish–brown to yellowish red in the well drained positions (Nyamapfene, 1991). The soils are mainly well-drained, shallow to moderately deep, fine or medium – textured loamy sands to sandy clay loams over brown to red sandy clay loams to clays.

1.3.3 Climate

The climate experienced within the area is divided into two main seasons, that is, hot – rainy summer and cool – dry winter seasons. The summer season normally starts around October and ends in April, and the winter seasons start thereafter. Rainfall in Mwenezi is unpredictable, and the annual rainfall does not exceed 500 mm. The hottest months are normally October to April with maximum temperatures ranging from $28.5^{o}C$ to $31.4^{o}C$

(Figure 1.3). It is during this hot period that high amounts of rainfall are received, with November, December, January and February being the wettest, receiving more than 90mm per month on average (Figure 1.2). The coldest months are June, July and August, with minimum temperatures of 6.0 ^{o}C, 5.6 ^{o}C and 8.0 ^{o}C, respectively (Figure 1.3). The average annual minimum temperature recorded during the period 1970 to 2000 was 13.3 ^{o}C.

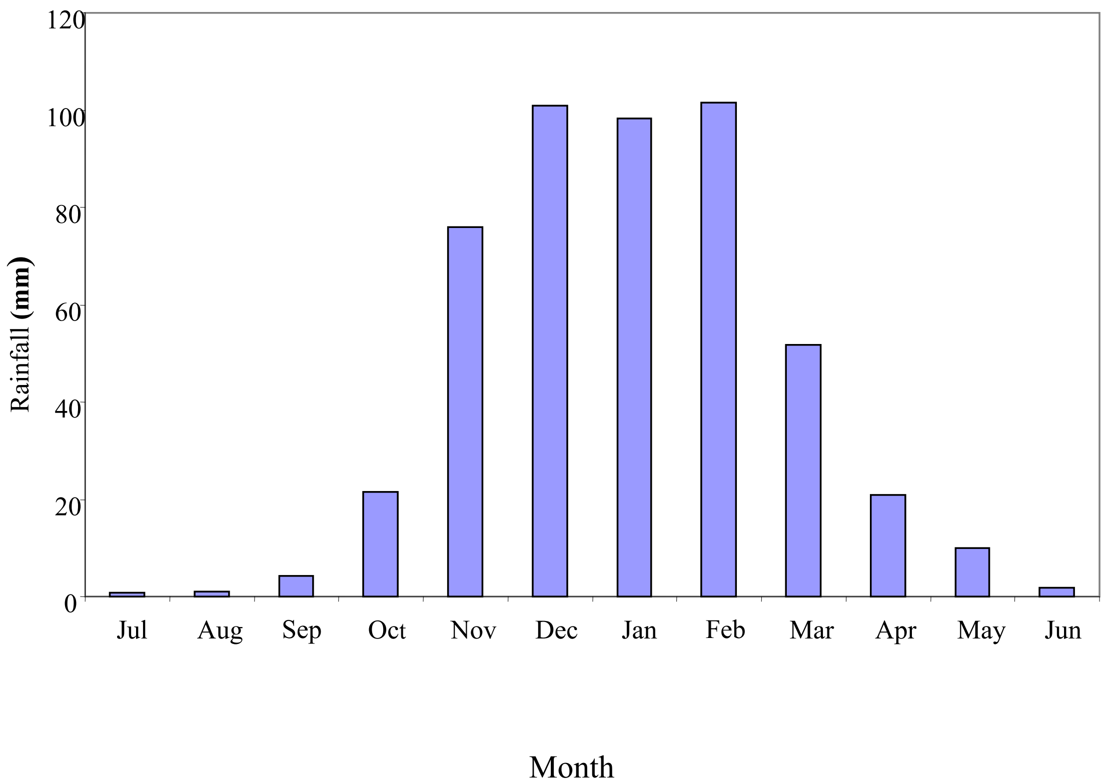

Figure 1.2 Long term average rainfall for Mwenezi (Source: Zimbabwe Meteorological Services Department, 2005)

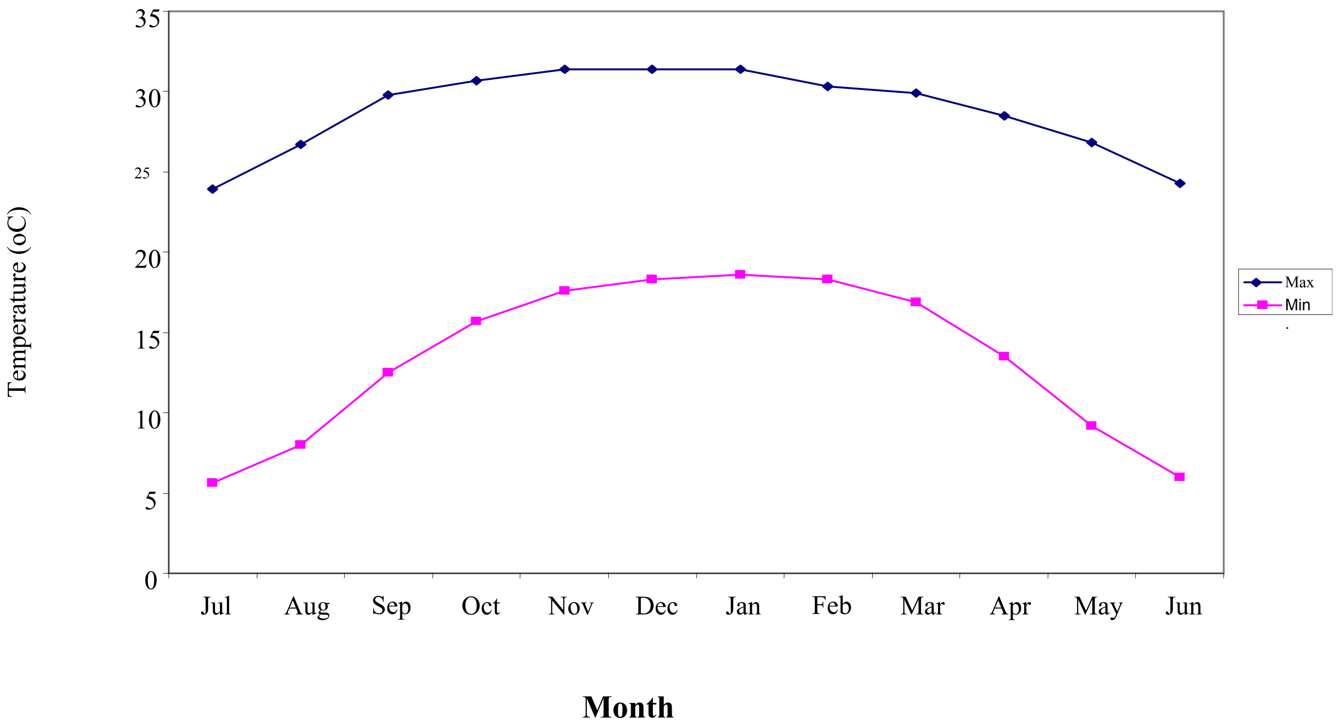

Figure 1.3 Long term average maximum and minimum temperatures for Mwenezi (Source: Zimbabwe Meteorological Services Department, 2005)

1.3.4 Vegetation

The southern African region comprises a variety of vegetation types, ranging from rainforests, woodlands, thickets, shrub-lands and grasslands to semi-arid and arid. Southern African forests and woodlands are mainly composed of deciduous trees (McCullum, 2000). The duration of the leafless conditions depends partly on temperature and availability of soil moisture.

There are six main phytochoria (broad geographical areas with similar groupings of plant species) that constitute vegetation of the southern African region. These are Guineo-Congolian regional centre of endemism, Guinea-Congolia-Zambezia regional transitional zone, Zambezian regional centre of endemism, Afromontane archipelago-like center of endemism, Zanzibar-Inhambane regional mosaic, and Tongaland-Pondoland regional mosaic (McCullum, 2000. The Zambezian region is the largest phytochoria that covers the whole of Malawi, Zambia and Zimbabwe. It also covers more than 80% of Angola, large parts of Tanzania and Mozambique, and smaller areas in DRC, Namibia, Botswana and South Africa (McCullum, 2000.

Vegetation types that are predominantly found within the Zambezian region are: Zambezian dry evergreen forest, Zambezian dry deciduous forest, Zambian woodland and Itigi deciduous thicket (McCullum, 2000). The woodlands are the most widespread, and are of three types: Miombo, Mopane and Undifferentiated Zambezian. Mopane woodland is widespread in the drier half of the region, which includes Mwenezi District of Zimbabwe. The extensive area of soils derived from gneisses, in the south-eastern Lowveld of Zimbabwe, is typically under Mopane open woodland (Anderson *et al*., 1993; McCullum, 2000). It is dominated by *Colophospermum mopane* (particularly in lower slope positions where soils are often more or less sodic), with a high occurrence of *Combretum* sp, *Acacia* sp, *Sclerocarya birrea*, *Kirkia acuminata* and *Linnaea discolor* (McCullum, 2000; White, 1993). There are also dispersed trees of *Kigelia, Albizia* and *Berchemia* within Mwenezi.

1.3.5 Livelihood activities

In many communal areas, crops and livestock farming constitute a major component of the communal people's livelihood activities. Crops that are mostly grown in the area are maize, sorghum, millets, groundnuts, cotton and cowpeas, but due to low erratic rainfall, significant yields are only realized from the drought-tolerant plants.

In order to diversify livelihood options, the local community extracts Marula products for both subsistence and commercial purposes. Fruits are eaten raw, processed into wine (known in local language as Mukumbi). The nuts are cracked and eaten raw, and also used for oil extraction (personal communication, M. Matongo). The local community is also involved in gold panning activities along Runde River (especially during the very dry seasons), and harvesting Mopane worms (*Imbrassia belina*). Business enterprises have also been established based on these worms, in a bid to improve rural livelihoods.

1.4 Problem statement

The efforts in moving towards sustainable management are only likely to yield dividends if there is practical appreciation and participatory management of natural resources by the beneficiaries. *S. birrea* is one of the most highly valued indigenous trees in southern Africa, especially in areas of marginal rainfall (Cunningham & Davis, 1987; Hall *et al*., 2002; Karmann & Lorbach, 1996; Palgrave, 1983; Palgrave & Palgrave, 1985; van Wyk & Gericke, 2000; von Teichman & Robbertse, 1986; Walker, 1989; Wynberg *et al*., 2002). The species is also gaining economic importance as products are marketed more widely (Gadd 2002; SAFIRE, 2003; Shackleton *et al*., 2002).

When bark, fruit, wood and other parts of a species are harvested for the processing of various products (at household and/or commercial levels), there may be significant impacts on the population structure and distribution of the species, depending on the nature and intensity of the harvest (Peters, 1995). A number of external factors may affect the performance of plants and influence their probability of entering different life-cycle stages. These include herbivory and debarking by man (Ehrlen, 1995). According to Cunningham and Milton (1987), commercialization of the basket industry led to population structure changes in Mokola palm (*Hyphaene petersiana*). Also, *Berchemia discolor* whose bark is required for dying the baskets, has had its population decimated despite its wide conservation as a fruit species (Cunningham & Davis, 1997).

Though seldom mentioned, many woodland species are indeed harvested destructively. Destructive exploitation has reduced the economically exploitable populations of valuable timber species such as *Pterocarpus angolensis* (Childes & Walker, 1987), and *Ilala* palms (*Hyphaene petersiana*) (Mabalauta Working Group, 2000). It should also be noted that a woodland or forest that is exploited for fruits or seeds, unlike a logged forest (such as *Pterocarpus angolensis* and *Baikiaea plurijuga* forested area), maintains the appearance of being undisturbed. It is, therefore, easy to overlook the subtle impacts of harvesting of NTFPs (Peters, 1995; Bernal, 1998).

Harvesting of Marula fruit, like the harvesting of the vegetable ivory (*Phytelephas seemannii*), implies the removal of seeds from the population (Bernal, 1998). With time, reduced recruitment will alter the population size-class structure. In addition to its impact on seedling establishment and size structure, extraction of woodland products can also lead to loss of potential genetic material from the population. As the selective removal of the best fruits progresses, the resulting population tends to be dominated by trees of marginal economic value (Peters, 1995).

Although its economic importance is not close to that of *Mangifera indica* (mango) or *Anacardium occidentale* (cashew nut), Marula has definite economic potential. Despite the commercial importance of *S. birrea*, few data are available on abundance and distribution in Zimbabwe. In order to assess sustainability of harvesting a NTFP such as Marula fruit and bark, knowledge of the natural distribution, abundance, population structure and dynamics is very important. Ward 3, Mwenezi, which has got an almost intact Marula population that is currently being utilised by the local community, therefore, presents a relevant study area for population dynamics.

1.5 Study objectives

The current lack of knowledge on Marula population status and the potential impacts of exploitation on the population in Zimbabwe, preclude the development of sustainable harvesting strategies. It was against this background that this research was conducted to assess the abundance and distribution of *S. birrea*, determine the size structure of its population and understand its dynamics, establish whether there is any relationship between the incidence of debarked trees and size classes, and to establish whether the current *S. birrea* population will be able to sustain continued extraction.

The study attempted to answer the following questions:

1. What is the abundance of Marula in Mwenezi Ward 3, and how does it compare with documented levels?
2. How is Marula distributed in terms of its size classes?
3. What size class is mostly debarked, or damaged?
4. Does the Marula population in Mwenezi offer potential long term harvests given its present population structure?

2: LITERATURE REVIEW

2.1 Indigenous forest resource harvesting and potential impacts

The livelihoods of the majority of rural people in African drylands depend on forests and woodlands as sources of firewood and non–timber forest products (NTFPs) such as fruit, seed, fibre, medicines and vegetables (Hall & Bawa, 1993; Karmann & Lobarch, 1996; McCullum, 2000; Mudavanhu, 1998). NTFPs have been defined as biological resources other than timber which are harvested from natural or managed woodland or forest (Mudavanhu, 1998; Peters, 1994; Peters, 1995).

Natural plant populations are often exploited for subsistence or commercial purposes. The rapidly increasing resource demands have resulted in overexploitation of many species to the point of population collapse or near extinction (Hall & Bawa, 1993; Lande *et al*., 2003). Tropical tree species exhibit characteristics that render them susceptible to over-exploitation. They are generally low density resources which are difficult to access. They often produce low yields. Their low densities and scattered distribution complicates pollination. These species also have low recruitment rates due to high seedling mortality (Peters, 1995).

Available evidence indicates that in many cases both timber and NTFPs are not being exploited on a sustainable basis. *Ilala* palms (*Hyphaene petersiana*) are commonly used for craft (basketry) and wine production in southern African countries such as Botswana, Namibia, Zambia and Zimbabwe (Cunningham, 1988; Cunningham & Milton, 1987; Mabalauta Working Group, 2000; Sola, 1998). The commercialization of basketry led to changes in the palm populations as well as scarcity of the species used to dye the palm fibre in North-western Botswana, due to growing demand (Cunningham & Milton, 1987). According to Mabalauta working group (2000) and Sola (1998), wine tapping from *ilala* palms involves the cutting of the growing "heart", leading to gradual reduction in vigour of harvested plants. Due to the destructive nature of palm wine harvesting technology, the structure of palm veldt changed from being dominated by tall palms to high densities of short, multi-stemmed palms (Cunningham, 1988).

The economically exploitable populations of some valuable timber species such as *Pterocarpus angolensis* have been reduced due to destructive exploitation (Childes & Walker, 1987). Bamboo yields in India have also been shown to decline, and some of the explanations for the decline include deforestation and over-exploitation by man (Hall & Bawa, 1993). Whilst some woodland species have suffered from massive logging for timber and fuel, *Sclerocarya birrea* and *Adansonia digitata* have been spared as both are protected by sacred and pragmatic controls (McCullum, 2000; Mudavanhu, 1998; Mukamuri & Kozanayi, 1999).

The impacts of harvesting timber and NTFPs can be summarized as those that kill adult trees (for example palm heart harvesting, logging for timber), and those that may disrupt populations of species surviving on the resource. This may depend on the intensity of exploitation, and the plant part being exploited. Extractive exploitation of woodland resources can also reduce vigour of harvested trees through debarking and leaf harvesting. Lower seedling establishment rates can also result due to removal of reproductive propagules (Mudavanhu, 1998; Peters, 1995). In as much as Peters (1994) asserts that harvesting fruits and seeds only adds to what is normally high seed mortality and may not adversely impact on regeneration, in the long term, commercial harvesting may be as devastating as logging in causing the disruption of local populations and the species at large.

Although several cases of overexploitation of resources have been reported, the exploitation of forest products can be sustainable, depending on the nature and intensity of harvesting, and the type of resource being exploited. Sustainable harvesting, as defined by many authors, is one in which commercial quantities of fruit, nuts, leaves and any other forest products can be harvested indefinitely from a limited area of forest or woodland with negligible impact on the structure and dynamics of the plant populations being exploited (Hall & Bawa, 1993; Mudavanhu, 1998; Peters, 1995).

2.2 Marula distribution in Africa

Sclerocarya birrea is an open woodland tree species that is widespread throughout the semi-arid, deciduous savannas of much of sub-Saharan Africa (Hall *et al,* 2002; Palgrave, 1983; Shackleton *et al*., 2002; Walker, 1989; Walker *et al*., 1986; Wild *et al*., 1972; von Teichman, 1982). The species may also occur as a component of riparian forest (du Toit, 1993; Hall *et al*., 2002; von Teichman, 1988).

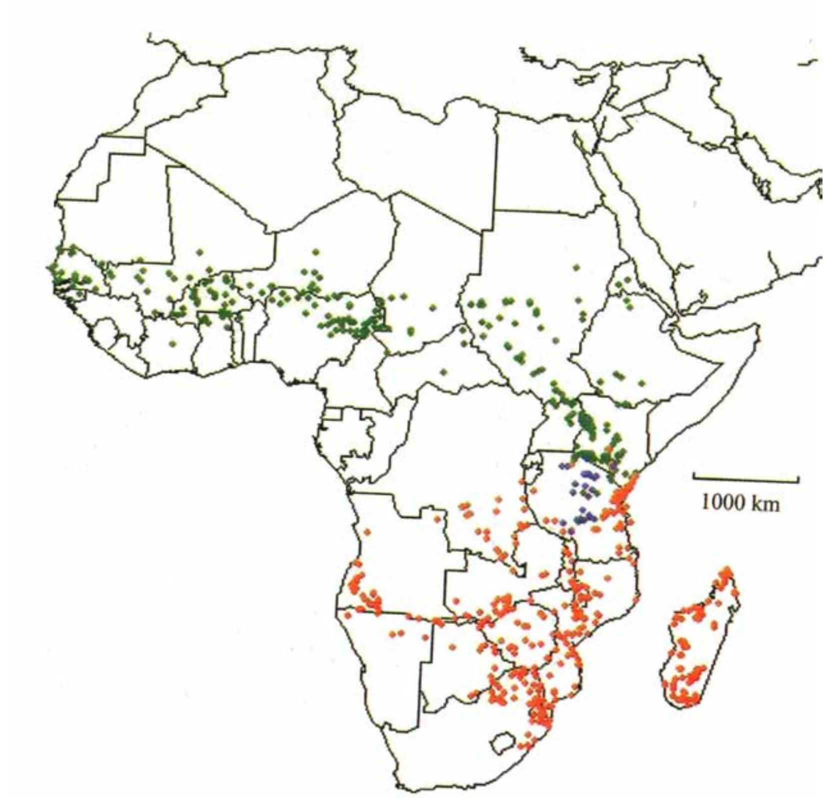

Figure 2.1 Distribution of *Sclerocarya birrea*: green - subsp. *birrea*; red - subsp. *caffra*; blue – subsp. m*ultifoliolata* (Source: Hall *et al*., 2002).

The three *S. birrea* subspecies occupy different parts of sub-Saharan range (Figure 2.1). Subsp. *caffra* is the most ubiquitous and occurs in Kenya and Tanzania (east tropical Africa); Angola, Malawi, Mozambique, Zambia and Zimbabwe (south tropical Africa) and, Botswana, Namibia, South Africa and Swaziland. It has also been recorded in Madagascar (Hall *et al*., 2002; von Teichman, 1982; Shackleton *et al*., 2002). Subsp. *caffra* is recorded only south of the Equator. Subspecies *multifoliolata* is said to be endemic to Tanzania, and occurs in mixed deciduous woodland and wooded grassland (Hall *et al*., 2002; Shackleton *et al*., 2002).

Important environmental factors in Marula distribution are mainly altitude, climate and soils. *S. birrea* is a constituent of medium to low elevation open woodlands (Gadd, 2002; Hall *et al*., 2002; Jacobs & Biggs, 2002a; McCullum, 2000; SEPASAL Database, 2001; Timberlake *et al.*, 1993; von Teichman, 1988). Subsp. *caffra* is associated with a strongly seasonal rainfall pattern with mean annual rainfall of 200–1500 mm, but higher population levels are found between 400 and 1000 mm (Hall *et al*., 2002; McCullum, 2000; Shackleton *et al*., 2002; Shone, 1979). It is common in hotter areas, and is relatively drought- tolerant (tolerating precipitation levels as low as 200 mm per year). It can, therefore, be fully exploited in the drier regions. For most Marula populations in the southern limit of subsp. c*affra*, minimum temperatures can be as low as 5-10 ^{o}C. A key factor that limits its distribution is sensitivity to frost. Populations in south-east Zimbabwe and southwards into South Africa, however, experience occasional frost (Coetzee *et al*., 1979; Hall *et al.*, 2002).

Marula is recorded on a wide variety of soils, from deep sands on granite to sandy loams and basaltic clays (SEPASAL database, 2001; Timberlake, 1980; Timberlake *et al*., 1983; von Teichman, 1982). It should, however, be emphasized that the species has got a preference for well-drained soils (Lewis, 1987; SEPASAL database, 2001), but it is less common on rocky surfaces. Various studies showed Marula populations to be highly clumped (Gadd, 1997; Jacobs & Biggs, 2002a; Lewis, 1987; Walker *et al*., 1986).

According to Lewis (1987), 75% of the population in Luangwa Valley, Zambia, was recorded on well-drained soils.

Previous studies on the population characteristics of Marula reported markedly unstable population structures with no immature trees, and little or no evidence of successful regeneration and recruitment (Gadd, 1997; Lewis, 1987; Walker *et al*., 1986). Severe browsing on Marula seedlings by *Aepyceros melampus* (impala) was noted (Lewis, 1987); Marula seedling mortality was, therefore, attributable to impala browsing in some instances.

2.3 Significance of Marula to African communities

Marula is a prolific fruit bearer which plays a very significant role in the lives of many people in Southern Africa (Hall *et al.*, 2002). Its widespread distribution in Africa is among other factors, evidenced by the various names that it has been given in different countries' vernacular languages. Some of the vernacular names include: Moroela (Afrikaans); Umganu (Ndebele); Mushomo and Mupfura (Shona); Morula (Sotho); Marula, Maroola and Cidar tree (English), Mfula (ChiChewa) and Mufula (Venda) (SEPASAL Database, 2001; Shackleton *et al.*, 2002; von Teichman, 1982).

The species' significance to the rural communities can be classified into nutritional, household, medicinal and cultural uses. Importance of *S. birrea* is reflected in selective conservation of the species and the fact that it is maintained in homesteads and arable lands (Clark *et al*., 1996; van Wyk & Gericke, 2000; Walker, 1989; Wynberg *et al*., 2002). Cutting down Marula is strictly a taboo amongst most rural societies. In certain cases, trees can only be cut with the permission of the chief (Wynberg *et al*., 2002)

Marula fruit is edible and highly nutritious; containing vitamin C of up to 180mg per 100g of flesh (Holtzhausen, 1991; Shackleton *et al*., 2002; Walker, 1989; van Wyk & van Wyk, 1997; van Wyk & Gericke, 2000; von Teichman, 1983; Wynberg *et al*., 2002). It is predominantly eaten fresh and also used in making traditional Marula beer (known as mukumbi in Zimbabwe). The kernels are very rich in protein (28-31%), and are also delicious (Palgrave, 1983; Wynberg *et al*., 2002). They contain about 60% of non-drying oil that is rich in protein. The oil is used for cooking in rural households (Hall *et al*., 2002). In Mberengwa (Zimbabwe), 98% of people interviewed indicated that they are involved in kernel extraction and consumption (Shackleton *et al*., 2002).

The part of Marula tree that is said to have the most significant medicinal properties is the bark (Hall *et al*., 2002; Holtzhausen, 1991; van Wyk & van Wyk, 1997; von Teichman, 1983). The presence of debarked trees especially near homesteads (Personal observation), could be due to use of bark in concoctions, among other uses. The bark extract is used in treating various stomach ailments, liver diseases, sore throat, skin eruptions and malaria, and to ease labour pains. It has proven antihistamine and anti-diarrhoea properties (van Wyk & van Wyk, 1997). Extract from the leaves have also found use in gonorrhoeal treatments (von Teichman, 1983). Leaves are also mixed with bark in a variety of medical treatments (Hall *et al*., 2002; von Teichman, 1986).

Household uses of *S. birrea* include the use of oil as a cosmetic, dye from the bark and ropes from living bark (Gadd, 2002; van Wyk & Gericke, 2000; van Wyk & van Wyk, 1997). The dye that is obtained from *S. birrea* is sometimes used for dying *ilala* palm leaves prior to weaving. The wood is soft and, therefore, popular for carving into drums, stools, kitchen utensils (forks and plates) and animal and bird carvings (Clark *et al*., 1996; Shackleton, 1996; von Teichman, 1983). Gum obtained from Marula is occasionally used as a weak adhesive. In Botswana and Namibia, it is used as a carrier for hunting poison (Hall *et al.*, 2002).

Several African cultures have specific beliefs and ceremonies associated with it, and as a result, exploitation is strongly influenced by regulatory controls and norms at the local level (Wynberg *et al*., 2002). Marula fruits or beer are the central feature of 'first fruits ceremonies' through much of south-eastern Africa with individual trees often selected as places for offerings to ancestors (Cunningham & Davis, 1997). Also, the importance of Marula beer extends beyond a simple role as an alcoholic beverage. Ceremonies that are associated with it are credited for contributing to social cohesion and maintenance of societal standards (Hall *et al*., 2002). Rules and taboos actually have important pragmatic value, and have ensured the survival of valuable trees and woodland areas (Mudavanhu, 1998; Mukamuri & Kozanayi, 1999).

2.4 Commercialization of Marula

Commercialization of *S. birrea* is influenced by a wide set of customary and government laws that regulate its use in southern Africa, comprising different tenure systems, access rights and levels of protection (Wynberg *et al*., 2002). It brings with it a number of threats to the subsistence users, resource base and to the institutions regulating resource use.

In southern Africa, Marula commercial products range from alcoholic beverages, jellies, wood carvings and curios, and oil (Hall *et al*., 2002; Madzara & Siamachira, 2003; McCullum, 2000). Most successful commercial enterprises that have so far been established are based on the fruit and kernels. The South African 'Amarula' cream liquor is internationally the most familiar Marula product, and its market continues to grow.

Marula oil extracted from the nuts is rich in oleic acid that is essential for the maintenance of healthy skin (Hall *et al*., 2002; Madzara & Siamachira, 2003). In Zimbabwe, it is used in soap-making, whilst in South Africa; it is used as aromatherapy carrier oil. Oil extracted from kernels in Madagascar, and processed in-country, is sold as a moisturizer (Hall *et al*., 2002). As a consequence of growing demand for Marula oil, institutions such as Marula Oil Network and Phytotrade Africa have been set up for the purposes of scaling up oil production in the region, and product development and marketing (Madzara & Siamachira, 2003). Recently, there has been the launch of a range of Marula kernel oil- based cosmetics by The Body Shop in the UK (Hall *et al*., 2002).

Use of Marula for commercial carving (wood carvings and curios) has been reported in Zimbabwe (Shackleton *et al*., 2002). There are claims that only male trees are used in wood carvings and curios. Selective logging of the male trees may subsequently lead to reduction in pollen sources that are required to keep the population fully productive. These claims have been disputed (Shackleton *et al*., 2002), and this is therefore, a cause for concern. In as much as the commercialization of *S. birrea* would improve rural livelihoods for Mwenezi communities, it presents new challenges to conservation since harvesting must be sustainable if the resource is to remain economically viable and important to the community.

2.5 The use of projection matrices in population studies

Projection matrix models are widely used in population studies to project the present state of a population into the future, either as an attempt to predict population dynamics or as a way of evaluating life history hypotheses (van Groenendael *et al.*, 1988). Their main aim is not to forecast accurately the future state of the population but to examine the ultimate consequence of the present state and the structure of life cycle, should everything remain the same. The recent use of population matrix models in plant population dynamics includes Valverde and Silvertown (1998) on demography of *Primula vulgaris* and Bernal (1998) on impact of harvesting *Phytelephas seemannii* seed.

Some of the most important models in plant population dynamics studies include Leslie matrix models, and Lefkovitch models. The Leslie model is age-based whilst Lefkovitch model is stage or size-based (Desmet *et al*., 1996; Donovan & Welden, 2002; Valverde & Silvertown, 1998). Though Leslie matrix models have longer history, Lefkovitch models are often more useful. This is mainly because focusing on life-cycle stages helps in identifying the critical transitions that may provide opportunities for management. In cases where one fails to use the Lefkovitch matrix models due to inadequate data, Leslie matrices can be used instead.

According to Werner & Caswell (1977), age class data are unreliable for savanna trees. Populations of the same age can respond differently to the same stimulus due to differences in size (Desmet *et al*., 1996; Donovan & Welden, 2002). Analysis of population structure is, therefore, restricted to size classes. The population size structure is simultaneously the outcome of the past demographic events and indicator of its demographic future (Bullock *et al*., 1996; Ricklefs, 1997). Variation in annual recruitment of individuals into a population is also evident in size structure of a tree species. The number of individuals in the population at time t + 1 depends on the number of individuals of each size class that were in the population at time t, as well as the movements of individuals into new classes (by birth or transition) or out of the system through mortality (Donovan & Welden, 2002).

3. METHODS

3.1 Identification of focal trees and demarcation of belt transects

Most recent 1: 12 500 air photos were scanned and geo-referenced using satellite images of Mwenezi taken on 3 June 2000 (ILWIS, 1997). The aerial photos were examined and conspicuous large trees (focal trees) were mapped out (grid reference points recorded).

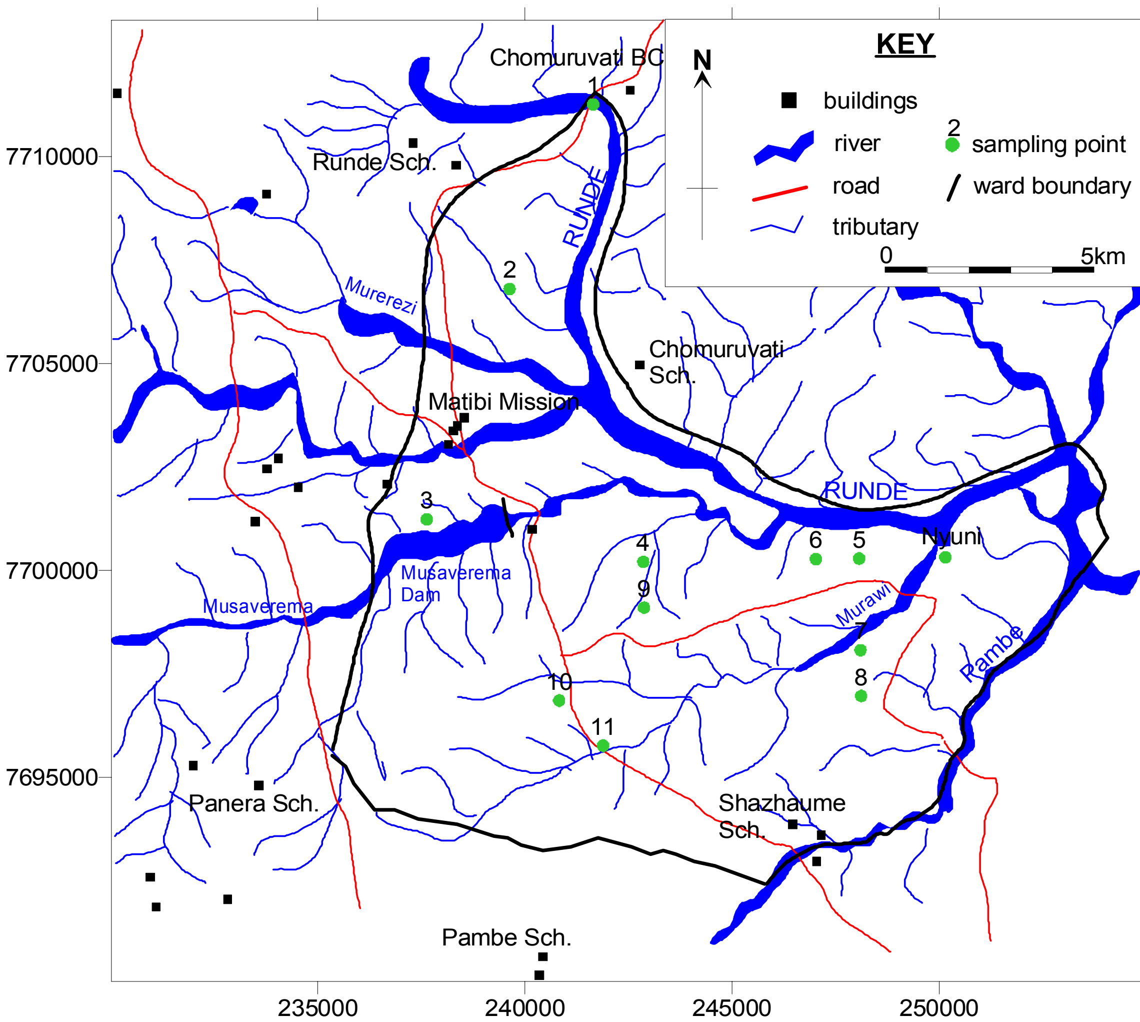

Figure 3.1 Transect locations relative to Nyuni processing centre in Ward 3 (sampling point is focal tree for the transect)

Sample sites were then located with varying distances (about 2km to 13.9km) from the Marula oil processing centre (Nyuni) in Mushezheveti Village, using geographical positioning system (GPS), map and photos. Eleven transects (belts) of variable lengths and fixed width of 20m were thus sighted from the focal trees relative to Nyuni processing centre (Figure 3.1). Belt length was determined by the density of *S. birrea* (Mapaure, 2001; Walker, 1976). The length of each transect ended after 10 large Marula trees were encountered. Belt 1, however, ended at 8 trees after encountering an impassable fence. Trees were defined as woody plants with basal diameter equal to or more than 5cm and height equal to or more than 2 m (Mapaure, 2001).

3.2 Population structure assessments

All Marula individuals encountered within transects (those with at least half of the rooted stem falling within transect (Mapaure, 2001)) were assessed. Measurements taken were: geographical position, height, long and short canopy diameters (D1 & D2), and diameter above basal swelling. Tape measure and ranging rods were used for measuring basal circumference and heights, respectively. Basal diameter was then calculated using the formula: circumference/π. Canopy cover was estimated by $((D1 + D2) /4))^2 \times \pi$, where D1 and D2 are the long and short canopy diameters, respectively. (Mueller-Dombois & Ellenberg, 1974). For each tree, the basal diameter measured was used to classify the species into size classes.

Due to drought that was experienced in some parts of Zimbabwe, including Mwenezi, Marula fruits were harvested earlier than is normally expected. No estimation of fruit production was, therefore, carried out, but only fruit evidence (few nuts or shells) was noted. Trees were categorized as fruiting or non-fruiting, based on fruit evidence. Debarking incidence was recorded on a present - absent basis. All stems falling within the belts were assessed for debarking and fruiting.

3.3 Data analyses

3.3.1 Analysis of variations across belts and size classes

The Kolmogorov – Smirnov test for normality was applied on total stem counts, debarked stems and fruiting stems. Only the total stem counts were normally distributed ($D+ = 0.173$, $D- = 0.068$, $p < 0.01$). Debarked and fruiting stem counts were then transformed using $\log_{10}(n + 1)$, where n was the observed count. After the transformation, both log (number fruiting + 1) and log (number debarked + 1) were significantly normal ($p < 0.05$). Two-way analysis of variance (F – test) for the total number of stems, log (number fruiting + 1) and log (number debarked + 1) was carried out to establish any significant differences across size classes and sites.

3.3.2 Classification of sampling sites

The 11 sites (belt transects) were classified into clusters based on number of Marula stems per size class (ten size classes were considered) within each of the sites. The classification was Hierarchical Cluster Analysis (HCA) using average linkage method.

Results were presented in the form of a dendrogram (Ludwig & Reynolds, 1988; Quinn & Keough, 2002).

3.3.3 Size structure analysis

Size classes were presented in the form of Domin/ Braun- Blanquet scale where trees were classified into ten classes, with smaller graduations nearer to the bottom of the scale (Kent & Coker, 1992). Size (basal diameter) class distribution graphs were plotted separately for the different sites. A single graph for the ward was also plotted from pooled data to show the status of Marula population in the area.

3.3.4 Correlation and Regression analyses

Pearson correlation analysis was carried out for basal diameter (BD), height, basal area and canopy cover, to determine covariation of variables. Regression analyses were then performed on significantly correlated ($p \leq 0.05$) variables (Sokal & Rohlf, 1995; Quinn & Keough, 2002). This was to done to describe the linear relationship between the co-varying variables, and determine how much of the variation could be explained by the linear relationship.

3.4.3 Population projection matrices

The Lefkovitch projection matrix models, which are based on the classification of plants into size categories (Valverde & Silvertown, 1998; van Groenendael *et al.,* 1988), could not be used in projecting the present state of Marula population structure into the future. This was due to the fact that the data were collected over a short time period, and therefore no data on mortalities, survivorships could be captured. Leslie Matrices were used instead (Donovan & Welden, 2002). Transition probabilities were obtained by calculating the proportion of individuals in each category likely to survive from one time-step to the next (Valverde & Silvertown, 1998).

Fecundity was defined by the mean number of seedlings and saplings produced per reproductive plant at a given time. Due to the fact that no data was captured on reproductive capacities of the trees, fecundity assumptions were made based on the fact that as Marula increases in size (age), its productive capacity tends to increase up to a point (Hall *et al*., 2002).

4. RESULTS

4.1 Marula distribution

A total of 173 Marula stems were found in 11 transects (belts) (256 634m^2). This approximated seven stems per hectare. Belt density ranged from 2 stems/ ha (Belt 1) to 27 stems/ ha in Belt 9 (Appendix 3). There were no significant differences in total stem number per belt ($F = 1.16$, $df = 10$, $p>0.05$), but highly significant differences were observed amongst size classes ($F = 4.41$, $df = 9$, $p<0.001$). Class 1 (0-5.0 cm) had the highest number of stems, while Class 10 (80.1-90.0 cm) had the lowest number of stems (0.09 stems on average) (Appendix 5). There was no significant linear relationship between Nyuni–to-belt distances ($r^2 < 0.025$, $p>0.05$) (Table 1), and therefore, no regression analysis was carried out.

Table 1. Correlation coefficients between distance from Nyuni and total stem count, fruiting and debarked trees

	Total stems	*Fruiting stems*	*Number debarked*
Distance from Nyuni (r)	-0.067	-0.149	-0.032
P - value	0.488	0.121	0.740

There was no variation in number of debarked stems across sites, based on the transformation: log (number debarked + 1) ($F = 1.65$, $df = 10$, $p>0.05$). Number of debarked stems, however, varied from size class to size class ($F = 4.30$, $df = 9$, $p<0.05$). Stems with basal diameters in the range 40.1 to 60.0 cm were the most debarked (Appendix 6). 24 debarked stems were recorded in the ward, with the size class range

40.1 to 60cm constituting 67% of the total number of debarked stems. The significantly higher numbers of fruiting trees ($F = 8.25$, $df = 9$, $p<0.05$) recorded were coincidentally in the classes with the highest number of debarked trees (Appendices 6 and 7).

4.1.1 Classification of sampling sites

Using similarity of 75% as the cut-off point, the sampling units were classified into four (4) clusters. They were grouped based on number of Marula stems per size class (ten size classes were considered) within each of the sites. Numbers 1 to 4 are cluster numbers. The clusters are namely: Cluster 1 (b1, b8), Cluster 2 (b6, b10), Cluster 3 (b3, b11) and Cluster 4 (b2, b4, b5, b7, b9) (Figure 4.1).

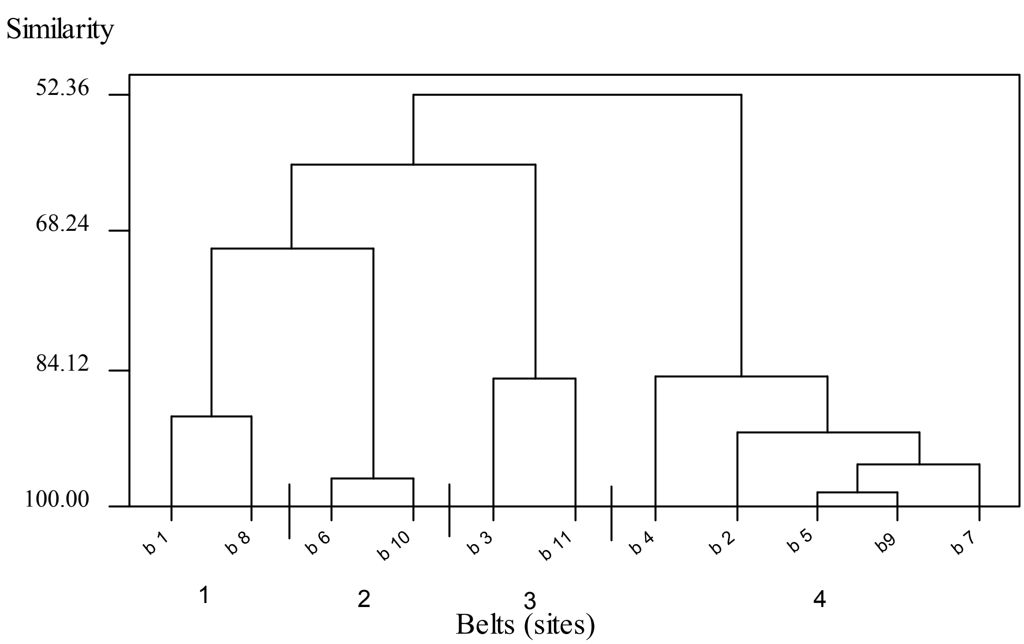

Figure 4.1 Hierarchical cluster analysis using average linkage for belt transects based on number of stems per size class

Cluster 4 constituted the highest number of similar belts (5), whilst only two belts were similar in each of the remaining clusters. There are cluster to cluster differences as shown in size class graphs below. Cluster 4 constitutes populations with inverse J-shaped distributions (Figures 4.3; 4.5-4.6; 4.8 and 4.10), whilst Cluster 2 grouped those with J-shaped distributions (Figures 4.7 and 4.11). Marula distributions in Belts 3 (Figure 4.4) and 11 (Figure 4.12) are positively skewed whilst intermediate size classes dominate in Belts 1 and 8 (Figures 4.2 and 4.9, respectively).

4.1.2 Size structure analysis

Large trees dominated every belt, but rarely exceeded 70 cm in diameter. A total of eight Marula stems were recorded in Belt 1, with all of them having basal diameters ranging from 20.1 to 50.0cm. Lower size classes are not represented in this belt. 50% of the stems recorded fell in the class 20.1 to 30.0 cm (Figure 4.2). The distribution of Marula in Belt 11 is similar to Belt 1 in that they both lacked lower size classes. There was also a gradual decrease in stems as diameter increased. The population in Belt 11 were, however, more skewed to the right (Figure 4.12).

The smallest size class of 0-5.0 cm constituted the highest number of Marula stems (42.9%) in Belt 2. There is almost a gradual decrease in number of stems as size class increased. The distribution approximated an inverse J-shape (Figure 4.3). High stem numbers were recorded in the lowest size classes followed by a sharp decrease in the higher size classes. Of the stems recorded, none exceeded 60 cm in diameter. Overall, the belt had stem density of 12 stems per hectare. Belt 2 is similar to Belts 5, 7 and 9 in that

Class 1 (0-5.0 cm) is the most abundant. Belt 7, however, lacks 20.1 to 30.0 cm size class.

There was representation of all size classes in Belt 3, except Class 1 (0-5.0 cm). Marula density was nine stems per hectare. The distribution of Marula stems across the size classes is unimodal (Figure 4.4). Greater proportion of stems is concentrated in the intermediate size classes. In Belt 4 (Figure 4.5), stems of up to 5 cm, and those that are 50.1 to 60.0 cm in diameter constituted the highest proportions of the total stem count (30%). Trees 40.1 to 50.0 cm in diameter constituted 45% of the total population in Belt 6, and the distribution approximated a J-shape, but with 5.1 to 10 cm – diameter class lacking Marula (Figure 4.7).

Belt 10 was dominated by large trees (40.1-50.0 cm) which constituted approximately 55%, with 20.1 to 70.0 cm – diameter classes (exclusive) constituting less than 10% of the total population (Figure 4.11). Ward 3 size distribution was very similar to Marula distribution in Belt 9. They, however, differed in that Ward 3 had two more distinct peaks and, therefore, approximated a bimodal distribution (Figure 4.13).

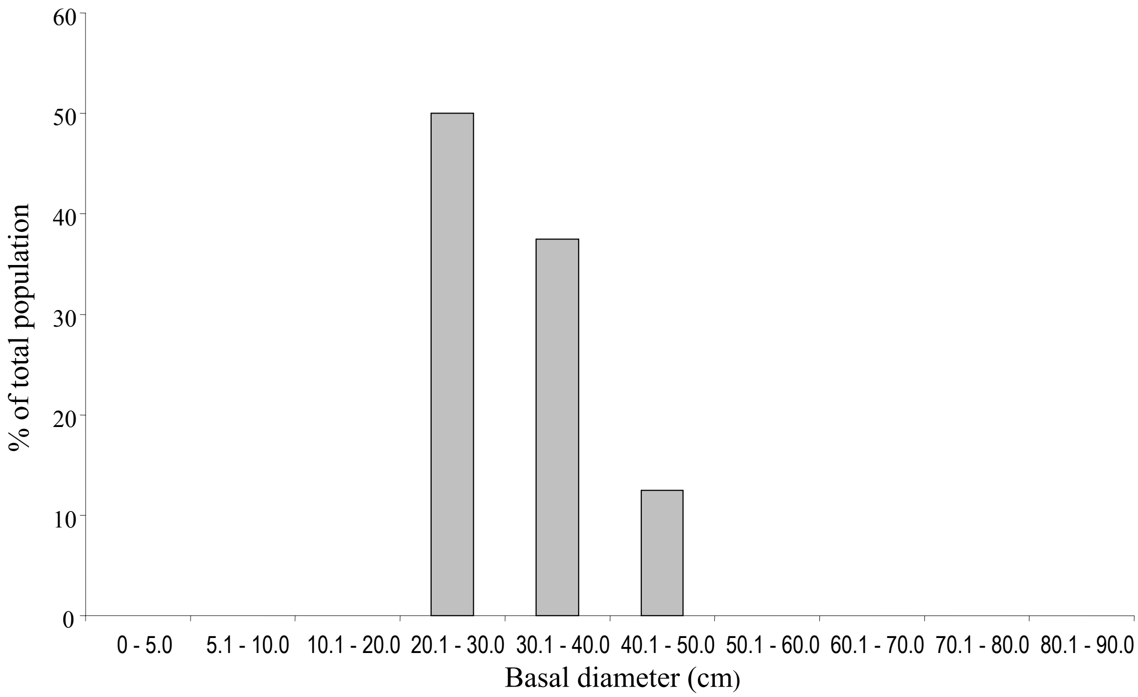

Figure 4.2 Marula size class distributions in Site 1

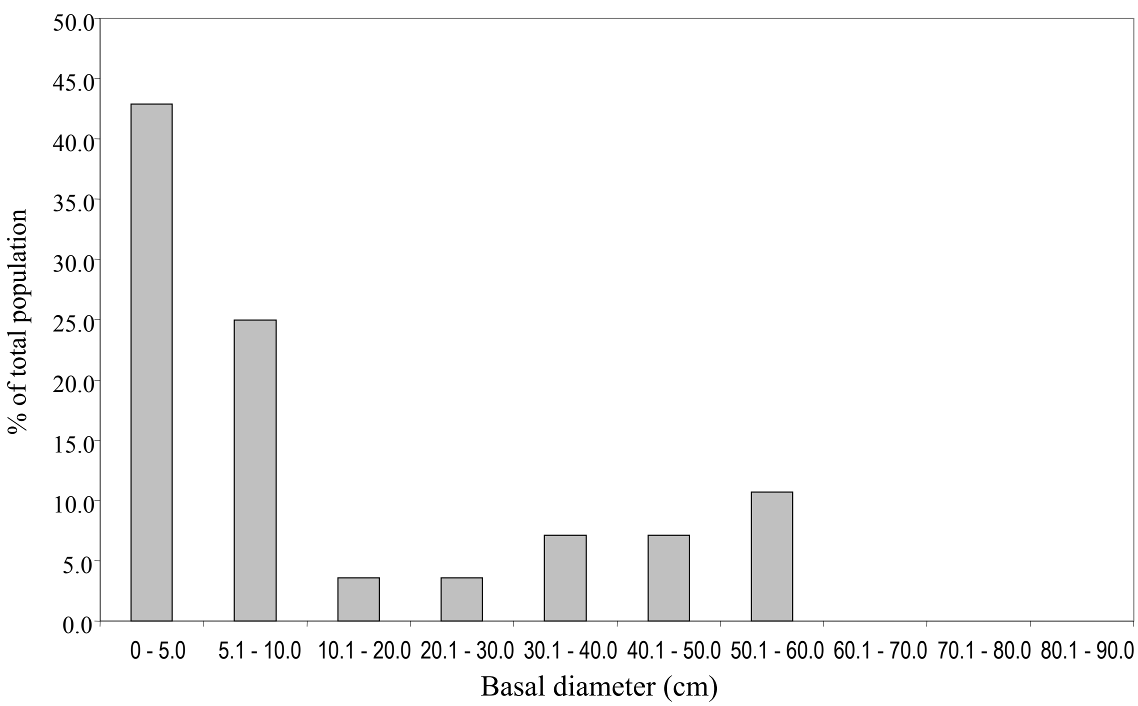

Figure 4.3 Marula size class distributions in Site 2

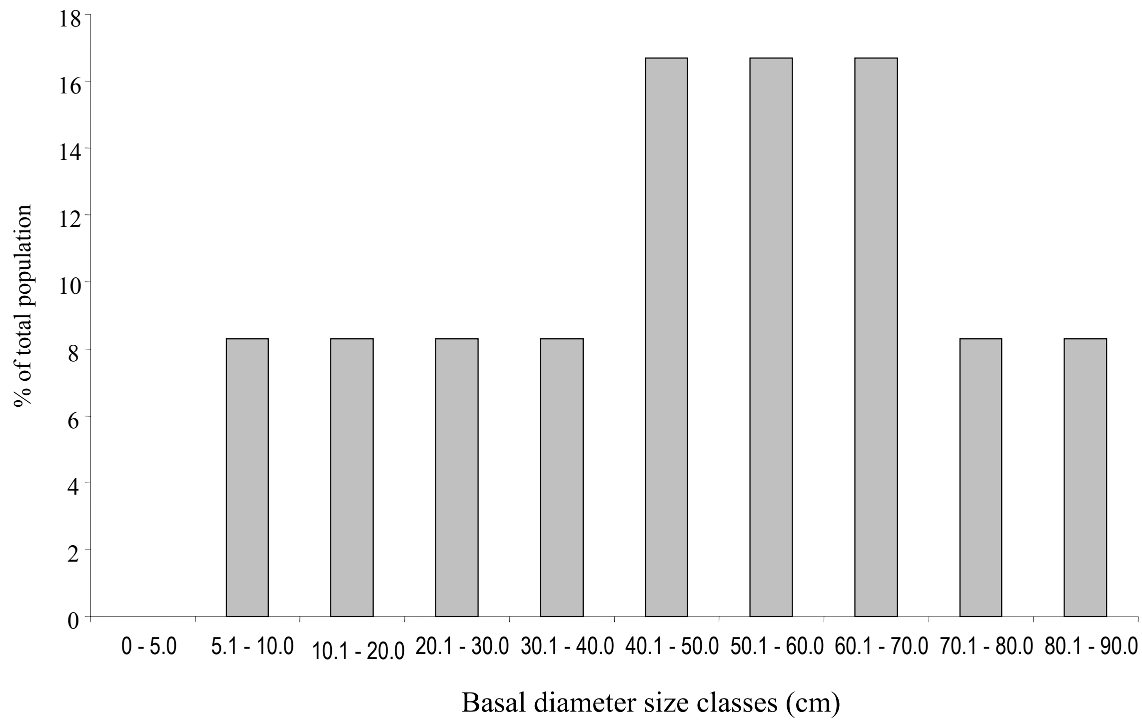

Figure 4.4 Marula size class distributions in Site 3

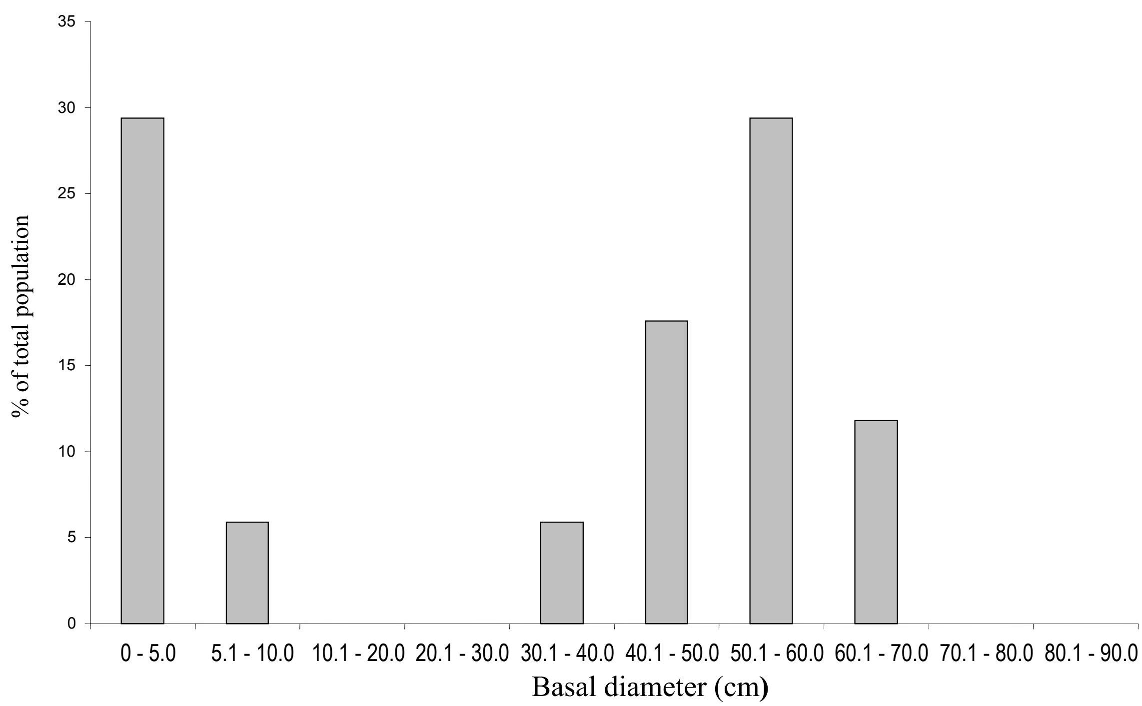

Figure 4.5 Marula size class distributions in Site 4

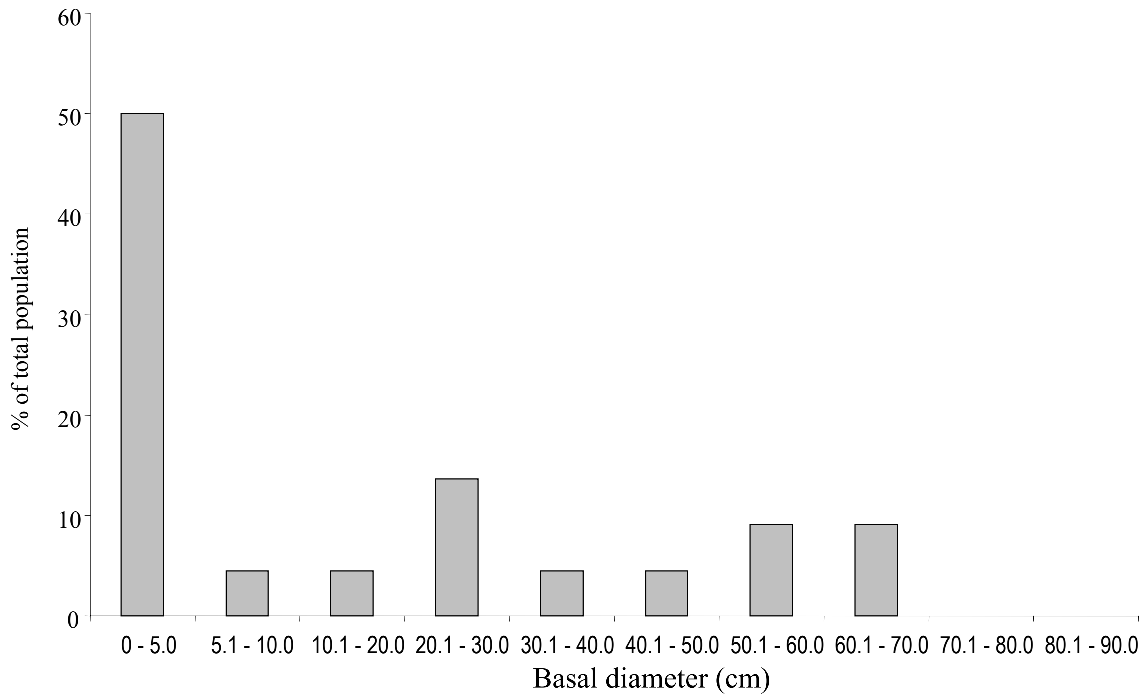

Figure 4.6 Marula size class distributions in Site 5

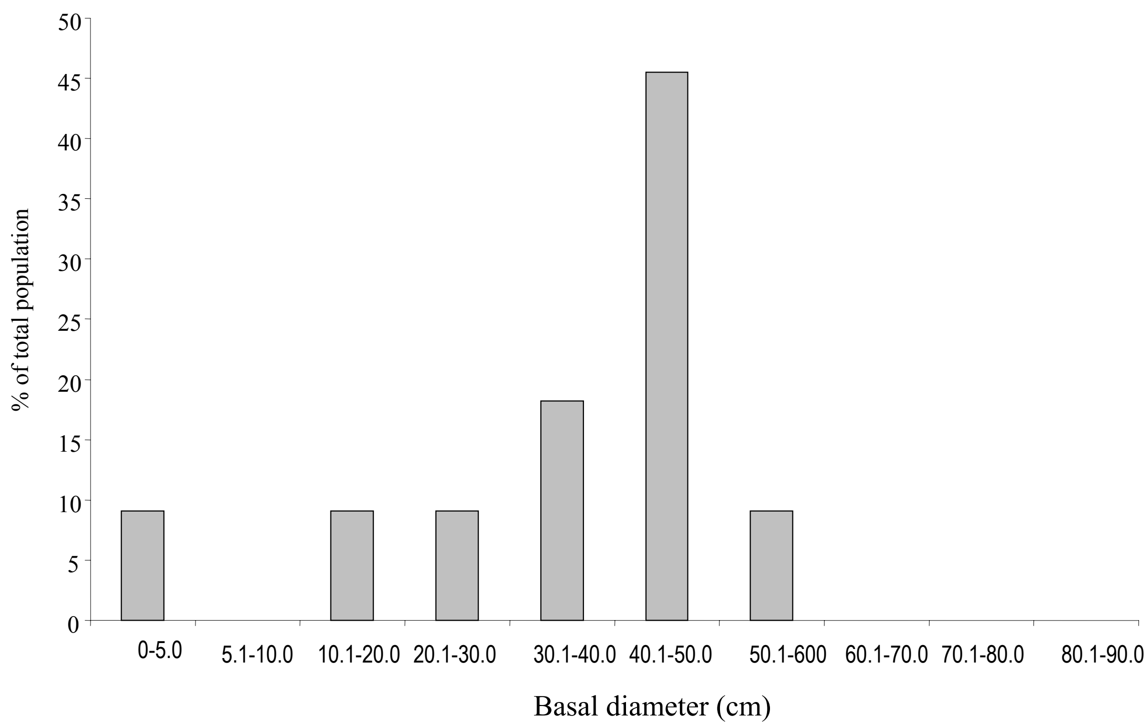

Figure 4.7 Marula size class distributions in Belt 6

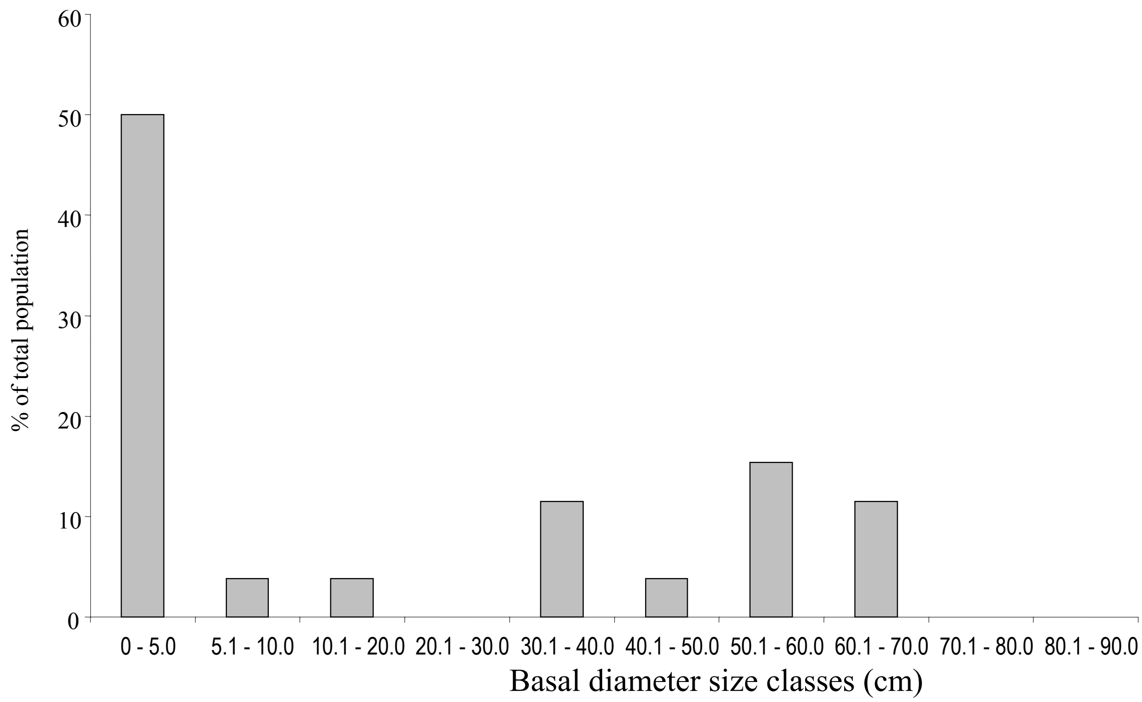

Figure 4.8 Marula size class distributions in Site 7

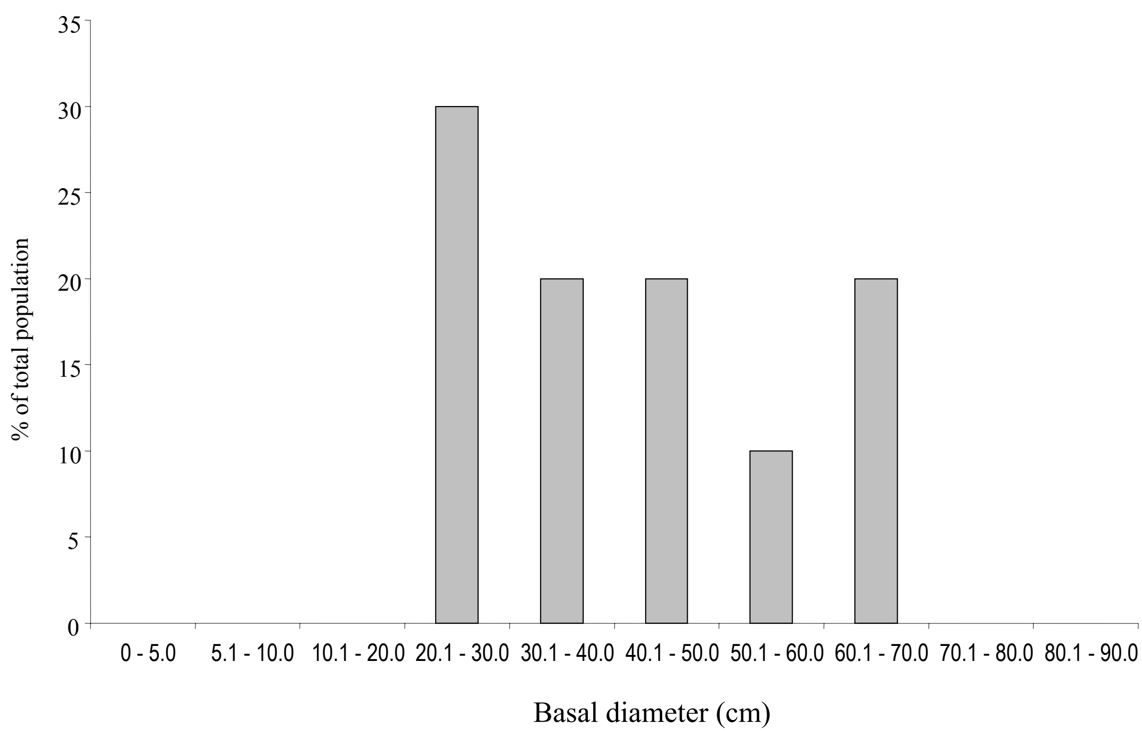

Figure 4.9 Marula size class distributions in Site 8

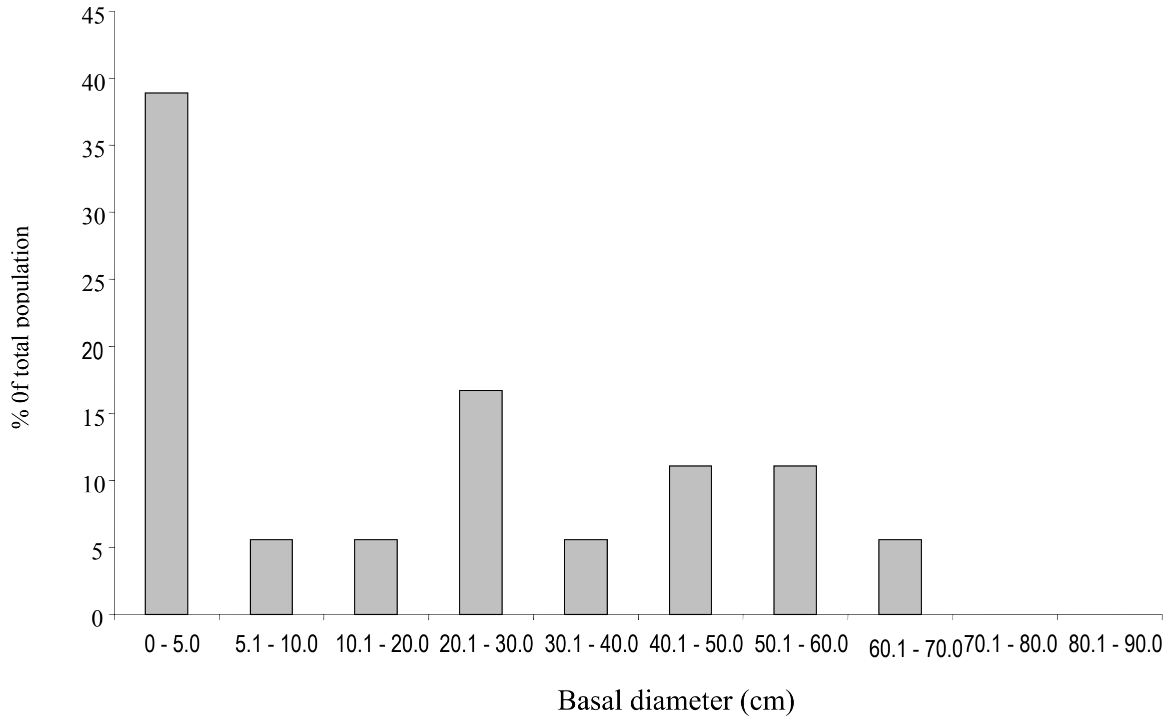

Figure 4.10 Marula size class distributions in Site 9

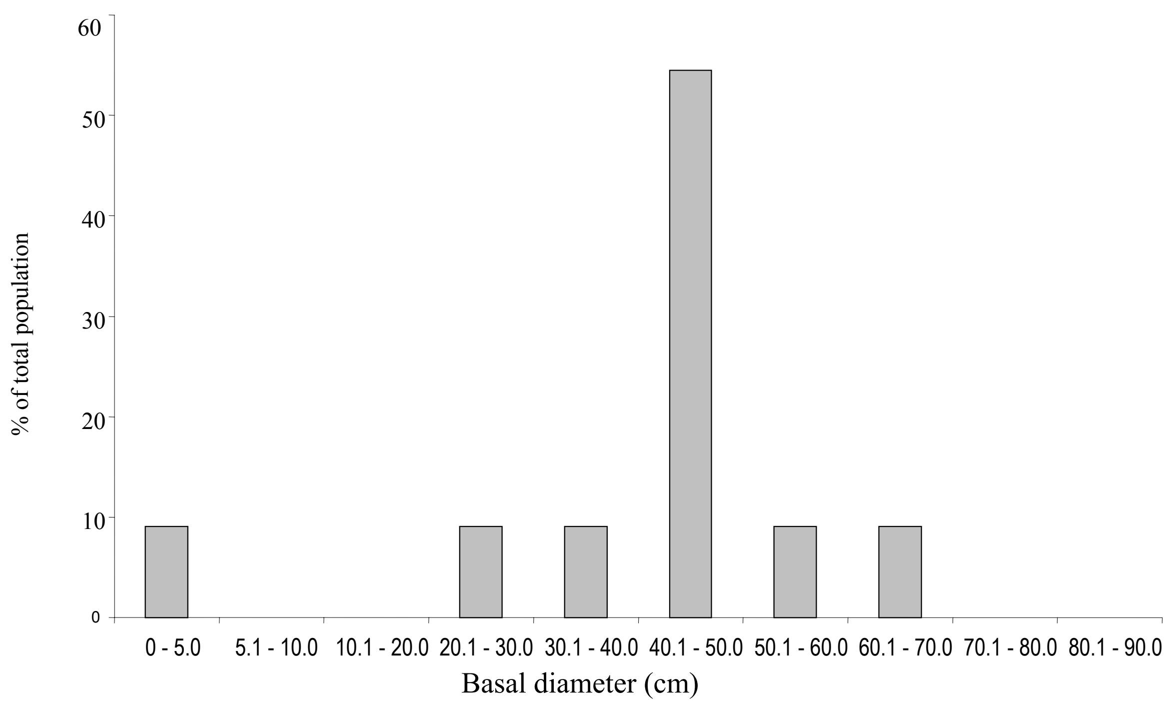

Figure 4.11 Marula size class distributions in Belt 10

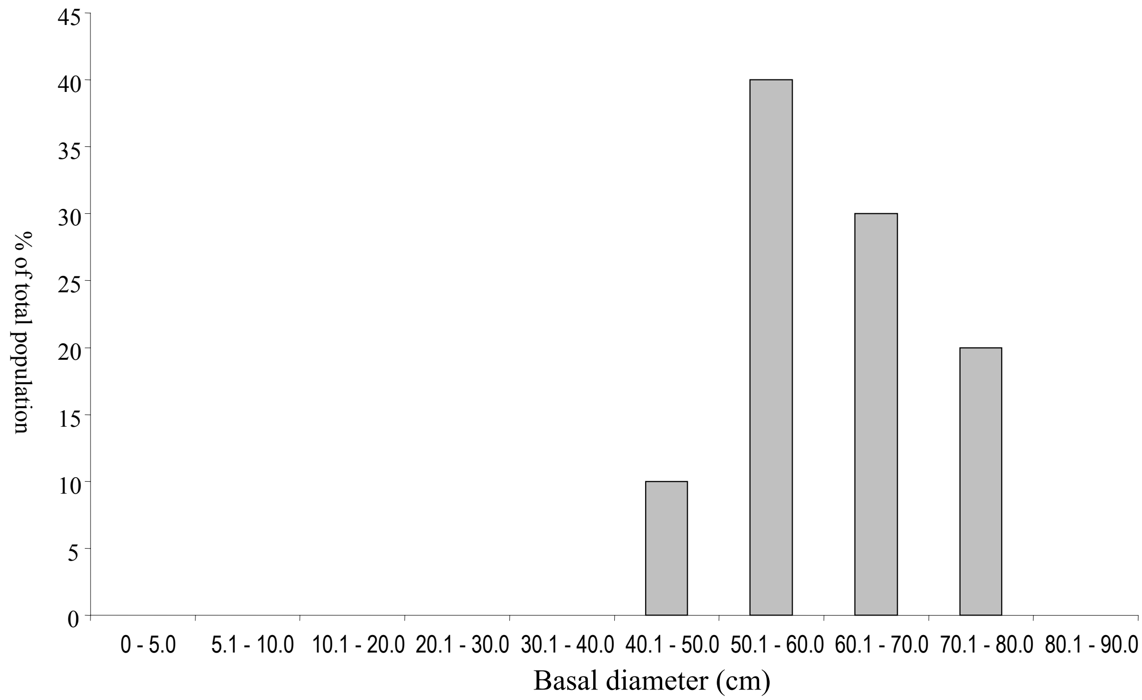

Figure 4.12 Marula size class distributions in Belt 11

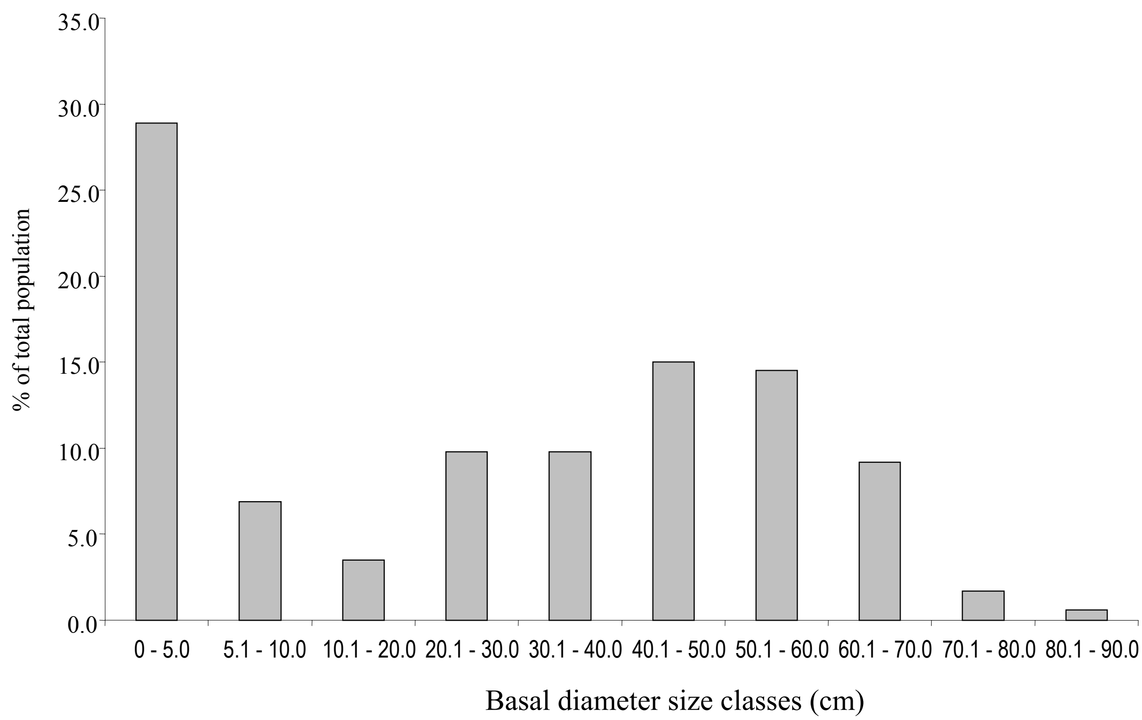

Figure 4.13 Marula size class distributions in Ward 3

4.2 Correlation and regression for Marula variables

Table 2 Correlation coefficients of basal diameter, height, basal area and canopy cover

	Height (m)	*Basal diameter (cm)*	*Basal area (cm^2)*
Basal diameter	0.896*	-	-
(cm)	0.840*	0.954*	-
Basal area (cm^2)	0.735*	0.734*	0.771*
Canopy cover (m^2)			

* Significant at $p < 0.05$

Canopy cover was highly correlated to height, canopy cover and basal diameter. There was also significant correlation between basal area and height and, basal area and basal diameter ($p<0.05$). A relationship was also significant between height and basal diameter (Table 2).

Regression equations for the positively correlated canopy cover relations obtained were as follows:

Canopy cover (m^2) = - 12.5 + 11.7 Height (m), R-sq = 54.1%, $p< 0.05$ Equation 1

Canopy cover (m^2) = - 7.64 + 1.98 BD (cm), R-sq = 53.9%, $p< 0.05$ Equation 2

Canopy cover (m^2) = 6.57 + 0.0396 BA (cm^2), R-sq = 59.4%, $p< 0.05$ Equation 3

The linear regression model was significant (Appendices 9 to 11), and all three equations showed positive relationships. When the explanatory variables were combined (Canopy cover (m^2) = 1.55 + 7.30 Height (m) - 1.34 BD (cm) + 0.0442 BA (cm^2)), the pooled contributions to total variation in canopy cover amounted to 63.5% (R-sq = 63.5%, $p<0.05$) (Appendix 8).

The height-basal diameter regression, Height (m) = 0.930 + 0.152 BD (cm), was significant (R-sq = 80.2%, $p<0.05$). Eighty percent of variation in height and basal diameter (BD) was explained by the equation (Appendix 12). Given basal diameters (BDs), heights could be estimated using the above equation, provided the data range coincides with the data range obtained from the study (Appendix 4). Also, changes in basal area were positively related to changes in basal diameter as shown in equation, BA (cm^2) = - 362 + 50.1 BD (cm) (R-sq = 91.1%, $p<0.05$). Basal area can therefore, be estimated using the equation given basal diameter (BD), with 91.1% confidence, provided BD values used fall within the Mwenezi data range.

4.3 Marula population projections

The pooled data from Ward 3 (total for the area of study) was classified into 5 size classes for consideration in Leslie matrix modelling. The size class distributions were as shown in Table 3 below.

Table 3 Size classes of *S. birrea*

Size class/ cm	0 - 5	5.1 - 20	20.1 - 40	40.1 - 70	> 70
Total stems	50	18	34	67	4

Fruiting stems	0	0	5	26	1
Fecundity/ stem	0	0	1	1.2	1.5

Studies have shown size Class 5.1-20 cm as the onset of fruiting. No fruiting stems were, however, recorded in Class 5.1-20 cm and therefore no fecundity was assigned to it. Transition probabilities between size classes were calculated by dividing number of individuals at Class 1 by number of individuals at Class 2 (for example).

Table 4 Transition matrix for the pooled data of *S. birrea*

Size classes (cm)				
0 – 5.0 (1)	**5.1 – 20.0 (2)**	**20.1 – 40.0 (3)**	**40.1 – 70.0 (4)**	**> 70 (5)**
0	0	1	1.2	1.5
0.360	0	0	0	0
0	0.889	0	0	0
0	0	0.971	0	0
0	0	0	0.060	0

Since the population has only five classes, the matrix becomes a five-row x five-column matrix. The fecundities are in the top row. The probability that individuals will survive and grow into the next size class is in the sub-diagonal. The probabilities of surviving and remaining in the same class are entered in the diagonal. The initial population vector is the total number of stems per size class as shown in Table 3.

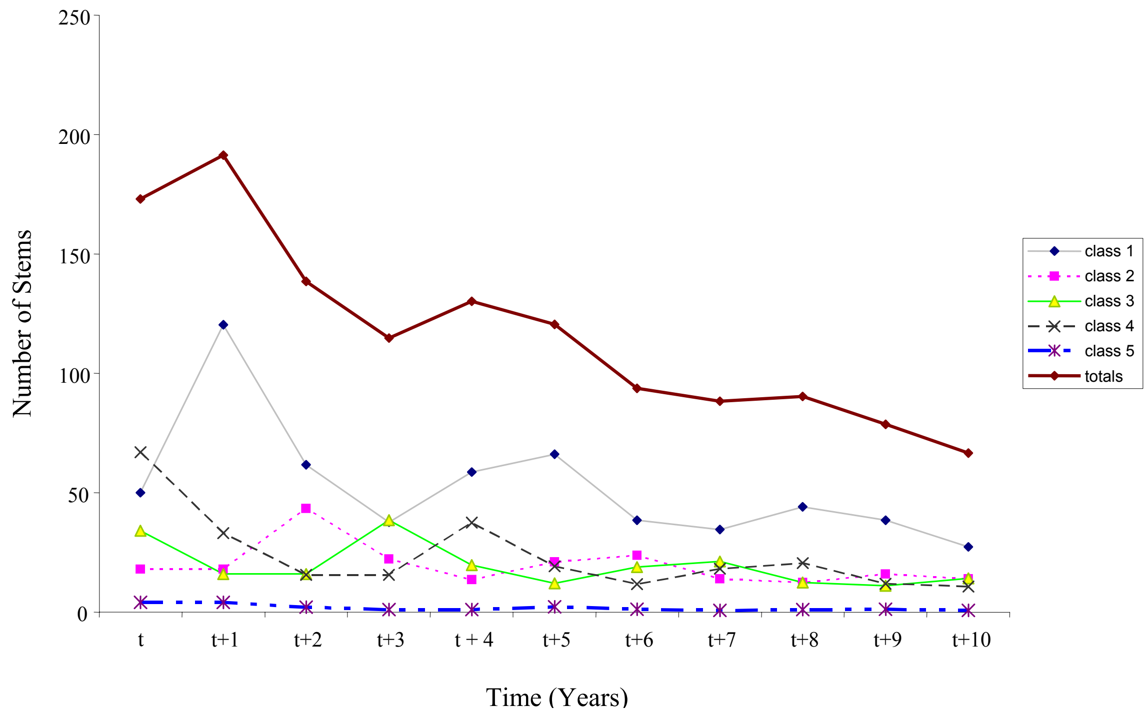

Figure 4.14 Projections of Marula population in Mwenezi

The letter t on Figure 4.14 denotes year of study and t+1 denotes one (1) year after study. There is an increase in total number of stems and Class 1 stems in a year's time (Figure 4.14). Number of stems in Class 2 and 3 show a downward trend two years after study. Classes 1 to 4 stem numbers tend to fluctuate but eventually decreasing as we approach ten years from time of study. The number of stems in Class 5 will generally be low, as shown in the figure above.

5. DISCUSSION AND CONCLUSIONS

5.1 Demographic characteristics of Marula

5.1.1 Variation in densities

Stem density varies from 2 stems/ ha to 27 stems/ ha. This range is consistent with earlier observations made on Marula (Gadd, 2002; Khonje *et al*., 1999; Shackleton, 1996). Khonje *et al*., (1999), for example, reported densities of 3, 9, 10 and 17 stems/ ha in natural communities of Malawi. Previous studies have shown that Marula naturally occurs at low stocking levels (Hall *et al*., 2002). Severe drought has also been identified as major threat to populations of Marula (Hall *et al*., 2002). There has been an increase in incidence and severity of droughts, in the recent decades, possibly due to climate change. This could probably explain the low stem densities observed in Mwenezi Ward 3. The lack of significant differences in total stem count across sites is also highlighted in lack of correlation between distances from sampling sites to Nyuni processing centre (Table 1). This, therefore, implies that distance from the centre is not an important factor in determining distribution of Marula. Results from the study also indicate that communities vary spatially, and cannot, therefore, be extrapolated from one area to another.

The lack of significant differences in total stem count, number of debarked stems and fruiting stems across the sites could be due to other factors influencing distribution of Marula. The lowest stem density recorded in Belt 1 (near Runde River) could be due to the fact that the belt was a constituent of a riverine ecosystem. In as much as *S. birrea* occasionally occurs as a component of riparian forests (du Toit, 1993; Hall *et al*., 2002; von Teichman, 1988), riparian conditions may not be the best conditions for its survivorship. Droppings similar to those of the browser impala (*Aepyceros melampus)* were observed within belt transect. The lower density might indicate browsing impact on the palatable seedlings. Rocky surfaces were also encountered in the greater part of the belt. Marula is generally less common on rocky surfaces (Timberlake, 1980), and the lower densities could, therefore, be attributable to this environmental condition.

Belt 9 was mainly covered in sandy soils, which are well-drained. *S. birrea* has got a preference for well-drained soils (Lewis, 1987; SEPASAL database, 2001). Besides the occurrence of well-drained soil conditions, there could be other factors that positively influenced stem density. There was no indication of significant numbers of browsers. Anthropogenic factors could, therefore, be at play. It is likely that moisture required for germination and regeneration was readily available (von Teichman, 1988), and thus the high stem density.

5.1.2 Population structure

The distribution of individuals among categories is usually skewed in natural populations, with an over-representation of the small categories and an under-representation in the larger- size categories (van Groendael *et al*., 1988). The present size structure reflects temporal variation in recruitment and mortality as vital rates in many species are stage or size-dependant (Bullock *et al*., 1996). If the *Sclerocarya birrea* population structure consists of many mature trees but without seedlings or saplings, it implies that the population is not reproducing itself (Harbour *et al.*, 1987), and therefore may not be sustainable.

The size structure graphs are here discussed in view of the clusters. In Cluster 1 (Belts 1 and 8), the greater number of stems is in the intermediate size classes reflecting growth of saplings that were established prior to exploitation (Peters, 1995). It should be noted, however, that trees of an almost similar size class tend to senesce and die at about the same time (Gadd, 2002; Jacobs & Biggs, 2002a). This may, therefore, lead to virtual disappearance of the population (Jacobs & Biggs, 2002a).
Episodic regeneration of Marula at intervals possibly exceeding ten years has also been offered as a possible explanation for the distribution (Walker *et al*., 1986).

The populations in Belts 6 and 10 approximate a positive exponential size class distribution (J-shaped). This distribution pattern suggests that recruitment could have occurred on an annual or regular basis (Hall *et al*., 2002; Mudavanhu, 1998). The J-shaped structure is normally associated with previous over-exploitation.

Marula in Belts 3 and 11 are positively skewed, though the skewness is much clearer for Belt 3. This distribution pattern suggests little or no regeneration, with the population largely dominated by larger trees. Although seed germinates readily once the bond between the opercula of the rest of the endocarp has been weakened (von Teichman, 1988), most seedlings are rarely recruited to the sapling stage. This is probably due to browsing and agricultural activities (Hall *et al*., 2002; Lewis, 1987). Poor representation of seedlings, saplings and immature trees has been observed in earlier assessments (Hall *et al*., 2002; Gadd, 1997; Lewis, 1987; Walker *et al*., 1986).

The sampling units in Cluster 4 approach a negative exponential (inverse J-shaped) distribution, with some of them showing two distinct peaks (bimodal distribution) (for example, Site 9).The fact that there were very high numbers in the lowest size classes followed by a sharp drop in the following size class, implies that there are very high levels of seedling mortality which preclude recruitment. One can, therefore, extrapolate from these data that seed production and germination are not the limiting stages in regeneration and recruitment. Instead, small to medium sized saplings are the most limiting stage. In as much as Belt 9 had the highest stem density, a closer look at the size structure revealed that the lowest size class constituted the highest number of stems. Given the fact that seedling mortality is normally very high, such a population will; over time have an altered size class distribution (Peters, 1995). Consequently, reduced regeneration and recruitment may result due to reductions in higher size classes (Jacobs & Biggs, 2002a; Peters, 1995).

The bimodal distribution can be as a result of parabolic growth curve where intermediate individuals grow at a faster rate relative to those at the two extremes of the distribution range. It can also be due to pulsed recruitment of cohorts of samplings (Desmet *et al*., 1996). From the pooled data, the distribution of Marula followed a bimodal distribution, which can also be averaged to an inverse J-shaped distribution (very similar to Site 9). Explanations suggested for Cluster 4 are thus applicable to Ward 3.

5.1.3 Debarking – size class relations

No variation in number of debarked stems was detected across the sites. Instead, the numbers varied with increasing size (basal diameter). The concentration of debarked stems in the higher size classes appears to conform to the logical explanation that in small-sized trees, the concentration of the active ingredients tends to be lower. Bark removal can kill the plants due loss of moisture and nutrients, by increasing susceptibility to fire or infection (Jacobs & Biggs, 2002b). Old wood underneath healed areas may burn or rot, leaving an apparently healthy individual with a hollow trunk (Coetzee *et al*., 1979).

Bark has a self healing response (Lewis, 1987), but it is not clear at what stage its healing response is most effective and efficient. If the bark fails to heal, detrimental effects may result over time, especially given the fact that the mostly debarked stem sizes overlaps with the highly productive size range.

5.1.4 Tree variable relationships

Basal diameter (BD), tree height and canopy cover are important tree characteristics (Avsar, 2004). There is also a close relationship between parameters such as diameter, height and canopy cover, as shown in the results. Saplings tend to increase in size at a faster rate relative to older trees (Desmet *et al*., 1996). This is also supported by observations of Hall *et al.* (2002). Mean annual diameter increment falls from around 4mm with individual with 15 cm (BD) to about 1mm in individuals with BD of 55 cm.

This relationship, however, varies from species to species. Basal diameter measurements can, therefore, be used to estimate growth. It has also been shown (from the results) that height could be estimated by BD, a measurement regarded easier to take.

Linear regression models are important in describing relationships between two variables (x and y), determining how much of the variation in Y can be explained by linear relationship with X, and how much of the variation remains unexplained. Linear regressions can also be used to predict new values of Y from new values of X (Quinn & Keough, 2002). In ecology, they are mostly used for explaining variability in Y (dependant variable). The equation: Canopy cover (m^2) = 6.57 + 0.0396 BA (cm^2), R-sq = 59.4%, $p< 0.05$, shows that 59.4% of the variation in canopy cover is explained by the relationship. It therefore, means that 40.6% variation remains unexplained, and this variation could be due to other factors or variables. The unexplained variation can, therefore, be investigated further and verified.

5.2 Population dynamics and implications on sustainability

The general decline in stem numbers in the different classes may be due to the varying degrees to which stem sizes are susceptible to mortality, either due to natural causes or browser effect. The decline in tree numbers in woodlands is attributed to seedling browsing or even, episodic regeneration (Lewis, 1987). Future shifts in size class composition are apparent as shown in Figure 4.14. The marked decrease in stem numbers per size class and overall stem numbers may imply that if the recruitment and fecundity levels (utilised in the projections) are maintained, the population levels may continue to decrease over time (Figure 4.14). It should, however, be noted that socio-economic conditions of the area, levels of current harvesting or the demand level are critical in determining the projected state of the Marula population. Due to the fact that there is often strong variability in productivity from year to year, there is need for monitoring the life cycle of a tree species over more than one season. It should, however, be noted that systems are more complex and thus difficult to model and study, requiring greater time and effort and consideration of much larger spatial units. Thus, the focus on population level dynamics of single species.

5.3 Conclusions

Knowledge on natural distribution, abundance, population structure and dynamics, and variation of these factors across a landscape, is important in assessing sustainability of harvesting a forest or woodland product. Size structure of populations is dynamic, and one cannot, therefore, expect to observe uniform size structure distribution across a landscape. The population structures from the study area generally revealed unbalanced size class distribution indicating *S. birrea* population with low recruitment capacity. The present size structure reflects temporal variation in recruitment and mortality. The relative abundance of Marula in Mwenezi is generally low, with an average of seven stems per hectare. The mostly debarked size class is the 40.1 to 60 cm. The concentration of debarked stems in the higher size classes appears to conform to the logical explanation that in small-sized trees, the concentration of the active ingredients tends to be lower.

The projected levels of Marula show a declining population based on the biological aspects (fecundity, recruitment) of the species. Given the fact that commercialisation also takes into account socio-ecological factors, including these would better estimate the projected population. Care, therefore, has to be taken when extracting NTFPs, without constant monitoring. There is no doubt that the Marula tree is important to rural communities for a wide range of reasons. In as much as commercialisation of Marula is anticipated to bring financial benefits to communities, it must not be to the detriment of the subsistence sector, or sustainability of the resource itself.

6. SUGGESTIONS FOR FURTHER RESEARCH

The current research focused mainly on the demographic attributes of Marula, it may also be necessary to further look at how much of the resource can be harvested without having any negative impacts on the population. Due to the fact that there is often variability in terms of growth rates, fruit production and even mortality, from season to season, studying Marula over a longer period of time is bound to produce more meaningful results (as it captures the variations). Modelling of population dynamics, which requires sufficient data, will then, better approximate future populations.

Debarking of Marula may enhance fungal infections that may lead to eventual death. Studies to determine levels at which Marula may be susceptible are essential, that is, resilience – recovery studies.

Extraction of non timber forest products has been recommended as strategy for conservation and sustainable use of tropical resources. The three attributes on which sustainability of resource utilisation is based: ecological soundness (part of the current study), economic viability and social acceptability; also need to be considered for Marula.

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APPENDICES

Appendix 1. Thirty- year average temperature (1970 – 2000) and rainfall (1961- 1991) for Mwenezi

Month	Rainfall (mm)	Maximum (^oC)	Minimum (^oC)
July	0.9	23.9	5.6
August	1.1	26.7	8.0
September	4.3	29.8	12.5
October	21.5	30.7	15.7
November	76	31.4	17.6
December	101	31.4	18.3
January	98.2	31.4	18.6
February	101.6	30.3	18.3
March	51.7	29.9	16.9
April	21	28.5	13.5
May	9.9	26.8	9.2
June	1.8	24.3	6.0
Annual	**489.0**	**28.8**	**13.3**

Appendix 2. Belt Positions in Mwenezi Ward 3

Position	Latitude (X)	Longitude (Y)
1	241639	7711262
2	239623	7706800
3	237625	7701231
4	242850	7700203
5	248059	7700282
6	247017	7700267
7	248092	7698068
8	248109	7696960
9	242868	7699096
10	240819	7696849
11	241877	7695758
Nyuni	250141	7700313

Appendix 3. Belt sizes and corresponding Marula densities

Belt	Dist. (m) from Nyuni	Width (m)	Length (m)	Area (m^2)	Stem no.	Density/ ha	No. fruiting	debark
1	13 830.7	20	1803.2	36064	8	2	0	0
2	12 423.8	20	1175.3	23506	28	12	1	1
3	12 553.6	20	692.3	13846	12	9	5	2
4	7 319.4	20	3187.8	63756	17	3	2	6
5	2 134.1	20	1304.1	26082	22	8	4	4
6	3 114.4	20	450.8	9016	11	12	2	1
7	3 007.8	20	1143.1	22862	26	11	7	1
8	3 916.1	20	1159.2	23184	10	4	3	1
9	7 371.3	20	338.1	6762	18	27	2	0
10	9 946.6	20	1143.1	22862	11	5	3	4
11	9 440.3	20	434.7	8694	10	12	3	4
Total	**-**	**-**	**-**	**256634**	**173**	**7**	**32**	**24**

Appendix 4. Distribution of Marula stems within size classes and across belts

Size Class	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
1	0	12	0	5	11	1	13	0	7	1	0
2	0	7	1	1	1	0	1	0	1	0	0
3	0	1	1	0	1	1	1	0	1	0	0
4	4	1	1	0	3	1	0	3	3	1	0
5	3	2	1	1	1	2	3	2	1	1	0
6	1	2	2	3	1	5	1	2	2	6	1
7	0	3	2	5	2	1	4	1	2	1	4
8	0	0	2	2	2	0	3	2	1	1	3
9	0	0	1	0	0	0	0	0	0	0	2
10	0	0	1	0	0	0	0	0	0	0	0

B ---- belt transects or sampling units within Ward 3

Size class (cm):				
1	0 – 5.0		6.	40.1 - 50.0
2	5.1 - 10.0		7.	50.1 - 60.0
3	10.1 - 20.0		8.	60.1 - 70.0
4	20.1 - 30.0		9.	70.1 - 80.0
5	30.1 - 40.0		9.	80.1 - 90.0

Appendix 5. Analysis of Variance for total number of Marula stems

Source	DF	SS	MS	F	P
Site	10	48.62	4.86	1.16	0.329
Class	9	166.55	18.51	4.41	0.000
Error	90	377.75	4.20		
Total	109	592.92			

```
                       Individual 95% CI
Site      Mean   -----+---------+---------+---------+------
 1        0.80    (----------*---------)
 2        2.80                     (---------*----------)
 3        1.20       (----------*----------)
 4        1.70           (----------*----------)
 5        2.20                (---------*----------)
 6        1.10      (----------*----------)
 7        2.60                   (----------*---------)
 8        1.00      (---------*----------)
 9        1.80            (----------*----------)
10        1.10      (----------*----------)
11        1.00      (---------*----------)
                 -----+---------+---------+---------+------
                     0.00      1.20      2.40      3.60

                       Individual 95% CI
Class     Mean   ------+---------+---------+---------+-----
 1        4.55                          (-----*-----)
 2        1.09        (-----*------)
 3        0.55      (-----*-----)
 4        1.55           (-----*-----)
 5        1.55           (-----*-----)
 6        2.36               (-----*-----)
 7        2.27              (-----*-----)
 8        1.45          (-----*-----)
 9        0.27    (-----*-----)
10        0.09   (-----*------)
                 ------+---------+---------+---------+-----
                      0.00      2.00      4.00      6.00
```

Appendix 6. Analysis of Variance for log (number debarked + 1)

Source	DF	SS	MS	F	P
Site	10	0.2368	0.0237	1.65	0.104
Class	9	0.5538	0.0615	4.30	0.000
Error	90	1.2891	0.0143		
Total	109	2.0797			

```
                       Individual 95% CI
Site      Mean   -+---------+---------+---------+---------+
 1      -0.000   (----------*----------)
 2       0.030        (---------*----------)
 3       0.060            (----------*---------)
 4       0.138                       (----------*---------)
 5       0.120                    (----------*----------)
 6       0.030        (---------*----------)
 7       0.030        (---------*----------)
 8       0.030        (---------*----------)
 9      -0.000   (----------*----------)
10       0.090                (----------*----------)
11       0.108                   (---------*----------)
                 -+---------+---------+---------+---------+
              -0.070      0.000     0.070     0.140    0.210
```

```
                       Individual 95% CI
Class    Mean   ---------+---------+---------+---------+--
 1      0.000   (--------*--------)
 2      0.000   (--------*--------)
 3      0.000   (--------*--------)
 4      0.000   (--------*--------)
 5      0.055          (--------*--------)
 6      0.180                          (--------*-------)
 7      0.192                           (--------*--------)
 8      0.082             (--------*--------)
 9      0.071            (--------*--------)
10      0.000   (--------*--------)
                ---------+---------+---------+---------+--
                        0.000     0.080     0.160     0.240
```

Appendix 7. Analysis of Variance for log (number fruiting + 1)

Source	DF	SS	MS	F	P
Site	10	0.2453	0.0245	1.87	0.060
Class	9	0.9740	0.1082	8.25	0.000
Error	90	1.1810	0.0131		
Total	109	2.4003			

```
                             Individual 95% CI
Site     Mean    ---------+---------+---------+---------+--
 1      -0.000   (--------*--------)
 2       0.030       (--------*--------)
 3       0.151                      (--------*--------)
 4       0.060           (--------*--------)
 5       0.120                  (--------*--------)
 6       0.060           (--------*--------)
 7       0.168                        (--------*--------)
 8       0.078             (--------*--------)
 9       0.060           (--------*--------)
10       0.090              (--------*--------)
11       0.078             (--------*--------)
                 ---------+---------+---------+---------+--
                        0.000     0.080     0.160     0.240
```

```
                             Individual 95% CI
Class    Mean    -------+---------+---------+---------+----
 1      -0.000   (------*------)
 2      -0.000   (------*------)
 3      -0.000   (------*------)
 4       0.055         (-----*------)
 5       0.082           (------*------)
 6       0.235                          (-----*------)
 7       0.246                           (------*-----)
 8       0.169                    (------*------)
 9      -0.000   (------*------)
10       0.027      (------*------)
                 -------+---------+---------+---------+----
                      0.000     0.100     0.200     0.300
```

Appendix 8. Regression analysis of canopy cover, basal diameter, height and basal area

Predictor	Coef	StDev	T	P
Constant	1.549	5.660	0.27	0.785
Height (m)	7.296	1.671	4.37	0.000
BD (cm)	-1.3406	0.5137	-2.61	0.010
BA (cm^2)	0.044186	0.008015	5.51	0.000

S = 38.67   R-Sq = 63.5%

Source	DF	SS	MS	F	P
Regression	3	441947	147316	98.49	0.000
Residual Error	170	254267	1496		
Total	173	696214			

Appendix 9. Regression analysis of canopy cover and height

Predictor	Coef	StDev	T	P
Constant	-12.518	5.525	-2.27	0.025
Height (m)	11.7111	0.8231	14.23	0.000

S = 43.12 R-Sq = 54.1%

Source	DF	SS	MS	F	P
Regression	1	376403	376403	202.44	0.000
Residual Error	172	319811	1859		
Total	173	696214			

Appendix 10. Regression analysis of canopy cover and basal diameter

Predictor	Coef	StDev	T	P
Constant	-7.636	5.266	-1.45	0.149
BD (cm)	1.9785	0.1395	14.18	0.000

S = 43.20 R-Sq = 53.9%

Source	DF	SS	MS	F	P
Regression	1	375247	375247	201.09	0.000
Residual Error	172	320967	1866		
Total	173	696214			

Appendix 11. Regression analysis of canopy cover and basal area

Predictor	Coef	StDev	T	P
Constant	6.568	4.153	1.58	0.116
BA (cm^2)	0.039566	0.002495	15.86	0.000

S = 40.55 R-Sq = 59.4%

Source	DF	SS	MS	F	P
Regression	1	413436	413436	251.47	0.000
Residual Error	172	282778	1644		
Total	173	696214			

Appendix 12. Regression analysis of height and basal diameter

Predictor	Coef	StDev	T	P
Constant	0.9305	0.2165	4.30	0.000
BD (cm)	0.151570	0.005735	26.43	0.000

S = 1.776 R-Sq = 80.2%

Source	DF	SS	MS	F	P
Regression	1	2202.2	2202.2	698.46	0.000
Residual Error	172	542.3	3.2		
Total	173	2744.5			

Appendix 13. Regression analysis of basal area and basal diameter

Predictor	Coef	StDev	T	P
Constant	-361.50	45.14	-8.01	0.000
BD (cm)	50.091	1.196	41.89	0.000

S = 370.3 R-Sq = 91.1%

Source	DF	SS	MS	F	P
Regression	1	240516058	240516058	1754.39	0.000
Residual Error	172	23580152	137094		
Total	173	264096210			

Appendix 14. Regression analysis of basal area, height and basal diameter

Predictor	Coef	StDev	T	P
Constant	-339.67	47.34	-7.18	0.000
Height (m)	-23.46	15.84	-1.48	0.141
BD (cm)	53.647	2.681	20.01	0.000

S = 369.0 R-Sq = 91.2%

Source	DF	SS	MS	F	P
Regression	2	240814521	120407261	884.37	0.000
Residual Error	171	23281688	136150		
Total	173	264096210			