# CHAPTER 1

# INTRODUCTION

## 1.1 Thematic background

Sustainable use of the vegetation, both extractive and non-extractive, is a dynamic process towards which one strives in order to maintain biodiversity and to enhance ecological and socio-economic services, recognizing that the greater the equity and degree of participation in governance, the greater the likelihood is of achieving these objectives for present and future generations (IUCN 2001). The sustainable use of a natural resource will be determined, to a large extent by the interaction between biological, social and economic factors.

Dzerefos and Witkowski (2001) define sustainable harvesting of natural resources as the removal of a natural resource without depleting it or compromising its ability to regenerate. Sustainable harvesting of medicinal resources is critical to the survival of indigenous forests (Hartshorn 1995, Obiri *et al.* 2002, Hamilton 2003, Shukla and Gardner 2006, Bhattarai *et al.* 2010, Njoroge *et al.* 2010). Quantifying levels of sustainable harvesting requires planning and monitoring (Laurance 1999, Obiri *et al.* 2002). It is therefore important for conservation authorities to take the initiative to form partnerships with local people and to promote a sense of ownership rather than exclusion from protected areas (Dzerefos and Witkowski 2001). It is also emphasized that adjusting the harvestable size-class intervals according to the size of the mature tree is necessary to avoid recommending the use of particularly those naturally small tree species that may be currently harvested (Obiri *et al*. 2002).

The high number of plant species that are used for medicinal purposes should be acknowledged, with approximately 28% (between 50 000 and 80 000) of plant species worldwide reported to have ethnomedicinal use (Farnsworth and Soejarto 1991, Van Seters 1995, Louhaichi *et al*. 2011). These plant species are being used in various human cultures around the world for medicinal purposes and many of them are subjected to uncontrolled local and external trade. The contribution of unsustainable harvesting to annual extinction rate is indeed a matter of great concern as it could imply the loss of potential drugs against incurable conditions such as dementia, cancer, influenza or AIDS (Rates 2001, Gurib-Fakim 2006, McChesney *et al.* 2007).

According to Van Eck *et al.* (1997), people living in rural areas have learned through many years of experience to use natural resources sustainably. It has also been found that throughout Africa the gathering of medicinal plants was traditionally restricted to traditional medical practitioners. However, due to a number of factors traditional medical practitioners currently also involve the services of their trainees or middlemen in the collection of medicinal material.

According to Hartshorn (1995) and Boudreau *et al.* (2005), modern forest management systems are intended to focus on balancing the needs of users against the regeneration ecology and growth or supply of the resource base to ensure the sustainable use and conservation of forest resources. To develop optimum harvesting systems it is essential to understand the effects of harvesting on the composition and structure of the residual population, which is the base of the natural resource. It is against this background that even in harvesting of medicinal plants the balance between supply and demand needs to be maintained. The ecosystem needs to be maintained through monitoring of populations if the subsistence of people's activities is to be achieved.

Currently, in most African forests subsistence harvesting of natural resources is not effectively managed and unsustainable harvesting rates are defined by various factors such as short-term needs of consumers, power of traditional authorities, size of the consumer community, availability of suitable tree stem sizes, and forest size and accessibility (Oates 1999, Boudreau *et al.* 2005).

### 1.2 Problem statement and rationale for the study

For any resource, a relationship exists between resource capital, i.e. the resource population size, and the sustainable rate of harvest (Boudreau *et al.* 2005, Stewart 2009). Sustainable harvesting of medicinal resources can be achieved if people only harvest what they need for treatment. The impact of gathering medicinal material on the plant population is also influenced by factors such as the part of the plant harvested, with root and bark harvesting being the most harmful forms of harvesting (Williams *et al.* 2007). It is also influenced by factors such as frequency of harvesting, time or season of harvesting in relation to the developmental stage of the plant.

The high percentage of indigenous medicinal plant material traded in the Venda region in the form of roots and bark is a cause for concern, because these forms of harvesting have the largest negative effect on the plant. Sixty one percent of the medicinal plant material traded in the Venda region is in the form of roots, while bark material contributes 15 percent, with 22 percent of whole plants and 2% for leaves and fruits (Tshisikhawe 2002).

The bark of many different forest and woodland tree species in the Venda region are used, although a relatively small number are in high demand and intensively used (Tshisikhawe 2002). Intense and frequent harvesting of the bark from species with a high market demand often results in ring-barking of trees. The trees subsequently die, and the species become rare over time. This practice is obviously unsustainable and will almost certainly result in the extinction of many forest and woodland tree species (Diederichs *et al.* 2002). The trend towards increased commercialization of medicinal plants in South Africa has compounded the problem and resulted in overharvesting and in some cases near-extinction of some valued indigenous species (Newton and Vaughan 1996, Williams *et al.* 2000, Tshisikhawe 2002, Botha *et al.* 2004a, 2004b).

*Elaeodendron transvaalense* Jacq. and *Brackenridgea zanguebarica* Oliv. are some of the medicinal plant species that are facing a serious threat of extirpation in the Venda region. These species are amongst some of the medicinal plant species commonly traded in Venda muthi shops (Tshisikhawe 2002). In both species the bark from the stem as well as the roots are preferred and harvested for medicinal purposes.

*Elaeodendron transvaalense* is a medicinal plant that is used in the treatment of a number of ailments. Among its many uses the species is used in the treatment of any stomach disorder in a patient (Mabogo 1990, Tshisikhawe 2002). It is often believed that its application can be helpful in cleaning the blood of a patient from any foreign material. Traditional healers therefore refer to the species as "mukuvhazwivhi" which when literally translated means "sin-washer" because of its ability of cleaning any foreign material that may be in the patient's blood system (Mabogo 1990, Tshisikhawe 2002). When a species such as *E. transvaalense*, is used as a generalist its many uses force collectors to collect its medicinal material in bulk, which can put the species under severe threat of overexploitation and consequently local extinction.

*Brackenridgea zanguebarica,* which is only found in the Thengwe area of Limpopo province (Palgrave 1988, Raimondo *et al.* 2009) is also a very important medicinal plant species in South Africa as a whole (Van Wyk *et al.* 1997, Tshisikhawe 2002). Records on its collection from the Thengwe tribal authority indicate that the plant is collected by users who come from as far as KwaZulu-Natal (Tshisikhawe 2002). Its uses are mainly magical, although it can also be used for a number of medical conditions such as treatment of wounds, worms, amenorrhea, swollen ankles and aching hands (Tshisikhawe 2002). In Venda the plant is commonly known as 'mutavhatsindi'. The name implies that the plant is a property of the 'Vhatavhatsindi' clan found within the Vhavenda tribe. They believe it is their sole responsibility to protect the plant, which they regard as a present from God (Ramaliba pers comm.[1]).

[1] Ramaliba, Traditional Healer, Thohoyandou, South Africa, Communication 2007

Williams (1996) has recorded the plant in the Witwatersrand muthi trade where it was only referred to as 'hlabasindi'. Muthi traders in Witwatersrand have ranked the plant species second to *Siphonochilus aethiopicus* 'isiPhephetho' in terms of scarcity.

## 1.3 Study aim and objectives

The aim of this study was firstly to evaluate the extent, severity and threat of bark harvesting on plant species in the Venda region. Thereafter the study focused on two species, viz. *Elaeodendron transvaalense* and *Brackenridgea zanguebarica*, and assessed the impact caused by harvesting medicinal material on the population of these two species. These two species were selected because, in spite of both having their bark harvested for medicinal purposes, there are many underlying differences. Although *Elaeodendron transvaalense* is not common it has a wide distribution. It is regarded as a generalist with many medicinal uses. Furthermore, it occurs in areas where there is open access to these plants and harvesting is not controlled. In contrast, *Brackenridgea zanguebarica* has a very restricted distribution in South Africa and it is classified as Critically Endangered in South Africa (Raimondo *et al.* 2009). Furthermore, it has more specific uses and harvesting is controlled by strict measures.

The project aimed to answer the following questions:

i. What is the overall state of bark harvesting in the Venda region?
ii. Is sustainable harvesting of *E. transvaalense* and *B. zanguebarica* achievable considering the harvesting pattern?
iii. How can sustainable bark harvesting of indigenous plants be achieved or maintained?

iv. Is the size of the Brackenridgea Nature Reserve large enough to adequately conserve the species?

v. What recommendations can be proposed on the integrated management of these two species in the Venda region?

To answer the key questions the following objectives were set:

i. to estimate the extent of bark harvesting for medicinal purposes in the Venda region,
ii. to determine the vulnerability of species commonly used for bark harvesting in the Venda region,
iii. to determine the size class distribution of the two species and size classes targeted for harvesting,
iv. to use sensitivity analysis from matrix model to establish the key life-history stages, which are in most need of conservation measures, of *Elaeodendron transvaalense*,
v. to investigate the adequacy of the Brackenridge Nature Reserve for the conservation of *B. zanguebarica*,
vi. to compare current with past harvesting in the Brackenridge Nature Reserve and recommend better management approach.

**1.4 Structure of the dissertation**

The dissertation starts with a general introduction in Chapter 1, and literature review in Chapter 2. The study area, as well as materials and methods are covered in Chapter 3. Chapters 4 to 7, which are to be submitted for publication in various scientific journals, present the results and discussion of the investigation. Chapter 4 evaluates the overall extent and threat of bark harvesting in the Venda region and the effects of trade in medicinal plant species in the region. Chapter 5 and Chapter 6 investigate the population biology of *Elaeodendron transvaalense* and *Brackenridgea zanguebarica* respectively. Chapter 7 evaluates the conservation efforts of *Brackenridgea zanguebarica* in the Brackenridgea Nature Reserve. A general synthesis with management recommendations is provided in Chapter 8. Finally, all the references cited in the dissertation were compiled in one chapter (Chapter 9). The main body of this dissertation is presented in the form of papers and therefore each chapter has been prepared as a free-standing unit. As a consequence, it is inevitable that there will be some repetition between chapters.

**References**

BHATTARAI, S., CHAUDHARY, R.P., QUAVE, C.L. AND TAYLOR, R.S.I. 2010. The use of medicinal plants in the trans-Himalayan arid zone of Mustang District, Nepal. *Journal of Ethnobiology and Ethnomedicine* **6: 14-24.**

BOTHA, J., WITKOWSKI, E.T.F. AND SHACKLETON, C.M. 2004a. Market profiles and trade in medicinal plants in the Lowveld, South Africa. *Environmental Conservation* **31: 38-46**.

BOTHA, J., WITKOWSKI, E.T.F., AND SHACKLETON, C.M. 2004b. The impact of commercial harvesting on *Warburgia salutaris* ('pepper-bark tree') in Mpumalanga, South Africa. *Biodiversity and Conservation* **13: 1675-1698.**

BOUDREAU, S., LAWES, M.J., PIPER, S.E. AND PHADIMA, L.J. 2005. Subsistence harvesting of pole-size understorey species from Ongoye Forest Reserve, South Africa: Species preference, harvest intensity, and social correlates. *Forest Ecology and Management* **216: 149-165.**

DIEDERICHS, N., GELDENHUYS, C. AND MITCHELL, D. 2002. The first legal harvesters of protected medicinal plants in South Africa. *Science in Africa: Africa's first on-line science magazine*. November 2002.

DZEREFOS, C.M. AND WITKOWSKI, E.T.F. 2001. Density and potential utilization of medicinal grassland plants from Abe Bailey Nature Reserve, South Africa. *Biodiversity and Conservation* **10: 1875-1896.**

FARNSWORTH, N.R. AND SOEJARTO, D.D. 1991. Global importance of medicinal plants. In: Akerele, O., Heywood, V. and Synge, H. (Eds.) Conservation of medicinal plants, pp. 25-42. Cambridge University Press, Cambridge.

GURIB-FAKIM, A. 2006. Medicinal Plants: Traditions of yesterday and drugs of tomorrow. *Molecular Aspects of Medicines* **27: 1-93.**

HAMILTON, A. 2003. Medicinal plants and conservation: issues and approaches. Paper presented to International Plants Conservation Unit, World Wide Wildlife Foundation, UK.

HARTSHORN, G.S. 1995. Ecological basis for sustainable development in Tropical forests. *Annual Review of Ecology and Systematics* **26: 155-175.**

IUCN. 2001. Analytic framework for assessing factors that influence sustainability of uses of wild living natural resources. Technical Advisory Committee. IUCN SSC Sustainable Use Specialist Group.

LAURANCE, W.F. 1999. Reflections on the tropical deforestation crisis. *Biological Conservation* **91:109-117.**

LOUHAICHI, M., SALKINI, A.K., ESTITA, H.E. AND BELKHIR, S. 2011. Initial assessment of medicinal plants across the Libyan Mediterranean coast. *Advances in Environmental Biology***5: 359-370.**

MABOGO, D.E.N. 1990. The ethnobotany of the Vhavenda. Master of Science dissertation, University of Pretoria, Pretoria, South Africa.

McCHESNEY, J.D., VENKATARAMAN, S.K. AND HENRI, J.T. 2007. Plant natural products: Back to the future or into extinction? *Phytochemistry* **68:2015-2022.**

NEWTON, D.J. AND VAUGHAN, H. 1996. South Africa's *Aloe ferox* plant, parts and derivatives industry. TRAFFIC East/Southern Africa Publishers. Johannesburg, South Africa.

NJOROGE, G.N., KAIBUI, I.M., NJENGA, P.K. AND ODHIAMBO, P.O. 2010. Utilization of priority medicinal plants and local people's knowledge on their conservation status in arid lands of Kenya (Muringi District). *Journal of Ethnobiology and Ethnomedicine* **6: 22-29**.

OATES, J.F. 1999. Myth and Reality in the Rainforest - How Conservation Strategies are Failing in West Africa. University of California Press, Berkeley.

OBIRI, J., LAWES, M. AND MUKOLWE, M. 2002. The dynamics and sustainable use of high-value tree species of the coastal Pondoland forests of the Eastern Cape Province, South Africa. *Forest Ecology and Management* **166: 131-148.**

PALGRAVE, K.C. 1988. Trees of Southern Africa. 4$^{th}$ edition. Struik Publishers. Cape Town, South Africa.

RAIMONDO, D., VON STADEN, L., FODEN, W., VICTOR, J.E., HELME, N.A., TURNER, R.C., KAMUNDI, D.A. AND MANYAMA, P.A. 2009. Red list of South African Plants. *Strelitzia* **25.** South African National Biodiversity Institute, Pretoria.

RATES, S.M.K. 2001. Plants as source of drugs. *Toxicon* **39: 603-613.**

SHUKLA, S. AND GARDNER, J. 2006. Local knowledge in community-based approaches to medicinal plant conservation: lessons from India. *Journal of Ethnobiology and Ethnomedicine* **2: 20-24**.

STEWART, K. 2009. Effects of bark harvest and other human activity on populations of African cherry *(Prunus africana)* on Mount Oku, Cameroon. *Forest Ecology and Management* **258: 1121-1128.**

TSHISIKHAWE, M.P. 2002. Trade of indigenous medicinal plants in the Northern Province, Venda region: their ethnobotanical importance and sustainable use. Master of Science dissertation, University of Venda, Thohoyandou, South Africa.

VAN ECK, H., HAM, C. AND VAN WYK, G. 1997. Survey of indigenous tree uses and preferences in the Eastern Cape Province. *Southern African Forestry Journal* **180: 61-64.**

VAN SETERS, A.P. 1995. Forest based medicines in traditional and cosmopolitan health care. Rainforest Medical Foundation, The Netherlands.

VAN WYK, B.E., VAN OUDTSHOORN, B. AND GERICKE, N. 1997. Medicinal plants of South Africa. Briza Publications, Pretoria, South Africa.

WILLIAMS, V.L. 1996. The Witwatersrand muthi trade. *Veld and Flora* **3: 12-14.**

WILLIAMS, V.L., BALKWILL, K. AND WITKOWSKI, E.T.F. 2000. Unraveling the commercial market for medicinal plants and plant parts on the Witwatersrand, South Africa. *Economic Botany* **54: 310-327.**

WILLIAMS, V.L., WITKOWSKI, E.T.F. AND BALKWILL, K. 2007. The relationship between bark thickness and diameter at breast height for six tree species used medicinally for bark in South Africa. *South African Journal of Botany* **73: 449-465.**

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Historical development and current state of medicinal plant use

Traditional medicine derived from indigenous plants has always played a role in the healthcare of indigenous people of Africa and in particular of South Africa (World Health Organization 2002, Tabuti *et al.* 2003). It continues to play an important role in the health of the Vhavenda people. The utilization of indigenous plants for medicinal purposes has many facets, which have developed with the advancement of mankind over the years.

Howell and Mesher (1997) argue that our ancestors developed an elaborate set of unwritten rules about how people can interact with their land. These rules were taught from an early age as part of storytelling. The most important rules have to do with the scale of harvesting natural resources. People were taught to only take what they needed. Unnecessary harm of any living creature would bring swift chastisement. Everyone was therefore brought up with this code of ethics instilled into them from infancy. This kind of practice reflected a very strong conservation ethic.

Tree resources, like any other natural resource, have always been used by indigenous people. According to Mabogo (1990) plants have been used by the Vhavenda people as a source of food and beverages, oils, polishes and dyes, medicines, firewood, crafts, rustic work and construction of huts and kraals. Vhavenda people harvested a considerable amount of medicines from the forest. They used these medicines to treat themselves relatively free of charge, although some patients were required to pay varying amounts in the form of livestock, grain or money. Some medicines were exchanged for other valuable articles or other medicines, especially with people from other parts of the country where such medicines were unavailable or unknown.

Von Malitz and Shackleton (2004) argue that historical information, as indicated by the persistence of many customary practices for the management of natural resources today, suggests that the systems incorporating local codified rules, taboos and norms were used in part to govern the use of forest and woodland resources from the earliest time. The chiefs and tribal authorities were generally responsible for setting and enforcing resource controls and regulations. Chieftancies were powerful institutions that were respected and obeyed by local people, and had absolute authority. According to Williams *et al.* (2000), strict customary conservation practices which regulated plant collection times and quantities were respected and adhered to. However, the demand for medicinal plant material has increased with the advent of urbanization and the consequent commercialization of traditional health care.

In the past, harvesting of medicinal plants was an activity for the traditional medical practitioners. Religious beliefs and norms instituted by, for example, local traditional healers also influenced resource use. The importance of these norms is corroborated by Mabogo (1990) who indicated that in Venda, taboos and superstitions that existed around certain plant species prevented them from being overexploited. For instance, the collection of medicinal material from *Brackenridgea zanguebarica* has to be done by a naked person. Some forests were also proclaimed as sacred and entrance is reserved to people from a specific clan. Sacred forests were surrounded by myths, which made it difficult for people from other clans to utilize their resources. Even the collection of commodities such as firewood and fruits were prohibited from sacred forest sites.

Currently, because of the expanding trade in medicinal plant products people who may not necessarily be traditional healers are also involved in harvesting of medicinal material (Tshisikhawe 2002, Botha *et al.* 2004a, 2004b). In most cases these commercial traders of indigenous medicinal material are not familiar with the rituals associated with the collection of such material. Engaging middlemen in the collection of medicinal material poses a serious threat of overexploitation to medicinal plant species.

Harvesting of medicinal material has therefore become a domain of untrained, and often indifferent, commercial gatherers who do not have other sources of income. In some cases medicinal plant material is harvested and transported to urban areas for trade. Harvesting of medicinal plants for trade in order to meet the urban demand is an environmentally destructive activity (Williams *et al.* 2000). According to Kohira and Ninomiya (2003), such socioeconomic activities cause large tracts of primary forest to become degraded and fragmented. Patches of remaining forests inevitably become small and their future uncertain as a result of such socioeconomically driven reasons. The tree communities in those remnant patches are likely to suffer greater ecological stresses and ultimately contain species that decline for reasons other than natural forest dynamics (Kohira and Ninomiya 2003).

## 2.2 The concept of sustainable use

The Chiang Mai Declaration of 1988played a major role in acknowledging the use of medicinal plant material in the health care of the majority of the population in most developing countries. It also noted that the loss of certain medicinal plant species and reduced supply of other important plant species through unsustainable harvesting would have a direct impact on human health and wellbeing (Bodeker 1995). There is no question that unsustainable extraction methods, involving excessive debarking or the felling of entire trees, are currently threatening plant species and indigenous forests (Cunningham and Mbenkum 1993, Hartshorn 1995, Hamilton 2003, Lawes *et al.* 2004, Njoroge *et al.* 2010). This is ascribed to the fact that the demand has become so high that these unfavourable practices are becoming common. The increase in demand is partly due to an increase in trade of medicinal plant materials.

According to Robinson (1993), the specific objectives of the World Conservation Strategy are to maintain ecological processes and life support systems, to support biological diversity, and to ensure that the use of natural resources is sustainable. The focus is therefore on the natural environment and human dependence on our environment. The World Conservation Strategy therefore promulgated the concept of conservation through sustainable development and explicitly recognizes the sustainable concept (Heywood and Iriondo 2003, Abensperg-Traun 2009, Jackson and Kennedy 2009). Sustainable development being defined as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development 1987).

The Convention on Biological Diversity (CBD) also stipulates three broad objectives which are to conserve and sustainably use biological diversity while fairly and equitably sharing the benefits that accrue from the use of its genetic resources (Puppim de Oliveira *et al.* 2011). Throughout its history the CBD has provided quantifiable and intrinsic values, benefits and services upon which human societies depend materially, culturally, aesthetically and spiritually (Harrop and Pritchard 2011).

South Africa has more than 3 000 medicinal plant species (Dladla 2001). The demand for muthi is likely to increase and exceed supply because of population growth and the increasing level of urbanization since most urban dwellers rely on muthi markets for their indigenous medicinal materials. Furthermore, trade in traditional herbs and medicine is booming as many unemployed people turn to the selling of muthi for their livelihood (Williams *et al.* 2007). The boom in muthi trade is aided by the fact that approximately 80 percent of South Africans rely on traditional healing (Steenkamp 2003, Van Staden 2008, Williams *et al.* 2007).

In African countries with high rural population densities and small cities, the gathering of medicinal plant products is expected to be small scale but with a high frequency, and where a species is popular and supplies are low due to habitat destruction and agricultural expansion, the tree will suffer a "death of thousand cuts" rather than once-off ring-barking due to commercial harvesting.

Sustainability is seen, not as a fixed ideal state or an end point, but as a process of attempting to improve the management of systems through learning, understanding and better use of knowledge (Marschke and Berkes 2005). In understanding sustainability it is therefore also important to understand the ecological processes that take place in a forest such as gap dynamics, dispersal and regeneration. These ecological processes are influenced by a numbers of factors that in turn can also be influenced by human activities. The use of resources should be in such a way that allows stable harvest rates into perpetuity (Etnier 2007). In wooded environments the unwanted eco-impacts on natural resources may also include exploitation of trees for fuel wood (Kuniyal 2002). Moreover, the factors affecting ecological processes in forest ecosystems are not static but fluctuate in space and time, thereby contributing to a unique biodiversity (Osho 1996, Kohira and Ninomiya 2003).

### 2.3 Size-class distribution

The first step in developing sustainable harvesting strategies is to gain an understanding of the population structure of the species (Everard *et al.* 1994, Obiri *et al*. 2002, Lawes and Obiri 2003, Gaugris and Van Rooyen 2007). It is therefore important to understand the life span and life history strategies of a species before subjecting the population to modelling techniques. A tree's life history strategies provide critical information for understanding its population dynamics and for estimating the regeneration cycle and turnover in a forest ecosystem. In general, the population growth rate of woody plants depends more heavily on the survival of adult individuals than on fecundity or growth (Kurokawa *et al.* 2003). Information on how a plant population is regenerating gives valuable data for resource management purposes and is widely used in planning for sustainable management.

Size-class distributions are commonly used as a tool for understanding plant population dynamics for trees (Lykke 1998, Condit *et al.* 1998, Niklas *et al.* 2003a, 2003b). To compile a size-class distribution of a population, individuals within a sample population are grouped into size classes based on stem diameter, stem circumference or stem length. Size-class distributions are regarded as a way of understanding plant population structure as well as the stability in the population (Cunningham 2001, Shaukat *et al.* 2012). The size class distribution reflects the reproductive capacity, the recruitment of new individuals (relative to mortality rate) into the population, the chance of plants in one size class surviving into the next size class as well as the prevalence of disturbance regimes (Shaukat *et al.* 2012).

## 2.4 Matrix modeling

According to the IUCN (2001) the use of natural resources is a part of human nature. Making use sustainable on the other hand is controversial and a challenge, and requires forms of control and regulations. One popular approach to managing the use of natural resources involves combining the efforts of local communities and management institutions to create models that not only guarantee the continued existence of these resources, but also satisfy the food and income requirements of the communities.

Matrix population models have become popular and powerful tools for investigating the dynamics of age or stage-structured populations (Caswell 2001, Oli 2003). Not only are these models valuable as a tool for basic ecological research but they have gained acceptance and popularity with increasing applications in wildlife management and conservation biology (Link and Doherty 2002, Crone *et al.* 2011). Caswell (2001) has indicated that matrix population models provide linkages between the individual and the population as a whole. The link is built around a simple description of a life cycle. It is therefore important to acknowledge that individual organisms are born, grow, mature, reproduce and die. Each event is however surrounded by risks, which are influenced by the environment in which the individuals find themselves.

With the aid of these models it can be determined whether and at what level a species can be harvested sustainably (Pfab and Scholes 2004, Ndangalasi 2007). By subjecting the matrix to sensitivity and elasticity analysis they can indicate the relative importance of different transitions for maintaining population growth rate (De Kroon *et al.* 2000). Elasticity analysis isolates those matrix elements or life history processes that are most sensitive to change whereas sensitivity analysis is regarded as a scenario testing of those sensitive life history processes (Desmet *et al.* 1996).

According to Jensen (1995) the matrix model was initially developed by Lewis in 1942 and improved upon by Leslie 1945 and furthermore in 1948, to describe changes in population age structure over time. The earliest matrix models (Lebreton 2005) consider a discrete time step and age classes covering intervals equal to the time step (Lebreton 2005). Leslie modified his matrix model to describe population growth in a limited environment (Pykh and Efremova 2000). However, the Leslie matrix model has been of limited use in ecology because it models exponential population growth. Since then, several density-dependent matrix models have been developed (Jensen

1995, Zhao *et al.* 2005, Namaalwa *et al.* 2005). However, these density-dependent models are complex and require detailed knowledge of the species concerned.

According to Loibel *et al.* (2006), modeling techniques are important in population studies because of mainly two reasons. Firstly, modeling is an important tool in trying to understand how environmental uncertainties affect the population growth. Secondly, the models can be used to forecast the population's behaviour as well as to estimate their extinction risk and other statistics connected with the population extinction. A picture of what future generations may look like may be obtained by multiplying the probability matrix by the present state of the population. Matrix modeling can therefore give an idea as to whether the population is growing or declining. It outlines how different life aspects of the life cycle interact. Through experimental manipulation matrix models can help in examining the 'what if scenarios' outside the ranges of observed conditions (Crone *et al.* 2011).

The use of matrix modeling systems in plant ecology is often based on short-term data which are limited in developing an understanding long-term stochastic population dynamics. The use of long-term data (e.g. 20 years of data) is regarded as a strength in stochastic matrix modeling (Pfab and Scholes 2004). It may also require a lot of computation time in cases where detailed physiological processes are simulated (Porte and Bartelink 2002, Crone *et al.* 2011). In South Africa matrix modeling has not often been used to investigate the sustainability of harvesting a particular species. It has been used in assessing the sustainable harvesting of *Sclerocarya birrea* fruits and also in the population dynamics of *Pterocarpus angolensis* (Desmet *et al.* 1996, Emanuel *et al.* 2005). However, in the case of *Sclerocarya birrea* fruits, management of other uses within the broader landscape was found to be important in maintaining yields of fruit harvesting. In their study on *Pterocarpus angolensis* Desmet *et al*. (1996) found that the most important requirement for the survival of these populations was the continued presence of mature, reproductive individuals. These were the very size classes being targeted for felling.

Wiegand *et al.* (1999) observed that understanding the population dynamics of a long-lived species is enhanced by an integrated approach of field studies and modeling. None of these approaches can provide a complete view on its own however; they can mutually promote each other's findings. Population matrix models take advantage of the fact that the life cycle of any tree species can be divided into a few stage classes and the associated probability of moving from one stage class to the next (Cunningham 2001).

**2.5 Plant conservation target areas**

Sustainability of natural resources use is part of sustainable management which is seen as an elusive goal of conservation. In implementing an effective conservation plan which should lead to sustainable management much effort should be devoted to resolving the scientific, technical, sociological and economic issues (Heywood and Iriondo 2003). The protection of biodiversity, particularly of vascular plant species should be done through adequate reserve systems. Such reserve systems should consider viable population of all species throughout their natural range (Burgman *et al.* 2001).

One of the central issues in conservation science is to determine how much needs to be protected (Poiani *et al.* 2000, Sanderson *et al.* 2002, Svancara *et al.* 2005, Tear *et al*. 2005). Many methods have been proposed to answer this question, but no universally accepted method has yet been developed. The method for setting conservation targets for any plant species developed by Burgman *et al.* (2001) may be particularly useful when there are insufficient data or time to conduct a formal population viability analysis. In this method the regional targets are used to assess the effectiveness of current conservation areas and development of new conservation management plans (Gaugris and Van Rooyen 2010). The method has only been applied once in a South African setting (Gaugris and Van Rooyen 2010). Setting of targets may help a great deal in conservation efforts of species to achieve viable populations.

**References**

ABENSPERG-TRAUN, M. 2009.*CITES,* sustainable use of wild species and incentive-driven conservation in developing countries, with an emphasis on southern Africa. *Biological Conservation* **142: 948-963.**

BODEKER, G.C. 1995. Introduction: Medicinal plants for Conservation and Healthcare. Institute of Health Sciences, University of Oxford, Oxford.

BOTHA, J., WITKOWSKI, E.T.F. AND SHACKLETON, C.M. 2004a. Market profiles and trade in medicinal plants in the Lowveld, South Africa. *Environmental Conservation* **31: 38-46**.

BOTHA, J., WITKOWSKI, E.T.F. AND SHACKLETON, C.M. 2004b. The impact of commercial harvesting on *Warburgia salutaris* ('pepper-bark tree') in Mpumalanga, South Africa. *Biodiversity and Conservation* **13: 1675-1698.**

BURGMAN, M.A., POSSINGHAM, H.P., LYNCH, J.J., KEITH, D.A., McCARTHY, M.A., HOPPER, S.D., DRURY, W.L., PASIOURA, J.A. AND DEVRIES, R.J. 2001. A method for setting the size of plant conservation target areas. *Conservation Biology* **15: 603-616.**

CASWELL, H. 2001. Matrix population models: construction, analysis and interpretation. Sinauer Associates, Sunderland.

CONDIT, R., SUKUMAR, R., HUBBEL, S. AND FOSTER, R. 1998. Predicting population trends from size distributions: a direct test in a tropical tree community. *American Naturalist* **152: 495-509.**

CRONE, E.E., MENGES, E.S., ELLIS, M.M., BIERZYCHUDEK, P., EHRLEN, J., KAYE, T.N, KNIGHT, T.M. LESICA, P., MORRIS, W.F., OOSTERMEIJER, G., QUINTANA-ASCENCIO, P.F., STANLEY, A.,

TICKTIN, T., VALVERDE, T. AND WILLIAMS, J.L. 2011. How do plant ecologists use matrix population models? *Ecology Letters* **14: 1–8.**

CUNNINGHAM, A.B. 2001. Applied ethnobotany: people, wild plant use and conservation. Earthscan Publication, London.

CUNNINGHAM, A.B. AND MBENKUM, F.T. 1993. Sustainability of harvesting *Prunus africana* bark in Cameroon. People and Plants Working Paper, 2. UNESCO, Paris, France.

DE KROON, H., VAN GROENENDAEL, J. AND EHRLEN, J. 2000. Elasticities: A review of methods and model limitations. *Ecology* **81: 607-618.**

DESMET, P.G., SHACKLETON, C.M. AND ROBINSON, E.R. 1996. The population dynamics and life-history attributes of a *Pterocarpus angolensis* DC. population in the Northern Province, South Africa. *South African Journal of Botany* **62: 160-166.**

DLADLA, S. 2001. Muthi Trade Boom: Unemployment finds refuge in traditional world. *Sunday World,* South Africa.p.19.

EMANUEL, P.L., SHACKLETON, C.M. AND BAXTER, J.S. 2005. Modelling the sustainable harvest of *Sclerocarya birrea* subsp. *caffra* fruits in the South African lowveld. *Forest Ecology and Management* **214: 91-103.**

ETNIER, M.A. 2007. Defining and identifying sustainable harvests of resources: Archeological examples of pinniped harvests in the eastern North Pacific. *Journal for Nature Conservation* **15: 196-207.**

EVERARD, D.A., VAN WYK, G.F. AND MIDGLEY, J.J. 1994. Disturbance and the diversity of forests in Natal, South Africa: lessons for their utilisation. *Strelitzia* **1: 275-285.**

GAUGRIS, J.Y. AND VAN ROOYEN, M.W. 2007. The structure and harvesting potential of the sand forest in Tshanini Game Reserve, South Africa. *South African Journal of Botany* **73: 611–622.**

GAUGRIS, J.Y. AND VAN ROOYEN, M.W. 2010. Evaluating the adequacy of reserves in the Tembe–Tshanini Complex: a case study in Maputaland, South Africa. *Oryx* **44: 399–410.**

HAMILTON, A. 2003. Medicinal plants and conservation: issues and approaches. Paper presented to International Plants Conservation Unit, World Wide Wildlife Foundation, UK.

HARROP, S.R. AND PRITCHARD, D.J. 2011. A hard instrument goes soft: The implications of the Convention on Biological Diversity's current trajectory. *Global Environmental Change* **21: 474-480.**

HARTSHORN, G.S. 1995. Ecological basis for sustainable development in Tropical forests. *Annual Review of Ecology and Systematics* **26: 155-175.**

HEYWOOD, V.H. AND IRIONDO, J.M. 2003. Plant Conservation: old problems, new perspectives. *Biological Conservation* **113: 321-335.**

HOWELL, J. AND MESHER, K. 1997. Taking care of each other: The relationship between the *Labrador metis* and the environment. Workshop on traditional and western scientific environmental knowledge. Northwest River, Labrador. September 10-11.

IUCN 2001. Analytic framework for assessing factors that influence sustainability of uses of wild living natural resources. Technical Advisory Committee. IUCN SSC Sustainable Use Specialist Group, Washington D.C. USA.

JACKSON, P.W. AND KENNEDY, K. 2009. The Global Strategy for Plant Conservation: a challenge and opportunity for the international community. *Trends in Plant Science* **14: 578-580.**

JENSEN, A.L. 1995. Simple density-dependent matrix model for population projection. *Ecological Modelling* **77: 43-48.**

KOHIRA, M. AND NINOMIYA, I. 2003. Detecting tree populations at risk for forest conservation management: using single-year vs. long-term inventory data. *Forest Ecology and Management* **174: 423-435.**

KUNIYAL, J.C. 2002. Mountain expedition: minimizing the impact. *Environmental Impact Assessment Review* **22: 561-581.**

KUROKAWA, H., YISHIDA, T., NAKAMURA, T., LAI, J. AND NAKASHIZUKA, T. 2003. The age of tropical rain-forest canopy species, Borneo ironwood *(Eusideroxylon zwageri)*, determined by $^{14}C$ dating. *Journal of Tropical Ecology* **19: 1-7.**

LAWES, M.J., EELEY, H.A.C., SHACKLETON, C.M. AND GEACH, B.G.S. 2004. Indigenous forests and woodlands in South Africa: Policy, People and Practice. University of KwaZulu-Natal Press, Pietermaritzburg, South Africa.

LAWES, M.J. AND OBIRI, J.A.F. 2003. Using the spatial grain of regeneration to select harvestable tree species in subtropical forest. *Forest Ecology and Management* **184: 105-114.**

LEBRETON, J.D. 2005. Age, stages, and the role of generation time in matrix models. *Ecological Modelling* **188: 22-29.**

LINK, W.A. AND DOHERTY, P.F. 2002. Scaling in sensitivity analysis. *Ecology* **83: 3299-3305.**

LOIBEL, S., DO VAL, J.B.R. AND ANDRADE, M.G. 2006. Inference for the Richards growth model using Box and Cox transformation and bootstrap techniques. *Ecological Modelling* **191: 501-512.**

LYKKE, A.M., 1998. Assessment of species composition change in savanna vegetation by means of woody plants' size class distributions and local information. *Biodiversity and Conservation* **7: 1261-1275.**

MABOGO, D.E.N. 1990. The Ethnobotany of the Vhavenda. M.Sc. dissertation, University of Pretoria, Pretoria, South Africa.

MARSCHKE, M. AND BERKES, F. 2005. Local level sustainability planning for livelihoods: A Cambodian experience. *International Journal of Sustainable Development and World Ecology* **12: 21-33.**

NAMAALWA, J., EID, T. AND SANKHAYAN, P. 2005. A multi-species density-dependent matrix growth model for the dry woodlands of Uganda. *Forest Ecology and Management* **213: 312-327.**

NDANGALASI, H.J., BITARIHO, R. AND DOVIE, D.B.K. 2007. Harvesting of non-timber forest products and implications for conservation in two montane forests of East Africa. *Biological Conservation* **134: 242-250.**

NIKLAS, K.J., MIDGLEY, J.J. AND RAND, R.H. 2003a. Size-dependent species richness: trends within plant communities and across latitude. *Ecology Letters* **6: 631-636.**

NIKLAS, K.J., MIDGLEY, J.J. AND RAND, R.H. 2003b. Tree size frequency distributions, plant density, age and community disturbance. *Ecology Letters* **6: 405-411.**

NJOROGE, G.N., KAIBUI, I.M., NJENGA, P.K. AND ODHIAMBO, P.O. 2010. Utilization of priority medicinal plants and local people's knowledge on their conservation status in arid lands of Kenya (Muringi District). *Journal of Ethnobiology and Ethnomedicine* **6: 22-29**.

OBIRI, J., LAWES, M. AND MUKOLWE, M. 2002. The dynamics and sustainable use of high value tree species of the coastal Pondoland forests of the Eastern Cape Province, South Africa. *Forest Ecology and Management* **166: 131-148.**

OLI, M.K. 2003. Partial life-cycle models: how good are they? *Ecological Modelling* **169: 313-325.**

OSHO, J.S.A. 1996. Modelling the tree population dynamics of the most abundant species in a Nigerian tropical rain forest. *Ecological Modelling* **89: 175-181.**

PFAB, M.F. AND SCHOLES, M.A. 2004. Is the collection of *Aloe peglerae* from the wild sustainable? An evaluation using stochastic population modeling. *Biological Conservation* **118: 695-701.**

POIANI, K.A., RICHTER, B.D., ANDERSON, M.G. AND RICHTER, H. 2000. Biodiversity conservation at multiple scales: functional sites, landscapes and networks. *BioScience* **50: 133-146.**

PORTE, A. AND BARTELINK, H.H. 2002. Modelling mixed forest growth: a review of models for forest management. *Ecological Modelling* **150: 141-188.**

PUPPIM DE OLIVEIRA, J.A., BALABAN, O., DOLL, C.N.H., MORENO-PENARANDA, R., GASPARATOS, A., IOSSIFOVA, D. AND SUWA, A. 2011. Cities and biodiversity: Perspectives and governance challenges for implementing the convention on biological diversity (CBD) at the city level. *Biological Conservation* **144: 1302-1313.**

PYKH, Y.A. AND EFREMOVA, S.S. 2000. Equilibrium, stability and chaotic behavior in Leslie matrix models with different density-dependent birth and survival rates. *Mathematics and Computers in Simulation* **52: 87-112.**

ROBINSON, J.G. 1993. The limits to caring: sustainable living and the loss of biodiversity. *Conservation Biology* **7: 20-28.**

SANDERSON, E.W., REDFORD, K.H., VEDDER, A., COPPOLILLO, P.B. AND WARD, S.E. 2002. A conceptual model for conservation planning based on landscape species requirements. *Landscape and Urban Planning* **58: 41-56.**

SHAUKAT, S.S., AZIZ, S., AHMED, W. AND SHAHZAD, A. 2012. Population structure, spatial pattern and reproductive capacity of two semi-desert undershrubs *Senna holosericea* and *Fagonia indica* in Pakistan. Pakistan Journal of Botany **44: 1-9.**

STEENKAMP, V. 2003. Traditional herbal remedies used by South African women for gynaecological complaints. *Journal of Ethnopharmacology* **86: 97-108.**

SVANCARA, L.K., BRANNON, R., SCOTT, J.M., GROVES, C.R., NOSS, R.F. AND PRESSEY, R.L. 2005. Policy-driven versus evidence-based conservation: a review of political targets and biological needs. *BioScience* **55: 989-995.**

TABUTI, J.R.S., DHILLION, S.S. AND LE, K.A. 2003. Traditional medicine in Bulamogi county, Uganda: its practitioners, users and viability. *Journal of Ethnopharmacology* **85: 119-129.**

TEAR, T.H., KAREIVA, P., ANGERMEIER, P.L., COMER, P., CZECH, B., KAUTZ, R., LANDON, L., MEHLMAN, D., MURPHY, K., RUCKELSHAUS, M., SCOTT, J.M. AND WILHERE, G. 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation. *BioScience* **55: 835 – 849.**

TSHISIKHAWE, M.P. 2002. Trade of indigenous medicinal plants in the Northern Province, Venda region: their ethnobotanical importance and sustainable use.

M.Sc. Dissertation, University of Venda for Science and Technology, Thohoyandou, South Africa.

VAN STADEN, J. 2008. Ethnobotany in South Africa. *Journal of Ethnopharmacology* **119: 329-330.**

VON MALTITZ, G.P. AND SHACKLETON, S.E. 2004. Use and management of forests and woodlands in South Africa: stakeholders, institutions and processes from past to present. In: Lawes, M.J., Eeley, H.A., Shackleton, C.M. & Geach, B.G. (eds). *Indigenous forests and woodlands in South Africa: policy people and practice*. pp. 109-135. University of KwaZulu-Natal Press, Pietermaritzburg.

WIEGAND, K., JELTSCH, F. AND WARD, D. 1999. Analysis of the population dynamics of *Senegalia* trees in the Negev desert, Israel with a spatial-explicit computer simulation model. *Ecological Modelling* **117: 203-224.**

WILLIAMS, V.L., BALKWILL, K. AND WITKOWSKI, E.T.F. 2000. Unraveling the commercial market for medicinal plants and plant parts on the Witwatersrand, South Africa. *Economic Botany* **54: 310-327.**

WILLIAMS, V.L., BALKWILL, K. AND WITKOWSKI, E.T.F. 2007. Size-class prevalence of bulbous and perennial herbs sold in the Johannesburg medicinal plant markets between 1995 and 2001. *South African Journal of Botany* **73: 144-155.**

WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT 1987.Our common future. Oxford University Press, Oxford.

WORLD HEALTH ORGANIZATION. 2002. Traditional Medicine Strategy 2002 – 2005. Traditional Medicine Strategy. www.who.int/medicines/publications/ traditionslpolicy/index.html.

ZHAO, D., BORDERS, B. AND WILSON, M. 2005. A density-dependent matrix model for bottomland hardwood stands in the Lower Mississippi Alluvial Valley. *Ecological Modelling* **184: 381-395.**