Bark re-growth and wood decay in response to bark stripping for medicinal use

By

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Declaration `

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

Plants have been used for centuries to treat a wide range of ailments in the history of all civilizations. However, a growing interest in medicinal plants requires appropriate management to prevent over-exploitation of target species. The challenge for scientists is to find equilibrium between resource exploitation and the maintenance of viable populations of target species. Sustainability of use requires an understanding of the ecological, economic and socio-cultural aspects of resource use and the interaction between these factors. This research focuses on the ecological and socio-cultural aspects required to underwrite species-specific sustainable harvesting systems for bark used for traditional medicine.

The social survey conducted in the form of structured interviews with traditional healers reported 69 plant species used for medicinal purposes in the southern Cape. The results suggested that resource users are aware of the increase in demand for medicinal plants in general, attributing this to an increasing recognition of traditional medicines and increasing prevalence of diseases. *Ocotea bullata* (Endangered), *Curtisia dentata* (Nearly Threatened) and *Rapanea melanophloeos* (Declining), as well as *Siphonochilis aethiopicus* (Critically Endangered), *Elaeodendron transvaalense* (Near Threatened) and *Cassipourea flananganii* (Endangered) that do not occur in the area naturally, were identified as species in high demand for their medicinal bark properties. Given the high demand and concerns about over-exploitation, a need for further ecological research to develop sustainable harvest systems was identified.

Two species, *O. bullata* and *C. dentata*, were selected from an earlier study on the response of several species to bark stripping, that was confined to a study period of three years after treatment. With this current study tree response to bark stripping and harvesting impact were assessed over a period of ten years to reveal the intra and inter-specific difference of wound occlusion (wound closure through bark-regrowth) and the anatomical decay consequences of bark stripping. This is, to the knowledge of the author, the first study to evaluate the structural-tree pathogen interaction following bark stripping on medicinal tree species in Africa. The results revealed species-specific differences in terms of both wound closure and efficiency in decay containment. *O. bullata* had a significantly better wound occlusion rate and a lower extent of decay. The relationship between tree diameter growth and the rate of wound occlusion allowed for the formulation of a preliminary model that will assist forest managers in developing bark harvest systems. Smaller trees showed poor bark regrowth and a significantly higher mortality, which suggest that a minimum tree size for harvesting needs to be stipulated in the harvest prescriptions. In contrast, *C. dentata* showed a much higher volume of decay within the stem, poor bark regrowth and a significantly higher mortality of bark-stripped trees. In conclusion, the harvesting of bark for *C. dentata* through bark stripping is not viable, and alternatives should be explored. *O. bullata* has a much greater potential for strip harvesting, both in terms of bark regrowth and the containment of wood decay following wounding.

Opsomming

Beskawings gebruik al vir eeue plante vir die behandeling van ‘n verskeidenheid van kwale. Die toenemende belangstelling in medisinale plante vereis egter oordeelkundige bestuur om die oorbenutting van teikenspesies te voorkom. Die uitdaging vir wetenskaplikes is om 'n balans tussen die benutting van hulpbronne en die handhawing van lewensvatbare populasies van teikenspesies te bewerkstellig. Standhoudende benutting vereis insig in die ekologiese, ekonomiese en sosio-kulturele aspekte van hulpbronbenutting, en die interaksie tussen hierdie faktore. Hierdie navorsing fokus op die ekologiese en sosio-kulturele aspekte wat nodig is om spesie-spesifieke, standhoudende oesstelsels vir bas wat vir tradisionele medisyne gebruik word, te onderskryf.

Die sosiale opname, in die vorm van gestruktureerde onderhoude met tradisionele genesers, dui op 'n totaal van 69 plantspesies wat vir medisinale doeleindes in die Tuinroete gebruik word. Gebruikers is oor die algemeen bewus van die toenemende vraag na medisinale plante, en skryf dit toe aan groter erkenning van tradisionele medisyne en ‘n toename in siektes. *Ocotea bullata* (Bedreig), *Curtisia dentata* (Byna bedreig) en *Rapanea melanophloeos* (Afnemend), asook drie spesies wat nie natuurlik in die gebied voorkom nie, *Siphonochilis aethiopicus* (Kritiek bedreig), *Elaeodendron transvaalense* (Byna bedreig) en *Cassipourea flananganii* (Bedreig), is geïdentifiseer as spesies in groot aanvraag weens hul medisinale eienskappe. Die hoë aanvraag en kommer oor oorbenutting het gelei tot die behoefte vir verdere ekologiese navorsing vir die onwikkeling van oesstelsels vir die spesies.

Twee spesies, *O. bullata* en *C. dentata*, is geselekteer van ‘n vroeëre studie oor die reaksie van verskeie spesies op basstroping wat beperk was tot ‘n studieperiode van drie jaar na behandeling. Die huidige studie was daarop gemik om die reaksie en impak oor ‘n periode van 10 jaar na behandeling te bepaal, en die intra- en inter-verskille van wond sluiting (wond sluiting deur die hergroei van die bas) en anatomiese verrotting na basstroping te beskryf. Dit is, tot die kennis van die outeur, die eerste studie om die struktuur-boompatogeen interaksie na basstroping op medisinale boomsoorte in Afrika te beskryf.

Die resultate dui op spesie-spesifieke verskille in beide wond en die beperking van houtverrotting. *O. bullata* het ‘n betekenisvolle hoër tempo van wondsluiting en effektiwiteit in die beperking van houtverrotting. Die korrelasie tussen boomdeursnee-aanwas en die tempo van wondsluiting het die ontwikkeling van ‘n voorlopige model om bosbestuurders te help met die ontwikkeling van oesvoorskrifte, moontlik gemaak. Kleiner bome toon swak bas-hergroei en betekenisvolle hoër mortaliteit, wat aandui dat ‘n minimum grootte vir oesbome neergelê behoort te word in oesvoorskrifte. In teenstelling toon *C. dentata* ‘n baie groter mate van houtverrotting, het swak bas-hergroei, en ‘n betekenisvolle hoër mortaliteit van gestroopte bome. Ter afsluiting, die oes van *C. dentata* deur basstroping is nie lewensvatbaar nie en alternatiewe behoort ondersoek te word. *O. bullata* het ‘n groter potensiaal vir standhoudende basstroping, beide in terme van bas-hergroei en die beperking van houtverrotting na oes.

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Dedication

This thesis is dedicated to the memory of my beloved late mother and the late Zeni Booysen.

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1 Chapter 1: Introduction

1.1 Background Information

Non-timber forest products (NTFPs) include all materials of biological origin derived from forests, excluding wood. This includes edible products like fruits, resins, animal products and medicinal plants (FAO, 1999). Non-timber forest products have been harvested by humans for subsistence and trade for thousands of years (Ticktin, 2004). The majority of South Africa's population still depends on resources from natural vegetation for subsistence and income generation. It is estimated that up to 80% of South Africans use plants for medicinal and cultural purposes (Mander, 1998), consuming 19 500 tonnes of plant material per annum. Harvesting of bulbs, fruits, roots and bark for medicinal purposes forms a large component of NTFP's harvested from natural systems.

Effective management of non-timber products is thus important to sustain the livelihoods of the people that depend on them. It is therefore an important aspect of sustainable management of natural forest, woodland and savanna in South Africa. According to Dold and Cocks (2002), baseline information in trade of medicinal plants has been well documented for the Eastern Cape, KwaZulu-Natal, Gauteng and Mpumalanga provinces. Medicinal plants have been highly commercialized; in Kwazulu-Natal alone, over 400 plant species with an estimated volume of 4 300 tonnes are traded per annum (Cunningham, 1988). Dold and Cocks (2002) reported a total of 166 species to be traded for medicinal and cultural use in the Eastern Cape. A recent study conducted in the Cape Peninsula area reported a total of 112 plants species (Mintsa Mi Nzue, 2009), and another study conducted within the boundaries of Cape Town reported a trade of 129 medicinal plants (Peterson et al., 2012). The estimated value of medicinal trade in South Africa is R270 million per annum (Mander, 1998).

Bark from different forest and woodland species forms one third of all the plant material used in traditional medicine in South Africa (Grace et al., 2003). Traditional medicines including bark are used to treat various ailments including skin diseases, stomach ailments, and gynaecological problems and also used to treat livestock for various diseases. *Curtisia dentata* and *Ocotea bullata* are among the top tree species that are exploited for their bark, especially in

Kwazulu-Natal and Eastern Cape (Dold and Cocks, 2002; Zschocke et al., 2000) Besides producing highly valued furniture wood, bark of *O. bullata* is used medicinally to remedy headaches, urinary disorders and stomach ailments. Due to the exploitation of *O. bullata* (Lauraceae), also known as stinkwood, for its bark, there has been a decline in their population numbers and sizes that has earned the species a national conservation status of endangered. Phytochemical and pharmacological research has been conducted on the species to seek to establish scientific basis for use of the species to treat a particular ailment, and its safety. Investigations resulted in the isolation of the novel compounds sibyllenone and ocobullenone, which contribute to the inhibitory activity of *O. bullata* bark, extracts (Zschocke et al., 2000). Zschocke et al. (2000) found the characteristic analytical fingerprints of leaf and bark extracts showed great similarities. This finding is of significance in species management, Geldenhuys (2004) recommended the substitution of leaves for bark as a means to avoid wounding of trees through bark harvesting.

In South Africa, *C. dentata* (Cornaceae) has been reported to be medicinally used to treat diarrhea and stomach ailments (Notten, 2004), to manage obesity (Afolayan and Mbaebie, 2010), and used in cattle for treatment of heart-water disease in the Eastern Cape (Dold and Cocks, 2001). In other Southern African cultures it has been used as an aphrodisiac, blood purifier and for relief from diarrhoea (Pujol, 2000). *C. dentata* populations has been reported to be declining and classified as vulnerable and protected in Kwazulu Natal (Cunningham, 1988), Scott-Shaw (1999) classified it as conservation depended and legally protected and Dold and Cocks, 2002 reported the species to be heavily traded, unsustainable harvested and conservation depended in South Africa

The high value of *C. dentata* in traditional medicine has stimulated phytochemical and pharmacological research on the species to establish scientific validation for its use and its safety in traditional medicines. Doughari et al. (2011) reviewed the ethno pharmacological application of *C. dentata*, concluding that it is a very effective source of antioxidants. Shai et al. (2007 & 2008) reported the presence of antibacterial and antifungal triterpenoids, while Breuer et al. (1978) reported the presence of fatty acid linoleic acid ($C_{17}H_{31}COOH$) responsible for cell development and regulation of cellular metabolism. Oyewole et al. (2012) verified the presence of antibacterial and antioxidant properties in *C. dentata* that support its use in the treatment of diseases in traditional medicine.

Harvesting has implications for the viability of medicinal plant species. Ecological impacts of harvesting have received attention in the literature (Ticktin, 2004). Harvesting affects the survival, growth and reproduction of individuals (Ticktin 2004; Gaoue & Ticktin, 2007), influences demographic and genetic patterns of populations (Gaoue and Ticktin, 2007) and can alter community structure and ecosystem processes (Ticktin, 2004). Tolerance to harvesting depends on the particular product, or part of an individual, that is harvested and its life history (Ticktin, 2004). For example, the harvesting of bark from trees interrupts the transportation of the water and nutrients from leaves to roots, resulting in internal stress that may compromise individual tree survival.

Research efforts have focused on biological, social and economic aspects of medicinal use to inform harvesting and management. However a large number of harvested species still lack ecological data which hinders the process of developing effective management of the target species. For some species significant effort has been devoted to the study of species-specific harvesting system, including demographic modelling and experimental harvesting studies (Gaoue and Ticktin 2007). To gain better understanding of the ecological consequences of bark harvesting, a commercial products from the wild (CP Wild) experimental project (Geldenhuys, 2000a; Geldenhuys, 2000b) was initiated in 2001 in the southern Cape natural forests. The two species, *O. bullata* and *C. dentata* which are widely used nationally and have been reported as harvested medicinally for their bark in the southern Cape forests (Geldenhuys and Lübbe, 1990; Mostert & Lübbe, 1991; Berry 1993a, b; Ferguson 1995), were selected.

The results obtained on the two species over a 36-month period provided some insight on how the species responded to bark stripping. The results indicated that *C. dentata* is slow in rate of wound closure due to its erratic growth and bark lift as bark dries out around the wound (Vermeulen et al., 2012). In contrast, the *O. bullata* demonstrated better bark regrowth, through phellagen edge growth development, and was less susceptible to insect and fungal attack compare to *C. dentata* (Vermeulen et al., 2012). The study described in this thesis is aimed at taking this project to conclusion by gathering longer term data of wound closure and tree growth. The study will further investigate the degree and extent of decay in barked-stripped trees in order to determine the full impact of bark stripping on these two species.

In the Southern Cape and Tsistikamma forests there has been a growing demand for medicinal plants with increasing incidences of illegal harvesting, including bark and medicinal plant trade reported (Figure 1.1). Among other incidences of illegal harvesting reported include the exploitation of *Bulbine latifolia* in the coastal forests of Harkerville (Vermeulen, 2009),. As national legislation, including the National Forests Act, 1998 (Act No. 84 of 1998), provides for the rights of communities living adjacent to natural forests of access to natural resources, there is a need to develop sustainable harvesting systems in order to ensure a flow of social and economic benefits in the long term, to meet the objectives of the Forest Act and honour international obligations with regard to conservation of biological diversity. To ensure sustainable management of medicinal plants, an understanding of the user demands and detailed studies on the dynamics and reproduction phenology of targeted species is crucial in order to develop sensible and sustainable harvesting systems. To understand the user needs in the southern Cape, a survey was conducted with traditional healers. The aim of the survey was to gather information of traditional healer's opinions on demand and availability of medicinal plants in the region.

Figure 1.1 Destructive bark harvesting (A) two stems of *Ocotea bullata* and (B) bark traded in an informal market (Photocredit: Wessel Vermeulen)

Studies have been conducted on wound closure and underlying anatomical variables beneath bark regeneration (Geldenhuys et al., 2007; Delvaux, et al., 2009; Vermeulen, 2009).

However, there is still a great need for in-depth investigation to further explore the consequences of bark stripping for structural wood formation and the pathogenic consequences to complement the available results. Wounds may seal but not heal on the inside (Shigo, 1984) or wounds may never completely close, but they may heal from the inside (Garret and Shigo, 1978). Therefore, by only considering the potential of wounds to seal, without an understanding of what happens inside the tree, one may misinterpret the long-term implications of bark stripping. The compartmentalization of decay in trees (CODIT) concept of Shigo and Marx (1977) provides a good theoretical framework of what happens in the case of cambial wounding. The concept describes how trees defend themselves by developing a boundary around the wound to minimize the extent of fungal spread and enclose decay that could endanger the remaining cambium. This study seeks to describe decay patterns and evaluate if there is a relationship between the amounts of decay in a wounded tree and the rate of wound closure and tree growth.

1.2 **Rationale**

There is a growing demand for access to medicinal plants from natural forests in the southern Cape (Vermeulen, 2009). Relevant legislation and policies provide for controlled access to natural resources, subject to the principles of sustainable harvesting. Therefore, there is a need to develop sustainable bark harvesting systems. In order to achieve this, there is a need to understand the user demands for medicinal plants in the region; this was done through structured interviews with the traditional healers practicing in and around the southern Cape. To understand ecological consequences of bark harvesting from *O. bullata* and *C. dentata* individuals, an experimental bark harvesting project was initiated in the southern Cape forests in 2001 to assess species-specific tree responses to bark stripping, especially in terms of bark regrowth and wound closure (Vermeulen, 2009). However, current assessments (Vermeulen, 2009) are based on results gathered/collected three years after bark stripping, which is a relatively short period. The proposed study would complement the experimental bark-harvesting project by assessing long term (10 years) species-specific wound closure responses. This study will be taken to a conclusion by also looking at the consequences of bark stripping for structural wood formation and eventual mortality. The knowledge emanating from this study will be useful for the implementation of conservation approaches for the sustainable harvesting of bark by South African National Parks and elsewhere.

1.3 Objectives & Key Questions

The objective of the study was to determine user needs in terms of medicinal plants, and further determine the impact of bark stripping on two highly valued medicinal tree species native to South Africa. The objectives focus on the bark-regrowth response as well as structural tree-pathogen interaction, aimed at revealing intra-specific and inter-specific differences of wound occlusion, defense reactions to bark stripping with the growth of the tree, the compartmentalization and the extent of decay within the tree stem.

Objective 1.

To assess medicinal plant use patterns and needs in the southern Cape

Key questions:

1. What are the most used medicinal plants in the southern Cape?
2. Are medicinal plant users aware of the status of some medicinal plants in the wild?
3. What are medicinal plant user’s perceptions of cultivated plants?

Objective 2.

To determine possible interspecific differences in wound occlusion after bark stripping and relevant factors influencing the occlusion progress.

Key Questions:

1. Do season, removed bark strip width, tree size and tree growth influence the rate of wound occlusion?
2. How does debarking affect the survival of the species?
3. What time spans are needed for complete wound closure after bark harvesting?

Objective 3

To assess the interspecific differences in terms of wound closure and its relation to decay progress.

Key questions

1. What is the extent and degree of tree decay following bark stripping?
2. Are there any interrelationships between wound occlusion rate, diameter growth and degree and extent of decay within a stem?
3. How effective is the CT scanner in detecting "changes" in density between bark, sound wood, barrier zone and rot?

1.4 **Thesis structure**

This thesis represents an attempt to understand the demand for medicinal plants species , tree reactions to stem damage and degree and extent of decay following bark stripping.

Chapter 1 gives background information, the study rationale, the main objectives and the research questions.

Chapter 2 investigates the opinions of traditional healers on demand and availability of medicinal plants in the Southern Cape.

Chapter 3 discusses findings on the experimental debarking project that seek to understand the responses of *O. bullata* and *C. dentata* to bark stripping in terms of bark regrowth and how it influences tree survival.

Chapter 4 deals with the pathological consequences (decay) caused by bark stripping of individuals of *O. bullata* and *C. dentata*. Chapter 5 discusses main findings of the study and management implications.

Chapter 5 discusses main findings of the study and management implications.

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2 Chapter 2: Medicinal plant use in the southern Cape

2.1 Abstract

Traditional medicine plays a major role in the primary healthcare of the majority of South African people. Medicinal plants are used to treat various diseases and for cultural and spiritual purposes. The study undertook to document medicinal plant use patterns in the Southern Cape. A total of 69 plant species with different plant life-forms, including geophytes, epiphytes, herbs, shrubs and trees were reportedly used in the study area. The majority of respondents reported an increase in demand for medicinal plants and predicted future demand increase attributing this among other things, to increasing prevalence of diseases and recognition of traditional medicine. Respondents further acknowledged the decline of medicinal plants from wild stock, stating unsustainable harvesting by irresponsibly collectors as a major reason for the decline. Furthermore respondents indicated an interest in use of cultivated plants. Cultivation, where practically possible can also be used in conjunction with controlled use of wild plants as a conservation approach that will partly address the challenge of over-exploitation of popular medicinal plants.

2.2 Importance of medicinal plants in South Africa

There is a wealth of archeological evidence from preserved monuments and written documents indicating that medicinal plants were used in prehistoric times (Petrovska, 2012). The tradition of using plants for medicinal purposes has been handed down from generation to generation. The World Health Organization (WHO) estimated that 80% of the world's population depends on traditional medicine for primary health care (Azaizeh et al., 2003). Traditional medicine remains important to African people because it is considered safe, has minimum side effects and is affordable, culturally acceptable and easily available. The use of traditional medicines is often in combination with the use of modern biochemical products. The use of plants from natural systems for medicinal purposes is well documented in different parts of South Africa, and Steenkamp (2003) emphasized that medicinal plants are also an element of religion and culture for African people.

South Africa has widely diverse cultures within the population, including Nguni, Xhosa, Ndebele, and Swazi ethnic groups. It is not only highly diverse in cultural groups, it is also known for high diversity of flora and endemism, with an estimated 24 000 species, comprising of more than 10% of the world's vascular plants (Germishuizen and Meyer, 2003). With high diversity of culture and flora, it is not surprising that approximately 3000 plant species are used for medicinal purposes (van Wyk et al., 1997). In Southern Africa alone there is an estimated 500 000 traditional healers that rely upon medicinal plants and herbs for the preparation of therapeutic substances (Mander and Le Breton, 2005).

Medicinal plants are used to treat diseases and for cultural and spiritual purposes. Medicinal plant species are often used for multiple health problems e.g. from treating headaches to treating serious illnesses such as cancer. In the Western Cape the corm (stem) of the geophyte *Bulbine* species is used mainly by the Rastafarian community as an aphrodisiac and a health drink (Vermeulen, 2009). In Kwazulu-Natal it is used by young men to harm a rival lover of their sexual partner (Bryant, 1970). Hutchings (1989) and Hutchings et al., (1996) reported that the species is used for treating wounds, ringworms, herpes and rashes, psychological ailments, and also to strengthen muscles. The *Bulbine* species have also been reported to be used for rheumatism, blood disorders, convulsions, diabetes and urinary complaints (Van Wyk et al., 1997).

Detailed inventories of plants with medicinal properties and their uses have been well drawn up in South Africa (Watt and Breyer-Brandwijk, 1962; Bryant, 1970; Hutchings, 1989; van Wyk et al., 1997; Mander, 1998; Diederichs, 2001; Matsiliza and Barker, 2001; Arnold et al., 2002; Grace et al., 2003; Mintsa Mi Nzue, 2009). Further studies have been conducted on the extent of trade of medicinal species in South Africa. In a study conducted in Kwazulu-Natal (Mander, 1998), over 400 plant species were reportedly used and traded for medicinal purposes. Williams, 2003 recorded more than 300 medicinal plant species traded in the Johannesburg Faraday market. A total of 166 medicinal plants were recorded in the study conducted in the Eastern Cape (Dold and Cocks, 2002).

The demand for popular medicinal plant species exceeds supply in most instances (Mander, 1998), which is a major concern for persistence of popular medicinal plant species especially outside conservation areas. *Warburgia salutaris*, a tree that is highly exploited for its bark, is used for coughs, colds and headaches (Van Wyk *et al.,* 2009). In Kwazulu Natal, the species is reportedly extinct outside protected areas and is critically endangered (Mander, 1998). The species has also been reported to be the most traded medicinal species in Limpopo (Mathibela, 2013). In Kenya, the species has also been reported to be highly exploited and declining in the wild (Kokwaro, 1991).

The decline and ultimate extinction of medicinal plants does not only threaten biodiversity, but ultimately threatens the livelihoods of populations that directly depend on them for primary healthcare and economic gain. Therefore sustainable harvesting is essential for both the conservation of target species and also for the livelihood of mainly rural communities. Various strategies and methods of conservation need to be explored to address this challenge, and the social, economic and political conditions essential for sustainable exploitation of medicinal plants has widely been debated in literature.

2.3 **Policy and Legislation**

There are several acts, ordinances and international conventions that pertain to exploitation of natural resources in South Africa. As far as management of the country's biodiversity is concerned, it all begins with the South African constitution (Act No 108 of 1996) that states that all South Africans have a right to a well conserved environment and people of South Africa have a right to benefit from natural resources for social and economic development.

The National Environmental Management Act (NEMA) (Act No. 107 of 1998) promotes cooperative governance in environmental management and also provides for the use of natural resources for social and economic development without compromising the integrity of the environment. The National Environmental Biodiversity Act (Act no 10 of 2004) seeks to protect genetic diversity, species, habitats and ecological processes within the framework of NEMA (1998). It further provides for equitable access to natural resources.

The National Environmental Protected Areas Act (Act no. 57 of 2003) provides for the protection and conservation of ecologically viable areas representative of South Africa's biological diversity and its landscapes and seascapes. It requires management in accordance with the norms and standards for inter-governmental co-operations and public consultations in matters of protected areas. It promotes the utilization of natural resources within protected areas for the benefit of adjacent communities in a manner that still ensures preservation of ecological characteristics of such areas.

The National Forests Act (Act no. 84 of 1998) makes provision for use of natural resources by local communities for both social and economic development provided that it is sustainable, and that it does not threaten the resource and ecosystem functioning or elements of biodiversity dependent on it. It promotes sustainable use of forests for environmental, economic, educational, recreational, cultural, health and spiritual purposes.

In addition, South Africa is a party to a number of international agreements and conventions, for example the International Convention on Biological Diversity, which recognizes dependency of indigenous and local communities on biological resources, and hence promotes equitable sharing of benefits arising from biological diversity while ensuring sustainability. Other relevant conventions that South Africa subscribes to include the Statement of Forest Principles (The Non Legally Authoritative Statement of Principles for a Global Consensus on the Management and Sustainable Development of All Types of Forests) and the World Conservation Union (IUCN) Policies and Guidelines (e.g. the Policy Statement on Sustainable Use of Wild Living Resources, the Principles and Guidelines on Indigenous and Traditional Peoples and Protected Areas, and the Policy on Social Equity in Conservation and Sustainable Use of Natural Resources).

Despite all these tools and instruments of policy and legislation, South Africa is still confronted with tough challenges with respect to the sustainable use and conservation of important natural resources. Vermeulen, 2009 reported the challenges to be due to (1) socio-economic circumstances in many forest areas in South Africa; (2) constraints with the development of ecologically sustainable harvest systems; (3) the high level of commercialization based on unsustainable harvest levels; and (4) lack of skills and financial resources to ensure the effective implementation. There is further a lack of effective mechanisms for the comprehensive management of resources and factual basis for evaluating the situation. Despite considerable ecological and social research done with regard to sustainable use, little attention has been paid to ensuring that the findings of research are implemented in practice. Further information about current management, extent of legal and illegal use and level of resource degradation is required in order to design a strategy to rectify the situation.

2.4 Case study of the southern Cape

2.4.1 Background information

While illegal and uncontrolled harvesting of medicinal plants is a major problem in the Eastern Cape and Kwazulu-Natal, the Southern Cape Afrotemperate forests have only experienced relatively low incidences of illegal harvesting since the 1980's but this is steadily increasing (Vermeulen, 2009). To date there is still a lack of information on the needs of traditional healers and medicinal plant users in and around the southern Cape. Vermeulen (2009) recorded a list of illegally harvested medicinal tree species in the southern Cape. Though illegal harvesting is not at an alarming rate in the Southern Cap forests, there are concerns for future exploitation of the resource especially with reported rapid influx of black community from the Eastern Cape mostly relying on traditional medicines. There is a great potential for sustainable bark harvesting in the Southern Cape and Tsitsikamma forests if measures are put in place to ensure sustainability (Vermeulen, 2009). A need for sustainable bark harvesting system for the Southern Cape was identified by Lubbe et al. (1991). In order to define sustainable harvesting systems, there is a need to gain understanding of resource needs for medicinal plants in the region and this study seeks to address this research need.

2.4.2 Study area

The study was conducted in the southern Cape with main focus in the George and surrounding areas. Fynbos and natural forests are the main vegetation types of the Southern Cape. The natural forests cover a total area of about 60 500 ha between 22°00' and 24°30'E of which 35 765 ha are managed by South African National Parks (SANParks).The natural forests are scattered between George and Humansdorp on the narrow coastal strip to the south of the Outeniqua and Tsitsikamma Mountains. The total area of fynbos is approximately 127000 ha of which 75896 is managed by SANParks.

2.4.3 Methods

Questionnaire used for this study was administered by Department of Water affairs and Forestry (DWAF) now known as Department of Agriculture, Forestry and Fisheries (DAFF) in 2005. Structured questionnaire (Appendix 1) was used to gather relevant information from traditional healers which are members of the southern Cape traditional healers association. The respondents were selected randomly with the assistance of the leader of the association. To overcome the language barrier, questions were asked in isiXhosa to respondents that were unable to communicate in English. It is important to note that, a list of species provided by respondents included all plant species that they use for healing including those that do not naturally occur in the southern Cape which are sourced from other areas including the Eastern Cape and Cape Town surrounding areas. Dold and Cocks (1999), Steenkamp (2003), Buwa and Van Staden (2006) and Mintsa Mi Nzue (2009) were used to translate the Xhosa plant names to scientific and common names. Additional information was collected from SANParks (A conservation agency managing part of the indigenous forests, fynbos and marine areas of the Southern Cape) through face-to-face meetings with rangers from the Wilderness, Knysna and Tsitsikamma sections of the Garden Route National Park to obtain names of plant species that are illegally harvested within the boundaries of the Garden Route National Park.

2.4.4 Profile of respondents

The survey was done on 17 key informants (traditional healers), with 82.5% (N=14) performing traditional healing, and 17.5% (N=3) involved in traditional healing by selling to other traditional healers and consumers. Of the total respondents, 41.1% (N=7) had been practicing in the Southern Cape for 5-10 years, 17.6% (N=3) for 10-15 years and 41.1 % (N=7) had been practicing for more than 15 years. All respondents were black Africans, 94.2% Xhosa and 5.8% Swati speaking. The respondents consisted of 53% males and 47% females.

2.4.5 Data Analysis

The data was entered in Microsoft Excel and mainly descriptive analysis done. Data obtained from questionnaires were to obtain a list of species used for medicinal purposes in the study area.

Furthermore, information on respondents' perceptions on medicinal plants demand, availability and use of cultivated plants was obtained from questionnaires.

2.4.6 Results

A total of 33 plant species have been recorded as illegally harvested for medicinal purposes in the Garden Route National Park (Table 2.1). This is based on plants that have been confiscated and observations of bark stripping on standing trees. The respondents reported having an average of 8.4 customers per day. In total, 79 plant species were recorded to be used for medicinal purposes in the southern Cape Route (Appendix 2). The most frequently cited species, their conservation status and plant part used are presented in Table 2. Twenty-six species were cited more than once by respondents (Table 2.2): *Rapanea melanophloeos,* had the highest frequency of citation at 16, followed by *Pittosporum viridiflorum* with 13 citations*, Afzelia quanzensis*, *Ocotea bullata* and *Curtisia dentata* had nine citations each. Of the most cited species, *R. melanophloeos, C. dentata, O. bullata, Siphonochilus aethiopicus, Elaeodendron transvaalense and Cassipourea flanaganii* are on the red data species list (Table 2.2).

The majority of the respondents (94.1%, N=16) interviewed were of the opinion that there has been an increase in demand for medicinal plants and treatment in the recent past, and predicted the same pattern for the future. One respondent (5.9%) was uncertain and stated that an increase in number of traditional healers makes it difficult to be certain. The respondents' reasons for the demand increase and frequency of the response appears in Table 2.3. The majority of respondents (64.3%) cited the increase in number of sick people to be the reason for the increase in demand for medicinal plants in the past. The other reasons included people being more exposed to diseases (17.6%), recognition for traditional medicine (23.5%) and an increase in diseases (11.7%). The respondents' response to the change in medicinal plants availability appears in Table 2.4.

All respondents indicated that popular medicinal plants have become scarcer in the wild. Reasons given for declining availability of medicinal plants included an increase in number of traditional healers and sick people (23.5%), uncontrolled destructive harvesting of plants (23.5%), and decreased access to the wild plants in protected areas (5.8%), while 23.5% of respondents were uncertain about the reasons behind the decline in medicinal plants. All respondents indicated a willingness to use cultivated medicine. More than 50% of the respondents indicated willingness to grow their own plants, 30% was willing to buy and grow their own plants and 18% were willing to buy cultivated plants.

Figure 2.1 Species confiscated within the boundaries of the Garden Route National Park (photocredit: Muneer Moses)

Table 2.1 The list of species illegally harvested in the Garden Route National Park,

Scientific name	English name	Parts	Growth form
Acorus calamus	Sweetroot	root	geophyte
Arctopus echinatus	Bear's Foot	root	geophyte
Agathosma betulina	-	leaves	shrub
Artemisia afra	African wormwood	leaves	shrub
Carpacoce spermacocea	-	leaves	herb
Geranium incanum	-	leaves	herb
Clausena anisata	Horsewood	leaves	shrub
Centella virgita	-	leaves	herb
Dassiepis hyraceum	Dassie urine	-	-
Dioscorea mundii	Hottentotsbrood	tubers	geophyte
Eriocephalus africanus v paniculatus	Wild Rosemary	leaves	shrub
Eriocephalus africanus	Wild rosemary	leaves	shrub
Geranium incanum	-	leaves	herb
Glottiphyllum regium	tongue-leaved mesemb	leaves	succulent
Helichrysum cymosum	Straw flower	leaves	herb
Helichrysum petiolare	Everlasting	leaves	herb
Hippia frutescens	-	Leaves	herb
Hypoxis hemerocallidea	African potato	root	geophyte
Leonotis leonurus	Wild dagga	leaves	shrub
Muraltia spinosa	Tortoiseberry	Leaves	shrub
Peucedanum galbanum	Blister bush	Leaves	shrub
Cliffortia odorata	Wildewingerd	leaves	shrub
Salvia africana-lutea	Beach salvia	leaves	shrub
Salvia africana-caerulea	Blue sage, African sage,	leaves	shrub
Sutherlandia frutescens	Cancer bush,	leaves	shrub
Zehneria Scabra	-	tubers	climber
Ornithogalum longibracteatum	Pregnant Onion	bulbs	geophyte
Curtisia dentata	Assegai	bark	tree
Ilex mitis	Cape holly	bark	tree
Ocotea bullata	Stinkwood	bark	tree
Rapanea melanophloeos	Cape Beech	bark	tree
Pterocelastrus tricuspidatus	Cherrywood	bark	tree
*Rhus chirindensis**	Red currant	bark	tree

Table 2.2 Southern Capes' mostly used medicinal plants in order of frequency

Frequency	**Xhosa name**	**Scientific name**	**Common name**	**National status**	**Parts used**
16	Umaphipha	*Rapanea melanophloeos*	Cape Beech	Declining	bark, leaves
13	Umkhwenkwe	*Pittosporum viridiflorum*	Cheesewood	Least Concern	bark
9	Mlahleni	*Curtisia dentata*	Assegaai	Near Threatened	Bark
9	Mnukani	*Ocotea bullata*	Stinkwood	Endangered	bark
9	UMdlavuza	*Afzelia quanzensis*	Mahogany bean	Least Concern	bark, root
5	Mmemezi	*Cassipourea flananganii*	Cape onion wood	Endangered	-
4	Roselina	*Cinnononum camphora*	Camphor tree	not evaluated	bark
4	Uchithibhunga	*Rhoicissus digitata*	Baboon grape	Least Concern	bulb, root
4	Umthathi	*Ptaeroxylon obliquum*	Sneeze wood	Least Concern	bark, root
3	Umnquma	*Olea europea subsp.africana*	Wild olive	Least Concern	leaves, root
3	Klein swart storom	*Thesium hystrix*	Klein swart storm	Least Concern	root
3	Intelezi	*Portulacaria afra*	Pork bush, Elephants food	Least Concern	leaves, root
3	Ilabatheka	*Hypoxis colchicifolia*	African potato	Least Concern	bulb root
3	Umnonono	*Strychnos henningsii*	Red bitter berry	Least Concern	bark, root
3	Ingwavuma	*Elaeodendron transvaalense*	Bushveld saffron	Near Threatened	
3	Intololwane	*Elephantorrhiza evoluta*	Elephants root, Elands bean		aerial parts and bulb
2	Inongwe	*Hypoxis zeyheri*	Broad leaved hypoxis	Least Concern	bulb, root
2	Umlungumabele	*Zanthoxylum capense*	Small knob wood	Least Concern	bark
2	Mvuthuza	*Knowltonia vesicatoria,*	Blister leaf	Least Concern	leaves, root
2	Isiphephetho	*Siphonochilus aethiopicus*	Wild ginger	Critically endangered	bark, root
2	Isidiyadiya	*Bersama lucens*	Glossy white ash	Least Concern	root, stem
2	Umwelela	*Tulbaghia alliacea*	Wild garlic	Least Concern	bulbs, leaves, root
2	Ubushwa	*Arctotoides arctoides*	Botterbom	Least Concern	-
2	Uphuncuka bemphethe	*Talinum caffrum*	Porcupine root, Flame flower	Least Concern	-
2	Umvunguta	*Kigelia africana*	Sausage tree	Least Concern	roots and leaves
2	Velabahleke	*Cyrtanthes brevifloris*	Yellow fire lily	Least Concern	bark, root

Table 2.3 Reasons for increases in medicinal plant usage

Proportions	Rationale for past and future increase
64.7%	Increase in number of sick people
23.5%	Recognition of traditional medicine
11.7%	Increase in diseases

Table 2.4 Reasons for depletion of some medicinal plant species

Proportions	Rationale for depletion
23.5%	Not certain
23.5%	Increase in traditional healers and increase in sick people
23.5%	Unsustainable harvesting by irresponsibly collectors
29.5 %	Lack of law enforcement

2.4.7 Discussion

2.4.7.1 Medicinal plant needs

The threat posed by illegal resource use in relation to faunal and flora species on biodiversity, particularly within protected areas, is well acknowledged in literature (Bleher et al. 2006; Hilborn et al. 2006; Yonariza & Webb 2007). However, due to the shortcoming linked to sampling methods especially for terrestrial species, limited research has been done that quantifies the extent of illegal harvesting of plant species within protected areas. In the southern Cape, 33 medicinal species have been reported as being illegally harvested (harvested within the boundaries of the Garden Route National Park without authorization from park management) and further information is required on the quantities harvested in order to improve conservation interventions.

The respondents (traditional healers) reported 69 plant species to be used for medicinal purposes, which comprise different life-forms such as geophytes, herbs and trees that are used to treat a variety of ailments. Minsta Mi Nzue (2009) reported 112 medicinal plants to be traded in Cape Town and surrounding areas, while 61 were reported in Limpopo (Mathibela, 2013). The slightly lower number of reported species on this study compared to the Cape Town study may be partly explained by lack of representation in the list of respondents and smaller sample size. Mathibela (2013) conducted the study in rather a small geographic area, which might explain a relatively smaller number of recorded species. In Kwazulu-Natal, over 400 plant species were reportedly traded in large quantities (Mander, 1998).

A total of 26 plant species were cited more than once during the study, with *R. melanophloeos*, *P. viridiflorum*, *A. quanzensis*, *O. bullata* and *C. dentata* having the highest frequency of citation. Similar patterns were obtained for three species in vegetation surveys conducted in Kwazulu-Natal, *O. bullata*, *C. dentata* and R. *melanophloeos* were reportedly exploited for their bark (Geldenhuys, 2002). Similar to this study, the studies conducted in the Cape Peninsula and surrounding areas recorded *R. melanophloeos, P. viridiflorum*, *Hypoxis colchicifolia, C. dentata, Olea europea* subsp. *africana, Zanthoxylum capense, O. bullata* and *Bersama lucens* as some of the most frequently cited by respondents (Mintsa Mi Nzue, 2009). These findings suggest that the demand for certain species is similar across regions. Furthermore, of the 26 species mentioned more than once in this study, several species contain a conservation status, with *R. melanophloeos* listed as "declining", one species, *S. aethiopicus* "critically endangered", *C. dentata* and *E. transvaalense* "near threatened" and *O. bullata and C. flananganii* "endangered". These are important findings as they indicate the list of species that needs prioritization when developing conservation strategies.

2.4.7.2 Awareness of demand increase for medicinal plants

The trend of increasing demand for medicinal plants has been reported both in South Africa and internationally. Several studies have highlighted the increasing demand for medicinal plants locally, which were mainly linked to a growing shortage of supply of widely used medicinal plants (Wiersum et al., 2006; van Wyk, 2008). Several plant species have been exploited to such an extent that they are rarely found outside protected areas (Cunningham, 1991a, 1991b; Williams, 2004). Resource depletion does not only pose a threat to biodiversity but it further has a devastating effect on people that depend on plants from natural systems for primary health care and income generation. It may further have serious effects on future cure of new diseases. The majority of respondents in this study (94.1 %) reported an increase in demand for medicinal plants in the recent past, and predicted similar patterns for the future. The respondents' reasons for an increase in demand included an increase in number of sick people, increasing recognition for traditional medicine, and an increase in prevalence of diseases. Mander (1998) suggested the post-apartheid policies and recent legal recognition of traditional healing system to be one contributing factor to an increase in demand for traditional medicines. In the Cape Peninsula, recognition of traditional medicine, failure of western medicines to cure certain diseases and increasing number of traditional healers and poverty were provided as reasons of increase in demand (Loundou, 2008). The other factors included rapid population growth, and perceptions that certain diseases are culturally related, poor services in public facilities, especially in rural areas (Mander, 1998) and increasing urbanization and the high level of commercialization based on unsustainable harvest levels (Vermeulen, 2009)

2.4.7.3 Perceptions on the depletion of medicinal plants

By virtue of rural resource users typically living in proximity to the resource and having historical relationship with their land, most resource users are aware of the status of natural resources (Cunningham, 2001; Shukla and Gardner, 2006). This is consistent with the findings in the southern Cape where all respondents have observed the decline in popular medicinal plants species, attributing this to an increase in traditional healers and sick people, unsustainable harvesting of target species by commercial collectors and lack of law enforcement. Similar to the study in Cape Peninsula, 83% of the respondents acknowledged the decline in certain medicinal species attributing this to overharvesting and poor harvesting methods (Loundou, 2008). In another study done in the Cape Peninsula (Mintsa Mi Nzue, 2009), 86% of the participants were aware of the decline in medicinal species attributing this to illegal harvesting, veld fires, housing developments, increasing number of traditional healers and lack of control mechanisms. One third of the respondents in a Johannesburg medicinal plant market also attributed the decline to over-harvesting and unsustainable harvesting methods (Williams, 2004).

There are several ecological studies that have suggested that certain harvesting intensities and methods impact on survival, reproduction of target species. For example, inappropriate bark harvesting methods such as ring barking of trees resulted in mortality of all trees of *Khaya senegalensis* (Gaoue and Tickin, 2007), *Garcinia lucida* in Cameroon (Guedje et al., 2007), and *Lannea kerstingii*, *Maranthes polyandra*, *Parkia biglobosa*, *Pseudocedrela kotschyi* in Benin (Delvaux, 2009). In the Eastern Cape (Wiersum et al., 2006), 80% of the respondents cited overharvesting to be the main reason for the decline. It is encouraging that in this study and previous studies conducted in the Eastern Cape and Western Cape, respondents indicated diverse awareness of medicinal species depletion and the possible causes of the decline. Awareness of the decline may encourage resource users to collaborate with conservation agencies to protect locally widely used medicinal plants. Wells (2003) suggested that community participation offers more effective prospects of achieving effective biodiversity conservation and increase local community participation in conservation and economic development for the poor.

2.4.7.4 Cultivation of medicinal plants

It is widely accepted that the current trends in medicinal plant use of popular taxa will not be sustainable in a long term. Therefore different conservation approaches have recently been explored in the literature in an attempt to curb further over-exploitation of medicinal plants from natural systems. Among those approaches is to develop improved forms of controlled use of naturally growing plants, as well as developing cultivation practices for widely exploited medicinal plant species. The need to cultivate popular indigenous plants biodiversity conservation strategy was identified over 60 years ago (Mander et al., 1996). Mander (1998) argued that the cultivation of medicinal plant species is essential in order to alleviate harvesting pressure from the wild and to sustain biodiversity in the remaining forest systems of South Africa. Wiersum (2006) viewed cultivation as a not only a tool to conserve natural medicinal plants but also as a means of poverty alleviation through increased income, social capital and human dignity.

In South Africa however, there is a cultural belief that cultivated plants are qualitatively inferior compared to plants collected from the wild. Similar concerns with cultivated plants were raised in Botswana where traditional medicinal practitioners indicated that cultivated plants are unacceptable as the healing power had been compromised (Cunningham, 1994). This cultural belief has had repercussions in regard to the acceptability of cultivated plants by traditional medicine practitioners. In this study however, all respondents indicated an interest in use of cultivated medicinal plants by either growing their own plants or buying cultivated plants. In a similar study in the Eastern Cape, 89% of the respondents indicated that they would use cultivated plants for healing and protection purposes (Wiersum, 2006). Studies in the Western

Cape have found similar results to the southern Cape study with 78% of respondents willing to buy and use cultivated plants (Loundou, 2008)

The concerns with the use of cultivated plants is partly supported by scientific studies that have indicated that the medicinal properties may differ between plants that grow in their natural environment and those grown in monoculture conditions (Schippmann, 2006). Some active medicinal ingredients may be lower in fast growing cultivated plants, while slow growing wild plants may have higher levels of active ingredients. However, this can be deliberately enhanced under controlled conditions of cultivation (Uniyal et al., 1991) with cultivation trials having shown great potential for meeting consumer demands (Mander et al., 1996). Though in the various previous studies respondents have indicated willingness to use cultivated plants, they highlighted that those plants that are collected for ritual practice and those indicated by the ancestors in dreams could only be collected from the wild. This suggests that, cultivation should ideally be practiced alongside controlled use of wild plants to address the challenge of over-exploitation of widely medicinal plants.

2.4.7.5 Controlled use of natural resources

Sustainability is of overriding importance in natural resource use, especially within conservation areas. Cunningham (2001) emphasized that use should be socially, economically, and ecologically sustainable. A need for sustainable bark harvest systems for the Southern Cape was identified by Lübbe et al. (1991). Vermeulen (2009) highlighted that there is great potential for bark harvesting in the Southern Cape and Tsitsikamma forests, if done sustainably. A systematic process of yield determination and development of harvest systems has been well documented in literature (Van Daalen 1988; Peters 1996; Cunningham 2001). The first steps in the process of developing resource harvest prescriptions and successful implementation of harvest systems is the identification of stakeholders and resource needs and defining the product (Fig 2.2), which is covered in this chapter. The process also entails delineating potential resource use areas and evaluating population dynamics, demography and reproductive phenology.

O. bullata, and *C. dentata* with a conservation status of “nearly threatened” and “endangered” respectively, were mentioned as important bark tree species in the southern Cape and elsewhere in South Africa. Therefore there is a need to develop harvest prescriptions for these species. Harvesting of bark from standing trees has been found to have devastating effects on the survival of trees depending on the method used and species (Vermeulen, 2009; Vermeulen et al., 2012; Delvaux 2009). This highlights the importance of gaining an understanding of species response to bark stripping in order to implement appropriate resource harvesting systems. Studies have been conducted to assess the impact of bark harvesting on these species, with results after three years indicating that stripping bark from the stems of *C. dentata* and *R. melanophloeos* resulted in poor bark regrowth, high susceptibility to insect attach which might have an impact on the survival of bark harvested trees (Vermeulen et al.,, 2012). The bark harvesting on the *O. bullata* was found to be less damaging, with good bark regrowth which indicates a potential for bark harvesting on this species (Vermeulen, 2009, Vermeulen et al., 2012). The following chapters will focus on the 5th step of schematic diagram (Fig. 2.2) of generic processes for the development of harvest systems and management prescriptions for sustainable resource use. Data for a ten-year period will be used to gain understanding on long term response in terms of bark regrowth and survival, as opposed to the shorter term data analyzed by Vermeulen et al. (2012) (Chapter 3) and pathological consequences of bark stripping (Chapter 4), which falls under harvest response in Fig 2.2 . The user needs survey and ten year experimental data generated will provide useful information towards developing sustainable harvesting systems for *O. bullata* and *C. dentata*.

2.4.8 Conclusion

Undoubtedly medicinal plants play an important role in the healthcare of South African people. Popular tree species, including *O. bullata* and *C. dentata* were identified as important and highly sought out for their bark medicinal properties. The findings from this study suggest that local resource users are aware of the increase in demand for medicinal plants in general, attributing this to increasing recognition of traditional medicines and increasing prevalence of diseases. The respondents further indicated that they are aware of the decline in popular medicinal plant species in the wild, suggesting unsustainable harvesting methods to be one of the reasons for decline. This is an important finding, as resource users may be more inclined to work with conservation agencies to protect popular medicinal plants. It is also interesting that resource users indicated an interest in use of cultivated plants. Cultivation and control of use of plants from natural can both be employed to prevent over-exploitation of widely used medicinal plants

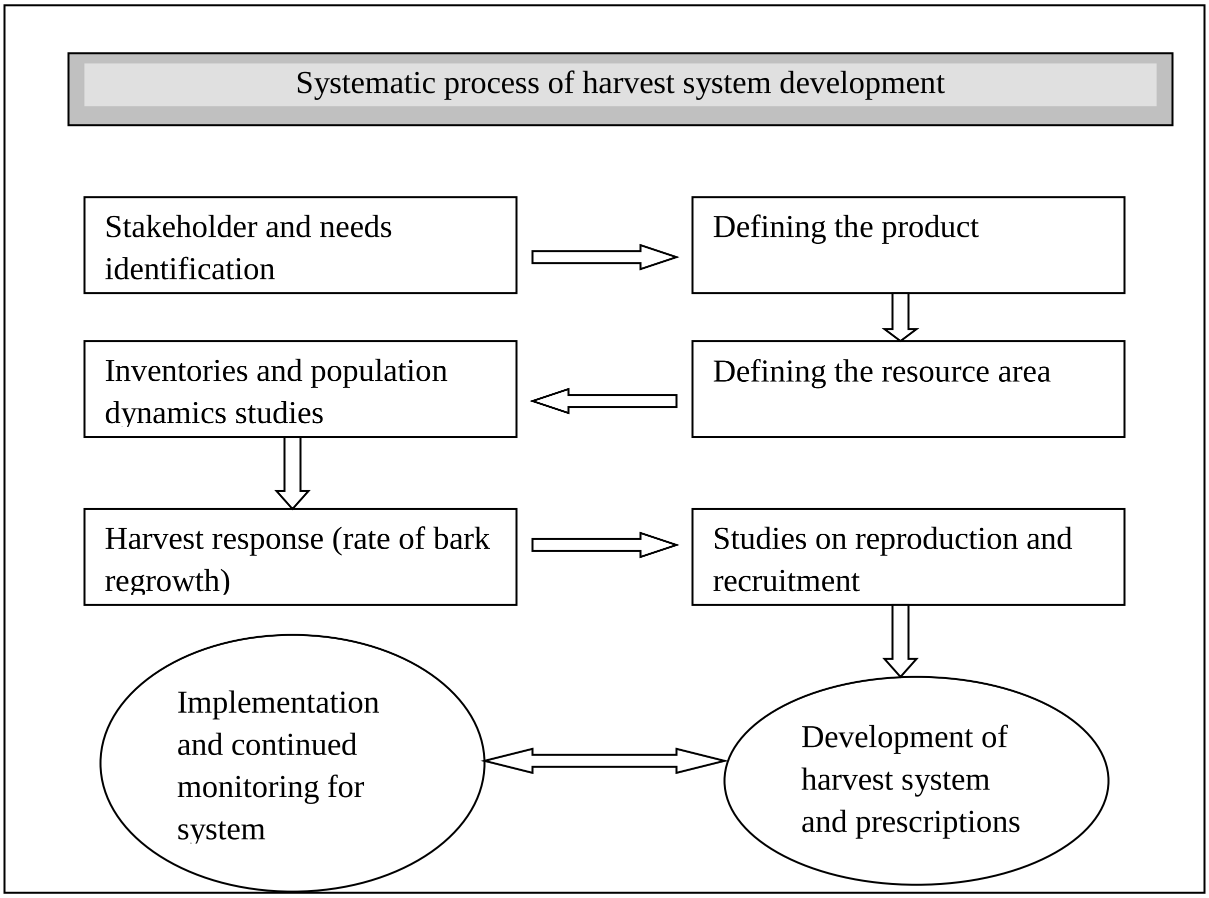

Figure 2.2 Flow diagram indicating the generic process for the development of harvest systems and management prescriptions for sustainable resource use (adapted from Peters, 1996).

2.5 **Acknowledgements**

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3 Chapter 3: Responses of *Ocotea bullata* and *Curtisia dentata* to strip harvesting of bark for medicinal purposes

3.1 Abstract

Bark products form important plant materials used in traditional medicine, both in South Africa and worldwide. However, harvesting of bark from living trees has been reported to impact on tree survival. To minimize the threats posed by uncontrolled bark harvesting, forest managers need to gain better understanding of the responses of different species to bark harvesting in order to develop sustainable bark harvesting guidelines. The aim of the study was to investigate the response of *Ocotea bullata* and *Curtisia dentata*, two frequently bark harvested tree species in South Africa. The study involved the experimental removal of 1 m long strips of bark along the stems of 179 trees. The study was conducted in Afrotemperate forests of the Southern Cape in South Africa. Different factors that may influence the rate of bark regrowth such as tree diameter growth, wound size and season of harvest that may influence the rate of bark regrowth were investigated. The results indicate that bark harvesting negatively influenced the survival of *C. dentata* but not that of *O. bullata*. Significantly better bark regrowth was recorded for *O. bullata* in comparison with *C. dentata*. Higher tree growth rates supported higher bark regrowth rates in both species. For neither of the species strip width and season did not significantly influence rates of bark regrowth. The results indicate that a sustainable harvesting of bark for *C. dentata* through bark stripping is not possible, while a certain potential was found for *O. bullata* where well growing trees that were able to close the wound within reasonable time.

Keywords: Bark harvesting cycle, Diameter increment, Medicinal use, Sustainable utilization, Wound occlusion

3.2 Introduction

Traditional medicine plays an important role alongside Western medicine in the healthcare of South Africa and Africa at large. In Africa, 70 - 80% of the population uses medicinal plants for primary healthcare (Cunningham, 1993). The different plant parts used for medicinal purposes include roots, bark, leaves, fruits and seeds. Besides being a highly valued furniture timber species, the bark of Stinkwood *(Ocotea bullata)* is used medicinally to remedy headache, urinary diseases, as emetic for emotional and nervous disorders and for treating diarrhea (Grace et al., 2003). The bark of Assegai *(Curtisia dentata)* has been reported to be traditionally used for stomach ailments, against diarrhea, as a blood strengthener and aphrodisiac (Hutchings et al., 1996) and against pimples (Grierson and Afolayan, 1999). In cattle it is traditionally used for the treatment of heartwater (Dold and Cocks, 2001).

Several studies have provided evidence of the ecological consequences of harvesting of plants or plant parts, which broadly involves the effects on survival, reproduction and growth of individuals (Ticktin, 2004; Gaoue and Ticktin, 2007), which in turn may alter genetic and demographic patterns (Gaoue and Ticktin, 2007), community structure and ecosystem processes (Ticktin, 2004). Harvesting of bark and roots has been found to be damaging in terms of tree survival (Cunningham, 1991; Peters, 1994; Witkowski et al., 1994; Davenport and Ndangalasi 2002; Geldenhuys, 2004; Vermeulen, 2006; Geldenhuys et al., 2007; Vermeulen, 2009; Vermeulen et al., 2012).

Bark accounts for one third of plant products harvested in South Africa (Cunningham, 1993; Grace et al., 2002) and there is thus a need for studies to generate quantitative data and explanatory knowledge on harvested species from indigenous vegetation in order to develop sustainable management strategies and ensure sustainable bark utilization. Sustainable management of medicinal bark requires knowledge of how individual trees belonging to different species will respond to different harvesting techniques (Geldenhuys, 2004).

Bark in this context is defined as all the tissues outside the vascular cambium (Srivastava, 1964; Esau, 1965). If stripped, wounds are formed, which expose the inner tissues to fungi and bacteria that may cause decay of the wood. The damage in phloem and xylem conducting tissues furthermore interrupts the transportation of water and nutrients. When the wood is exposed, wound closure is initiated either from wound margins (edge growth) and/or from the exposed surface of the xylem (Delvaux, 2009; Vermeulen, 2009).The process of wound closure is a key defense mechanism against bacterial and fungal infection to prevent stem decay (Shigo, 1986).

A few studies have been done that focus on wound closure reaction of medicinal plants and from these it appears that amount and rate of wound occlusion following wounding was found to be species-specific (Vermeulen, 2006; Geldenhuys et al., 2007; Guedje et al., 2007; Delvaux, 2009). The challenge with most tree species, that are bark harvested, seems to be their slow rate or the absence of wound closure. In recent studies done is South Africa and Benin, *Prunus africana*, *O. bullata* (Vermeulen, 2009), *Khaya senegalensis*, *Lannea kerstingii*, *Mangifera indica*, *Parkia biglobosa* and *Pseudocedrela kotschyi* (Delvaux, 2009) showed good wound occlusion and could be considered for harvesting of bark. In contract, *C. dentata*, *Rapanea melanophloeos* (Vermeulen, 2009), *Burkea africana, Detarium microcarpum, Lophira lanceolata, Maranthes polyandra, Pterocarpus ericanaceus* and *Uapaca togoensis* (Delvaux, 2009) showed poor or no bark regrowth and should not be considered for sustainable harvesting through bark stripping. The difference between the two groups may be due to differences in anatomical composition and tissue structure of wood and bark. Responses to tree damage depend on the tissues affected and the intensity of the damage (Guariguata and Gilbert, 1996; Pinard and Huffman, 1997). Neely (1988) reported the rate of wound occlusion to be influenced by season, species, and tree growth rate and wound size. Seifert et al. (2010) reported also a clear influence of site quality and tree diameter growth on wound occlusion rates.

There have been several studies to determine the limits of bark harvesting (harvest intensity) on species that survived ring barking such as *P. africana* (Cunningham and Mbenkum, 1993) and *M. indica* (Delvaux, 2009). The survival of ring-barked trees has been linked to their ability to recover bark easily thereby creating new transport structures for movement of water and nutrients between leaves and roots. In other species, such as *L. kerstingii*, *M. polyandra*, *P. biglobosa* & *P. kotschyi*, ring-barking resulted in the death of all ring-barked trees (Delvaux, 2009). This indicates the importance of determining harvest limits for individual species. *Quercus suber (Cork oak)* is one of the few species that has been bark harvested commercially for a long time and a scientific base for good practice and also legislative regulation of bark harvesting were established (Moreira et al., 2009). However, this is an exception, other species are not that well researched.

The information on the time needed to complete recovery is lacking for most other species; hindering effective management of bark harvesting. This study seeks to investigate the factors that influence bark recovery of *O.bullata* and *C. dentata* and possibly use these factors to predict the amount of time needed to complete bark recovery as a basis for providing recommendations for sustainable management of medicinal bark harvesting of *O. bullata* and *C. dentata*. The following research questions were addressed:

1. Do season, removed bark strip width, tree size and tree growth rate influence the rate of wound occlusion?
2. How does debarking affect the survival of the species?
3. What time spans are needed for complete wound closure after bark harvesting?

3.3 Study area

The study was conducted in the southern Cape natural forests, South Africa (Fig. 3.1). The closed-canopy natural forests of the Southern Cape have been classified by Mucina and Rutherford (2006) as Southern Afrotemperate forests. The Southern Cape forests are the largest forest complex of that type in southern Africa, covering a total area of 60 500 ha. They consist of mountain, coastal plateau and scarp forests, characterized by canopy tree species such as *Podocarpus falcatus*, *Podocarpus latifolius*, *C. dentata*, *Olea capensis* sub-species *macrocarpa*, *O. bullata*, and *Pterocelastrus tricuspidatus* in variable proportions depending on the forest type. The forests are managed for multi-use with the primary goal of conservation. The mean annual rainfall ranges from 550 to 1200 mm, with rain occurring throughout the year; with peaks in autumn and early summer.

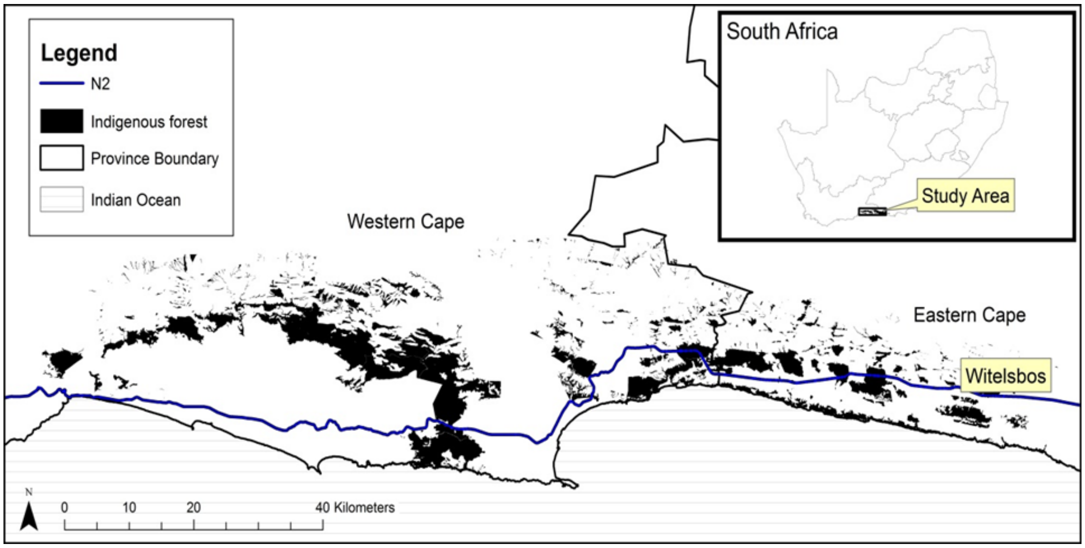

Figure 3.1. Map of southern Cape natural forests; indicating the location of the study site (Witelbos).

The bark stripping experiment on *O. bullata* and *C. dentata* was conducted in moist high forests at Witelsbos (33°59.5′ S, 24°06.0′ E) and control trees were situated to the west of Witelsbos, in Lottering (33^{0}94.7’S, 23^{0}69.5’E) and Storms River (33^{0}96.4’ S, 23^{0}89.5’E), respectively.

3.4 **Materials and methods**

The study is based on the Commercial Products from the Wild (CP Wild) experimental bark stripping project established in 2001 in the Southern Cape natural forests. The project layout has been described in Geldenhuys and Rau (2001), Geldenhuys et al. (2002), Vermeulen and Geldenhuys (2005) and Vermeulen (2009). The experiment involved 89 trees of *O. bullata* and 90 trees of *C. dentata* (Table 1) and measurements were done over a ten year period (2001-2012). Healthy trees were selected for the experiment and marked with numbers. Bark was harvested experimentally from approximately 50 cm above ground level in a vertical strip of 1 m. The bark was removed from each tree in two strips, on opposite sides of each stem; the one strip involving a partial removal and the other strip a total removal of the bark. For total bark removal an axe was used to cut two vertical lines through the bark onto the wood and then the bark was separated from the wood. For partial bark removal the bark was peeled from the stem with a sharp axe leaving a thin layer of inner bark (Vermeulen, 2012). Bark was harvested in summer (wet season) and winter seasons (dry season). Strip width wounds of 5, 10, 15 and 20 cm were applied (Table 1). A fungitoxic sealer was used on the lower half of the wound to assess if the sealer influences the rate of wound occlusion. In order to assess whether bark stripping affects the survival of the two species, a long-term comparable data in respect to forest type was used as a control (*O. bullata*: n= 192 and *C. dentata*: n= 267). The rate of wound closure through edge growth was done by recording wound width annually. Sheet growth was recorded as a percentage cover of sheet on the wound surface. Classes used to define sheet growth response to bark stripping were as follows: 0 = no sheet growth; 1 = 1–60%; 2 = >60 sheet growth. For the current study, analysis of data was restricted to the total bark removal treatment; the partial bark removal was not considered. For the purpose of determining tree growth rates, the diameter measurements were done above diameter at breast height (DBH), at approximately 1.7 m, to avoid unreliable measurements at the wound level.

Table 3.1 Number of trees per species, tree size class and wound strip width and season of wounding (adapted from Vermeulen, 2009).

		Strip width (cm)							
		Dry Season				Wet Season			
Species	Tree size	5	10	15/20	Total	5	10	15/20	Total
Curtisia dentata	Small[1]	6	6	5	**17**	5	4	5	**14**
	Medium[2]	6	3	5	**14**	5	6	5	**16**
	Large[4]	4	6	4	**14**	5	5	5	**15**
	Totals				**45**				**45**
Ocotea bullata	Small[1]	4	4	5	**13**	5	5	4	**14**
	Medium[3]	6	6	5	**17**	4	5	5	**14**
	Large[5]	4	5	5	**14**	6	5	5	**16**
	Totals				**44**				**44**

[1] 10–19 cm DBH; [2] 20–29 cm DBH; [3] 20–39 cm DBH; [4] ≥30 cm DBH; [5] ≥40 cm DBH

3.5 **Statistical analysis**

A Chi-square analysis was conducted using R (R Development Core Team 2005) to test if species (*O. bullata* and *C. dentata*), season (winter and summer) of bark harvesting, tree diameter class (small, medium and large) and strip width class (5mm, 10mm, 15/20mm) influenced tree survival after bark harvesting. We calculated the mean rate of bark recovery through edge growth by fitting a linear regression on the change of wound size over time (as reflected in wound width), and the slope was defined as the rate of wound occlusion. Since wound size became smaller with time, values of the rate of recovery were negative. Rates of recovery were therefore multiplied by minus one to transform them into positive values.

According to the Kolmogorov-Smirnov test the dependent variable (rate of wound occlusion) were not normally distributed when the two species were pooled. A square root transformation was applied in order to conform to achieve normal distribution. When individual species were tested separately, both showed normal distributions, so the untransformed datasets were used. A regression based on a General Linear Model was used to test if tree growth rate and other listed variables influenced the rate of wound occlusion in order to account for autocorrelation between consecutive measurements on the same tree. Statistical testing and modeling were performed in Stat Graphics Centurion XV version 15.2.14 (Stats point Inc. 2007).

For *O. bullata*, a linear regression model was used to quantify the relationship between the rate of annual wound occlusion (mm/year) and annual stem increment (as an independent variable). The model and parameters were used to check for significance and distribution of residuals: Annual wound occlusion= a + b (stem diameter increment). The model was used to simulate the time needed to completely close the bark stripping wound of known size. A simple linear regression model was established to support the estimation of wound closure depending on time in years (Equation 1)

$$WS = a + b \cdot t \qquad (1)$$

Where *WS* is the wound size in diameter (mm), *t* is the time after wounding in years and b is regression coefficients.

The intercept can be interpreted as the initial wound size while the slope parameter b multiplied with -1 represents the annual wound closing rate. The latter was estimated for each tree and used as the dependent variable in a regression model that was making use of the pooled data over all trees. Wound closure rate was estimated based on a set of independent variables such as strip width, season, and stem diameter class (measured at 1.3m), stem diameter growth rate and species in this modeling second step. The model for rate of closure, both species combined, with all variables included (strip width, season, DBH class, species and growth rate) was found to be significant ($F_{7,126}$= 37.30, $p< 0.001$, R-squared adj= 72.78%); with species and growth rate being highly significant variables. Regression modeling was performed with R (R Development Core Team 2013).

3.6 **Results**

3.6.1 Effects on survival

At the start of the research, a total of 178 trees were bark stripped. Over the ten-year study period, 24 trees (13.5%) had died. There was no significant difference in mortality of treated and control trees of *O. bullata* ($p= 0.893$)**.** In contrast, *C. dentata* showed significantly higher mortality of the treated trees compared with control trees ($p= 0.025$); as shown in Fig.3.2.

C. dentata had a significantly higher mortality when debarking had occurred in summer than in winter (p= 0.048). For *O. bullata* there was no significant difference in mortality between the seasons (p= 0.671). For *C. dentata* the harvest intensity (strip width as a total area of circumference harvested) was found to significantly affect survival (p= 0.0472); with the highest mortality in trees with high harvest intensity. Harvest intensity did not affect survival in *O. bullata* (p= 0.338). Mortality of debarked trees of *O. bullata* and *C. dentata* was significantly higher (p< 0.002) for smaller trees (62.5% of dead trees) than in medium (25.0%) and bigger trees (12.5%). This seems to be a result of the higher damage per stem circumference, which indeed showed a significant effect on the mortality rate (p< 0.002). At a species level, mortality of bark stripped trees was influenced by tree diameter class (Fig. 3.3), with the smallest trees having the highest mortality in both species *O. bullata* (p= 0.004) and *C. dentata* (p= 0.042).

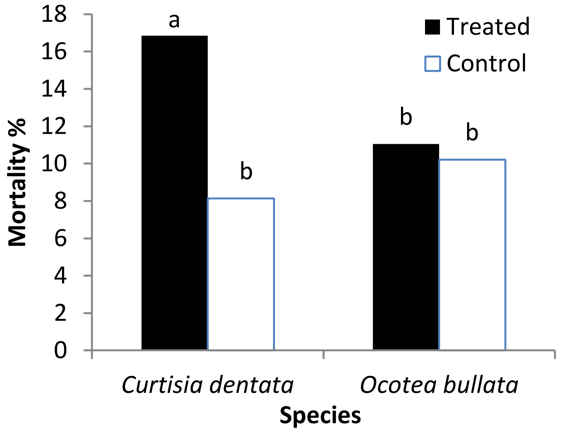

Figure 3.2 Mortality percentages of debarked trees and non-debarked trees of *Curtisia dentata* and *Ocotea bullata.* Identical small letters indicate non-significance in respect of sheet growth at 0 ≤ 0.05 confidence levels.

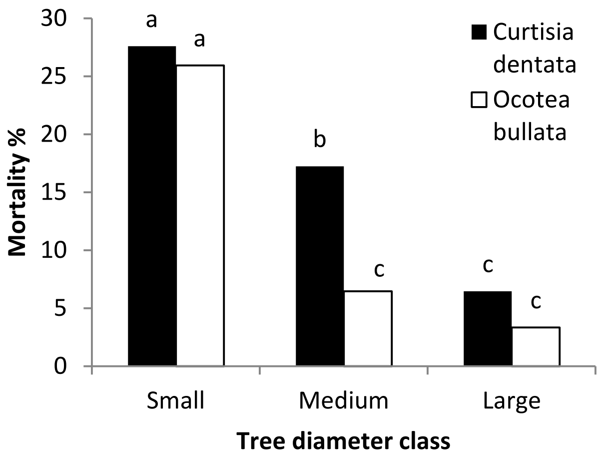

Figure 3.3 Mortality percentages of *Curtisia dentata* and *Ocotea bullata* per tree diameter class. Identical small letters indicate no significant difference at the $P \leq 0.005$ confidence levels.

3.6.2 Wound occlusion after bark stripping

There was a significant difference between the two species in terms of annual rate of occlusion for both cambial growth from the edge and cambium sheet growth. *O. bullata* had a significantly better bark regrowth compared to *C. dentata,* with mean occlusion rates (edge regrowth) of 8.15 mm and 0.24 mm per annum respectively ($p< 0.001$). For a total of 90 trees of *C. dentata*, 57.30% of trees showed negative bark regrowth (strip width increased). There was no statistical significant difference found between rate of occlusion and stem diameter classes and strip width in *C. dentata,* but a statistical significant difference was found with season (slower rates of occlusion for the summer treatment: $\chi^2 = 10.64$, df = 2, $p = 0.004$; n= 89). Sheet development showed a decline over the ten years, resulting from sheet cover dieback over time (Fig 3.4). *O. bullata* had significantly slower annual wound occlusion rates in smaller diameter class trees (Table 3.2).

The full model with all variables included for *O. bullata* ($F_{6,63}= 27.83$, $p< 0.001$; R-squared adj= 69.99%) and *C. dentata* ($F_{6,56}= 1.94$, $p< 0.10$, R-squared adj = 8.35%), showed that only diameter growth significantly influence the rate of wound occlusion in both *O. bullata* (F= 104.34, df = 1, $p< 0.0001$) and *C. dentata* (F= 4.54, df= 1, $p< 0.05$).

Table 3.2 Influence of season of wounding, tree size class (DBH) and wound strip width on rate of edge growth (Mean ± SE, mm/year) on *Ocotea bullata* during 10 years following experimental bark harvesting.

	Mean	SE
Season		
Summer	7.54^a	±0.947
Winter	9.96^a	±0.952
Tree size class		
Small	4.69^a	±1.208
Medium	11.24^b	±1.132
Large	10.31^b	±1.1475
Strip width		
5mm	10.16^a	±1.178
10mm	6.60^a	±1.148
15/20mm	9.50^a	±1.163

*Identical small letters indicate no significant difference at the $P \leq 0.005$ confidence levels.

Table 3.3 Regression parameters, sample size and adjusted R^2 of the occlusion rate models for *Ocotea bullata*

Species	Parameter 1 (intercept)	Parameter 2 (diameter increment)	n	R^2
O. bullata	2.5857	3.5943	69	0.6868

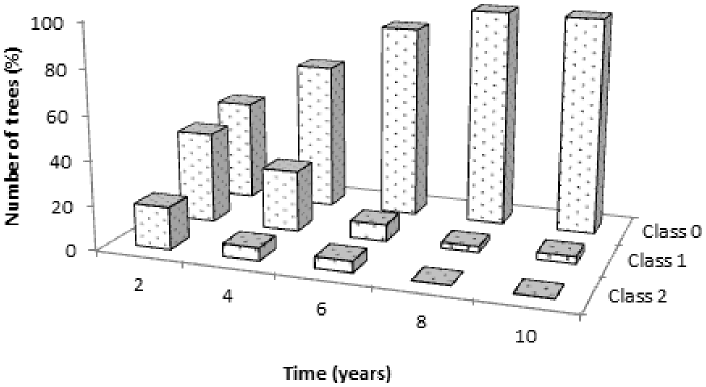

Figure 3.4. Bark recovery patterns through sheet growth for *Curtisia dentata* (class 0= 0% sheet re-growth; 1=1-60% sheet cover and 2= >60% sheet cover)

Fig 3.5a, b shows correlation between the rate of wound closure and tree diameter growth for both species. Associated model parameters for *O. bullata* (Table3.3), allows for the simulation of time needed for wound occlusion for a given initial wound size (Fig.3. 6 a, b).

Poor wound recovery and survival of bark-harvested *C. dentata* was associated with poor diameter growth rates (trees with DBH > 10 cm) of surviving treated (0.93 mm/year; n = 65) and untreated (0.67 mm/year; n = 12) trees in the moist/wet forests in and adjacent to the study area. These growth rates were lower (p = <0.0003) than those of a medium-moist forest nearby (2.73 mm/year; n = 12). At the Groenkop site trees of this species on steeper slopes had faster growth rates (1.49 mm/year > 0.69 mm/year; p = 0.013). These results suggest that *C. dentata* does not thrive on poorly-drained soils, such as would be expected on flat wet forest sites; this partly explains the poor recovery response to bark-stripping of the experimental population at Witelsbos.

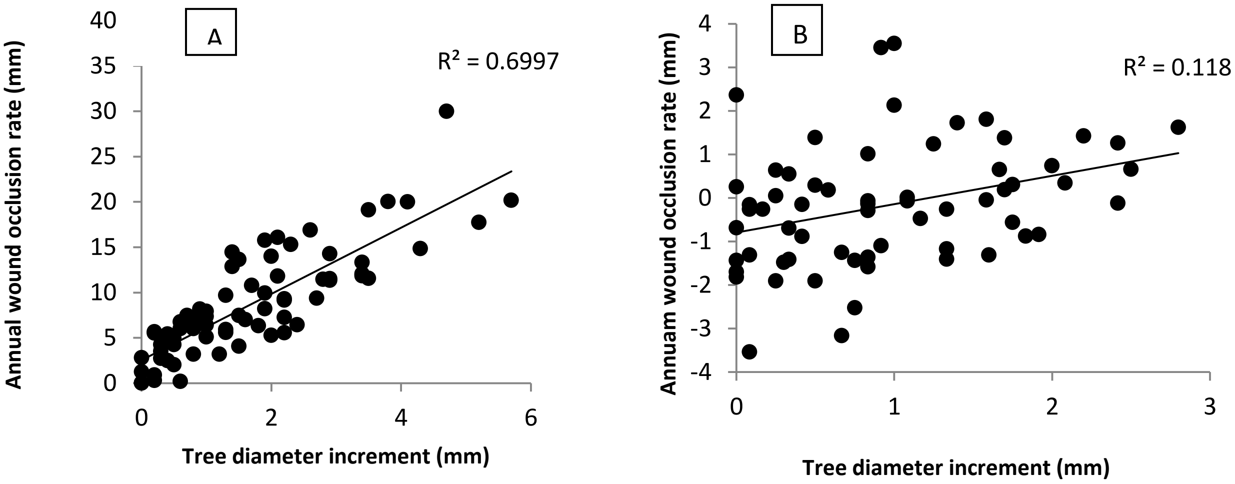

Figure 3.5**.** Annual rate of occlusion as a function of diameter increment of (A) *Ocotea bullata* and (B) *Curtisia dentata*

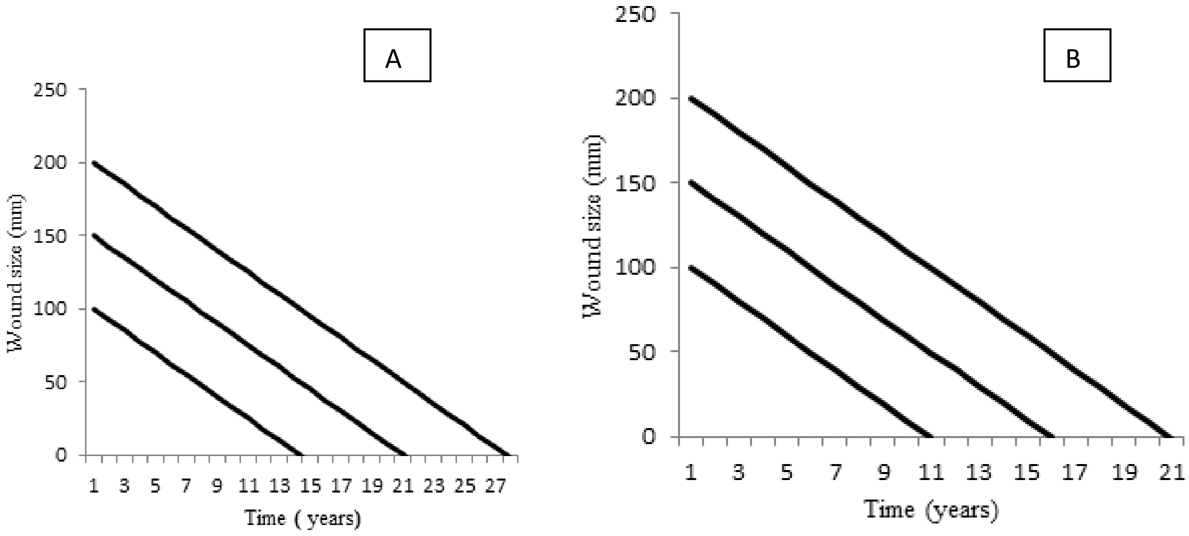

Figure 3.6. Simulation of time needed to complete wound occlusion for *O. bullata* wound width of 100, 150 and 200 mm with a stem diameter growth rates of (A) 1.5 and (B) 2.5 mm/annum.

3.7 **Discussion**

3.7.1 **Effects on survival**

Species-specific results showed debarking to significantly influence the survival of C. *dentata*, with mortality of debarked trees significantly higher than of control trees. The results contradict the findings of Geldenhuys (1982) that indicated *C. dentata* to be surprisingly resilient to ring-barking after a 30 month study. Contradictions in findings may be due to the short-term nature of the results reported by Geldenhuys (1982), while the current study represents long-term effects of damage regarding this species. Poor bark regrowth and high susceptibility to insect attack (Vermeulen et al., 2012) may be some of the contributing factors to high mortality in this species. This highlights a need for long-term studies for understanding the effects of damage to the survival of species. In contrast, *O. bullata* showed no significant differences in survival between non-debarked control and bark-stripped trees.

The season of bark harvesting was found to influence the survival of *C. dentata*. Summer-treated trees suffered significantly higher mortality than those treated in winter and wider strip width had a significant negative effect. The results indicate that harvesting smaller strips in winter might mitigate the impacts of bark stripping on the survival of the species. Strip width and season were not found to affect the survival of *O. bullata*. However, smaller diameter trees of both species showed significantly higher mortality compared with bigger trees (>20 cm). An explanation of this finding might be linked to rather higher percentages of the circumferences being harvested in smaller trees than in bigger trees with the same strip width treatment.

3.7.2 Bark recovery patterns

The results from this study confirmed that tree response to bark harvesting is strongly species-specific. This implies that sustainable harvesting quantities and patterns will differ between species depending on species' ability to effectively close the wound. The results are consistent with the findings reported after 36 months on the same sample trees (Vermeulen et al., 2012) and several other studies done in Africa (du Toit, 2000; Geldenhuys, 2004; Geldenhuys et al., 2007; Delvaux, 2009). *O. bullata* showed a good wound closure response through edge regrowth and lacked sheet growth, which is consistent with the findings by du Toit (2000) and Vermeulen et al. (2012). The smooth bark characteristics of this species could reflect the ability of phellogen to divide anticlinally and periclinally (Shigo, 1993), which is associated with good wound closure. *O. bullata* has been reported to be overexploited in Kwazulu-Natal Midlands (Geldenhuys, 2004; Geldenhuys et al., 2007) and illegal harvesting to be increasing in the Southern Cape forests (Vermeulen et al., 2009). The remarkable ability of *O. bullata* to resprout after fire and cutting (Lübbe and Geldenhuys, 1990) presents further opportunities to mitigate the impact of overharvesting by cutting heavily debarked trees and manage coppice growth as also advocated by Geldenhuys (2004) and Geldenhuys et al. (2007).

In contrast, *C. dentata* responded poorly in both edge and sheet bark regrowth, which is consistent with the results from du Toit (2000) and Vermeulen et al. (2012). The poor bark regrowth of *C. dentata* may be attributed to its susceptibility to insect and fungal attack, erratic bark regrowth and bark lift recorded by Vermeulen et al. (2012). Poor bark regrowth and survival of debarked trees of *C. dentata* leave little scope of sustainable harvesting of this species. The differences in *O. bullata* and *C. dentata* in their ability of wound closure may be attributed to the differences in anatomical and tissue structure (Shigo, 1986).

3.7.3 Influence of season, tree size and strip width on wound recovery

Good edge bark regrowth in *O. bullata* was recorded for trees >20 cm in diameter (Table 3.2). These results are also consistent with the study of Vermeulen et al. (2012) who recorded good bark regrowth in bigger diameter trees on the same trees after 36 months. This is an important finding given that inventories conducted in Kwazulu-Natal (Geldenhuys 2004) and in Cameroon (Guedje et al., 2007) indicated that bark harvesters avoid smaller trees and target bigger trees that have better vitality and good bark recovery, which might consequently mitigate the impact of bark harvesting on the species. However, if the demand for bark of a certain species is very high, as for example in the case of *Prunus africana* in Cameroon, Madagascar and Island of Biko, all sizes were found to be bark-harvested (Cunningham and Mbenkum 1993; Steward, 2003). The poor annual recovery rate in smaller trees of *O. bullata*, higher incidence of tree dieback (Vermeulen et al., 2012) and poor survival found in smaller trees suggests that a minimum tree diameter should be defined in the development of bark harvesting guidelines for this species.

Poor bark regrowth and survival in response to experimental bark harvesting in *C. dentata* suggest that this species is not suitable for bark stripping from living trees. In contradiction to the findings of Vermeulen at al. (2012), season was found not to significantly influence bark regrowth of *O. bullata* after ten years (Table 3.3). In this study poor edge bark regrowth was encountered in *C. dentata* harvested in the summer season. In another study conducted in Benin, *L. kerstingii* and *P. biglobosa* showed significantly better bark recovery in the rainy season, whereas *K. senegalensis*, *M. indica* and *P. kotschyi* were not influenced by bark harvesting season (Delvaux et al., 2010). The humidity of the wound is an important factor that allows the start of the bark recovery process (Neely, 1988; Stobbe et al., 2002). Vascular cambium shows great variation in the period and intensity of activity (Fahn, 1985), which impacts on tree response to damage inflicted on tree bark during different seasons (Kozlowski et al., 1991; Schmitt and Liese 1992; Delvaux et al., 2010). The complexity of the role of season in wound closure processes does most likely not allow for accurate proposals that may contribute in the development of bark harvesting prescriptions based on the current findings.

Regarding both species, strip width had no effect on the rate of bark recovery through edge bark regrowth. These findings are consistent with those of Vermeulen et al. (2012). However, Delvaux et al. (2010) found that strip width (harvest intensity) influenced wound occlusion differently in different species: *Mangifera indica* was found to be the most resilient species, with all trees surviving ring-barking; while all ring-barked individuals of *Lannea kersingii, Maranthes polyandra* and *Parkia biglobosa* died after two years. Gaoue and Ticktin (2007) reported *K. senegalensis* to not survive ring barking at all. The mortality of ring-barked trees might be attributed to the species' inability to rapidly replace the interrupted phloem with transport structures through parenchymatic cells in the wood. In consequence the sugar transport to the roots is interrupted finally resulting in starvation of the trees. Differences in the response of species to strip widths highlights the importance of understanding bark harvesting limits species-specifically.

3.7.4 Tree growth rate and bark recovery

The rate of wound occlusion was found to be positively correlated with radial diameter growth of the tree for both species. This is consistent with the findings of most wound closure literature; wound closure is directly related to tree vigor on Norway spruce (Vasiliauskos and Stenlid, 1998; Vasiliauskas, 1998), in ash and oak (Koslowski et al., 1991), and on oaks, honey locusts and pin oak (Neely, 1970; Neely, 1988). In pruning studies, rate of wound occlusion was also linked to tree vigor for northern red oak (Nicolescu et al., 2013), wild cherry (Seifert et al., 2010) and coastal douglas-fir (Petroncio et al., 1997). These results confirm that tree vigor is of great importance for effective rates of wound occlusion. In this study tree growth analyses revealed that *C. dentata* does not thrive on poorly drained soils, reaching best development in medium-moist rather than wet forests (von Breitenbach, 1965). These site requirements were reflected in poor growth rates of experimental trees and can be considered to partly explain the poor wound recovery performance of this species at Witelsbos.

In the present study, the link of wound occlusion rate to tree vigor allowed for quantification of time needed to complete wound occlusion in *O. bullata* that would allow the sustainable bark harvest cycle to be determined if the correlation of occlusion time and decay in the tree cane be modeled. An example where this connection has been successfully established is the study of Seifert et al. (2010) where they found that the rate of wound occlusion depended on tree vigor, which allowed them to use regression models to predict the number of years to occlusion. Additionally, a relationship between the years to occlusion and the degree of stem decay was established, which facilitated useful recommendations regarding maximum branch diameter for pruning depending on diameter increment, while limiting extent of decay.

This indicates that tree vigor is of great importance in rate of wound occlusion and provides useful understanding that further allows informed management decisions. Even though several studies have been conducted to gain understanding of bark regrowth patterns in medicinal tree species, tree growth data is often not available. However, studies for *Quercus suber* have advanced sufficiently for sustainable harvest cycles to be determined reliably and such are being enforced by Portuguese legislation (Moreira et al., 2009).

3.7.5 Implications for management

Species differences were found in rates of wound occlusion, with *O. bullata* having a good annual rate of wound occlusion while *C. dentata* had a poor rate of closure with over 50% of the sample size showing increased wound sizes over the 10-year study period. The poor bark regrowth and high mortality rates following bark stripping deems this species unsuitable for bark harvesting. The good rate of wound occlusion recorded for *O. bullata* accompanied by strong links between rate of wound occlusion and tree vigor allowed for the formulation of a preliminary model that can assist forest managers to determine bark harvest cycles; thereby contributing towards the formulation of sustainable harvest prescriptions for the species. The results also indicated relatively poor bark regrowth and high mortality in smaller diameter trees, which further suggest that a minimum tree size for bark harvest trees needs to be stipulated. Differences in species responses to bark stripping found in this study highlight that species-specific prescriptions are necessary as different approaches might need to be applied to achieve sustainable bark harvesting.

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4 Chapter 4. Decay in consequence of bark harvesting of *Ocotea bullata* and *Curtisia dentata*

Abstract

Bark stripping for medicinal use is a common cause of damage in popular medicinal tree species in the natural forests of South Africa. *Ocotea bullata* and *Curtisia dentata* has been identified as being in high demand for their bark in the Southern Cape and other parts of South Africa, with a national conservation status of “Endangered” and “Nearly Threatened” respectively. Damage of tree stems promotes development of decay which may affect the long-term survival of damaged trees. In order to investigate the tree’s reaction to damage following bark stripping, five discs per tree on 10 trees per species were collected 10 years after experimental harvesting of bark. The study aimed at revealing intra-specific and inter-specific differences of wound occlusion, defense reactions to bark stripping with the growth of the tree, the compartmentalization and the extent of decay within the tree stem. The results indicated that *C. dentata* had a significantly higher percentage decay (35.1%) of wood compared to 5.1% for *O. bullata*, $p<0.001$, indicating that *O. bullata* was able to efficiently contain decay compared to *C. dentata*. For *O. bullata*, a strong positive correlation was found between the wound occlusion rate and the volume of decayed wood $r^2 =0.81$, indicating that individuals with higher rate of occlusion suffered higher percentage of decay. Furthermore, a positive correlation was also found between rate of wound occlusion and density loss $r^2 =0.72$. For *C. dentata*, no correlation was found between rate of wound occlusion and percentage neither decay nor density loss. With poor bark regrowth, a significantly higher mortality (reported in chapter 3) and a high extent of decay in *C. dentata*, renders the species unsuitable for sustainable bark stripping. On the contrary, *O. bullata* had good bark regrowth (reported in chapter 3) and efficient decay containment providing the basis for sustainable bark harvesting through a bark stripping harvesting method. This study highlights the need to gain an understanding of both the wound occlusion and pathological consequences of bark stripping in order to understand long-term implications of bark stripping on trees, especially for development of sustainable bark harvesting systems.

Key Words: CT scanner, wood decay, bark stripping, wood density; compartmentalization

4.1 Introduction

Trees are exposed to various destructive agents that affect main stems directly, including environmental factors like fires (Odhiambo et al., 2014) and human and animal induced damage such as bark stripping or destruction caused by machines during harvesting activities (Isomäki and Kallio; 1974, Hecht et al., 2014). Harvesting of bark for medicinal purposes is a common disturbance in the natural forests of South Africa. In South Africa it is estimated that as much as 19 500 tonnes of plant material per annum are extracted from indigenous forests and woodlands, with bark from natural trees forming one third of all products harvested (Grace et al., 2003). The high demand for medicinal bark results in relatively high levels of bark stripping damage of popular medicinal tree species that directly impact on individual tree survival.

The persistence of tree individuals in their natural environment depends on their ability to avoid and respond to damage. As a survival mechanism, trees react in two ways to repair damage to stems: a protection reaction (compartmentalization) and a wound occlusion reaction (Delvaux, 2009). Wound occlusion entails production of tissues to close the wound, either through edge or sheet growth.

The protection reaction, initially described as a heartrot concept (Boyce, 1961), is based on the understanding of wood as a dead and non-responsive substance. The concept was later modified to include compartmentalization (Shigo and Shortle, 1969). Shigo and Marx (1977) then proposed a compartmentalization of decay in trees (CODIT concept). The CODIT concept describes how trees form protective boundaries between the wounded and unaffected wood to prevent the spread of pathogens. The mechanical barriers involve vessels plugged by tyloses and other materials, suberization of parenchyma cells, deposits of gums and resins, as well as chemical barriers such as phenolic substances. This increases resistance against inflow of air, desiccation and attack by microorganisms and provides a boundary between affected and unaffected tissues (Schmitt and Liese, 1993).

Wounds may seal but not heal internally (Shigo, 1984), or wounds may never completely close, but they may be enclosed in the compartmentalization process from the inside (Garret and Shigo, 1978). Therefore, by only considering the potential of wounds to close without an understanding of the severity of wood decay of adjoining woody tissues inside the tree, one may misinterpret the long-term implications of stem damage. Several studies have been undertaken to better understand the wound closure process following stem damage in medicinal tree species. The rate of wound closure was found to differ both between species and within tree species (Neely, 1988; Geldenhuys, 2004; Geldenhuys et al., 2007; Guedje et al., 2007; Vermeulen, 2009; Vermeulen et al., 2012). The investigation on the wound closure process in this thesis revealed *that O. bullata* had a significantly better bark regrowth compared to *C. dentata* (Chapter 3), the latter showing erratic bark regrowth, high susceptibility of insect attack ((Vermeulen et al., 2012) and higher mortality of bark-stripped trees (Chapter 3). Tree diameter growth was found to have a significant influence on the occlusion rates in *O. bullata*, while bark harvest season and wound width did not influence bark regrowth of either species (Chapter 3). Though attention has been paid to understanding the wound closure process in the two species following stem damage (Chapter 3), there is still a great need for an in-depth investigation to further explore pathogenic consequences in order to complement available results. The decay of wood within a tree trunk often decreases the dynamic strength of the wood, which may result in tree mortality (Lonsdale, 1999; Beall and Wilcox, 1987). The extent of density loss varies depending on the type of fungi involved and tree species with presence and severity of decay in the stem a major factor which predisposes trees mortality (Vasiliauskas 2001).

Analysis of structural weakness in stem wood caused by decay has been explored in arboriculture literature, including using scientific equipment to quantify decay, such as X-rays (Eslyn, 1959), ultrasonic decay detectors (Miller et al., 1966), and using the Shigometer (Shigo, 1974). Recently X-ray computed tomography (CT) has indicated great potential for detecting decay within both standing trees and felled trees. Seifert et al. (2010) were able to successfully detect and analyze branch size, growth rings and occlusion time and severity as well as extent of decay in *Prunus avium L*. using CT scan technology, thereby highlighting the accuracy and versatility of CT scans in analyzing wood characteristics.

Further studies have been conducted to gain an understanding of biochemical changes in wood structure following stem damage, in the context of the CODIT concept of Shigo (1984). The CODIT concept describes a series of steps that occurs in case of stem damage. Tree damage (e.g. bark stripping) activates repair genes, which manifests in formation of boundaries, reaction zones around the wounded areas that contain the decay and prevents the spread of wood rot fungi to healthy tissues. The reaction zone is described by Shain (1971) as a thin layer of coloured xylem between infected wood and sound sapwood, which serves as a protective barrier against spread of wood decaying fungi. Merela and Oven (undated) investigated the physical properties, elemental composition and physical properties of the reaction zone. The results indicated tylosis in vessels and accumulated coloured deposits in parenchyma cells, fibres and vessels. Furthermore, the reaction zone had a 1.2 times higher density and three times lower radial gas permeability than sound wood. However, for South African species, no quantitative characterization of this defense related changes and the interaction with wood decay has been done to date.

Focusing on the structural changes, the aims of this study was to (1) quantify the volume of decay and density loss in decayed wood in relation to stem diameter growth and wound occlusion rate on experimentally wounded trees, and (2) investigate the density of the reaction zone in relation to decayed wood and sound wood.

Research Questions

1. Is there a density differences between sound wood, decayed wood and reaction zone?
2. What is the extent and degree of decay along the tree trunk following bark stripping?
3. Is there a relationship between rate of wound occlusion and extent and degree of decay?

4.2 **Material and methods**

The study is based on the Commercial Products from the Wild (CP Wild) experimental bark stripping project established in 2001 in the Southern Cape natural forests (details on study area in Chapter 3). The project involved the removal of 1 m vertical/longitudinal strips of bark approximately 50 cm above ground (details in Chapter 3). The detailed project layout is described in Geldenhuys and Rau (2001), Geldenhuys et al. (2002), Vermeulen and Geldenhuys (2005) and Vermeulen (2009). The experiment involved 89 trees of *O. bullata* and 90 trees of *C. dentata*. Ten years after treatment (experimental bark harvesting), ten trees per species were selected randomly and felled using a chainsaw. Five discs of approximately 5 cm thickness were collected at different stem height, one below the wounded area, three at the wound level and one above the wound (Fig. 4.1a). The wood structure of the specimens was analyzed using computer tomography (CT scanning) at CT Scanner Central Analytical Facilities, Stellenbosch University, which allows for the examination of wood and quantification of volume of decay using images. An example of a reconstructed CT-scanned cross-section showing decay and sound wood is shown in Fig. 4.1b. The data from CT scanner was reconstructed and analysed with the imaging software VGStudio Max 2. In each scan, a stack of seven polymer discs of known densities were scanned with each sample disc. To generate a calibration function, the grey values of each polymer disc were plotted against the known actual density of the seven polymer discs and regression fit equation obtained, which is then used to determine the density of each sampled disc (Du Plessis et al., 2013). Image analysis techniques were applied to determine decayed structures with a local thresh-holding algorithm in order to detect decayed areas of lower density and to calculate a volume percent of decay for each individual sample. X-ray extinction, expressed in grey values was calculated for the decayed area in comparison with a healthy area further away from the wound. A line-probe sampling was additionally used to measure density fluctuations around the wound.

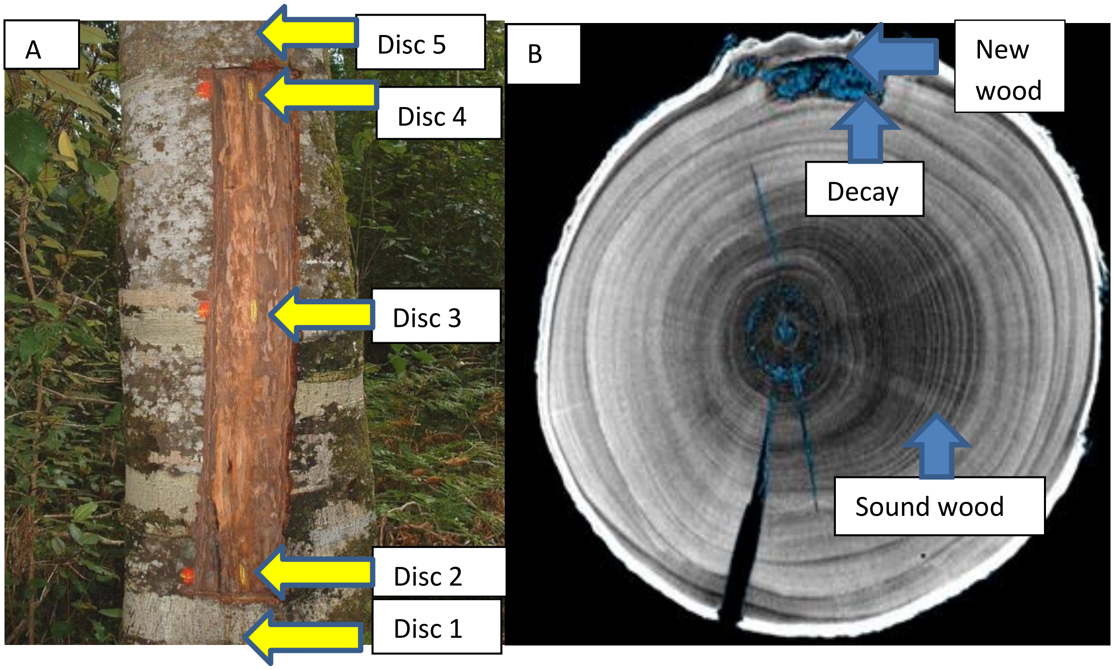

Figure 4.1. Position of discs 1-5 on a tree trunk (A) Computer tomography cross-section of *Ocotea bullata* (B) Decayed regions are highlighted to increase visibility, and new and sound wood (unaffected wood) are indicated.

4.3 Statistical analysis

The density reduction was calculated as the ratio of the average decay density to average sound wood density. Volume decay was calculated as the ratio of volume of decay to volume of sound wood. Data collected were subject to Pearson correlation analysis, and linear regression was used to determine the relationship of rate of wound occlusion with that of percentage decay, density loss, relative density loss and tree growth rate. Species differences means (rate of wound occlusion, volume decay, growth rates and relative density loss) were compared by least significant differences test, after conducting an ANOVA (Statistica software 9.0). A chi-square analysis that compared the number of discs with rot at a wound level and above as well as below the wound was conducted using the R statistical package (R Development Core Team 2013).

4.4 Results

4.4.1 Reaction zone

The reaction zone is described as a thin layer of modified, usually coloured xylem that forms between sound wood and infected wood that serves to protect unaffected wood from spread of pathogens (Shain, 1971). CT scanning results showed differences in densities with the density of the bark being highest, followed by the reaction zone, which showed a slightly higher density than sound wood and with decay showing the lowest density (Fig 4.2).

4.4.2 Species differences

The species differed in terms of density of sound wood, percentage decay, density loss and rate of wound occlusion. The percentage volume of stem decay on experimental trees was significantly higher for *C. dentata* with a mean of 35.1% compared to 5.1% for *O. bullata* ($P<0.005$) (Table 4.1). *O. bullata* showing a significantly higher rate of wound occlusion and higher density loss compared to *C. dentata*. However, *C. dentata* had a significantly higher ($p<0.001$) sound wood density compared to the *O. bullata* (Table 4.1). Furthermore, *C. dentata* showed higher percentage decay at the wound level (Disc 2-4) compared to the disc below the wound (Disc 1) and above the wound (Disc 5). The results indicate that percentage decay is higher at the wound level compared to above and below the wound in both species, with C.

dentata showing significantly higher decay at levels both below and above the wound compared to O. bullata (Fig 4.4). All discs of *C. dentata* indicated decay, but chi-squared tests on *O. bullata* showed a significantly high number of discs with decay compared to those without at wound level (Disc 2-4) when compared to discs below the wound (Disc 1) and above the wound (Disc 5) (X^2 =7.226, df = 2, p= 0.026, n = 43) (Fig 4.4).

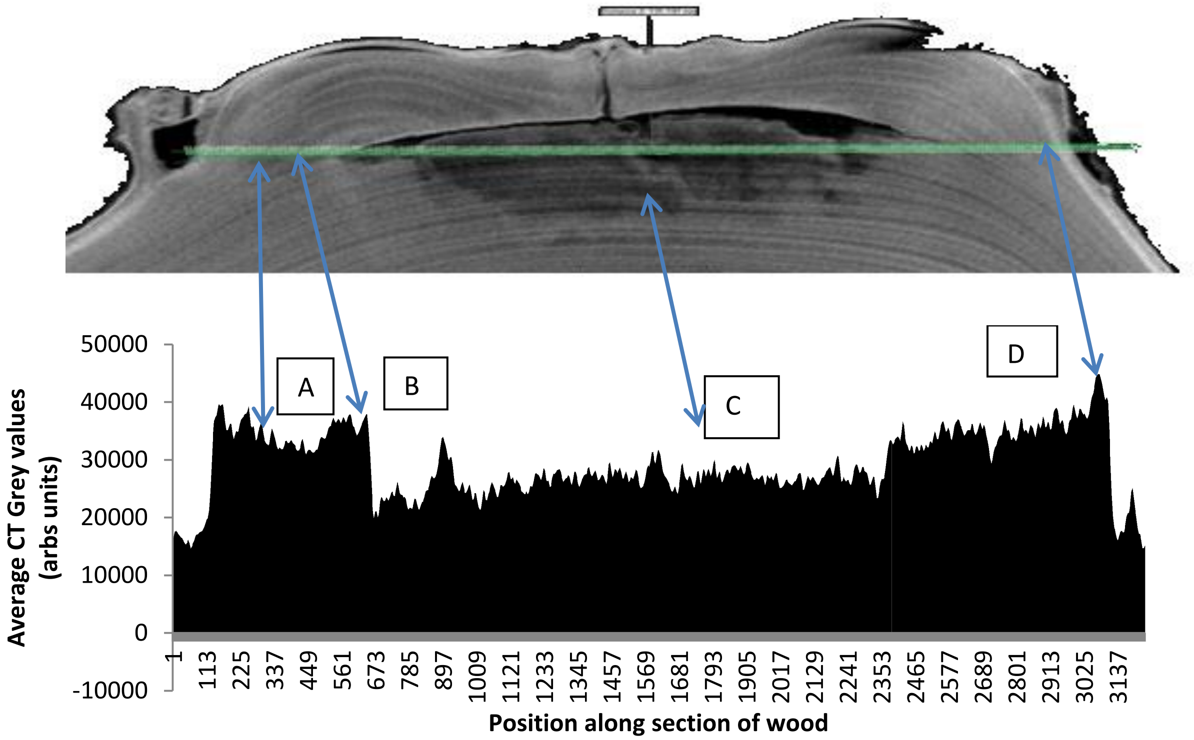

Figure 4.2. Cross-sectional view of the occluded *Ocotea bullata* showing change in grey-values values along the (A) sound wood, (B) reaction zone, (C) decay and (D) bark.

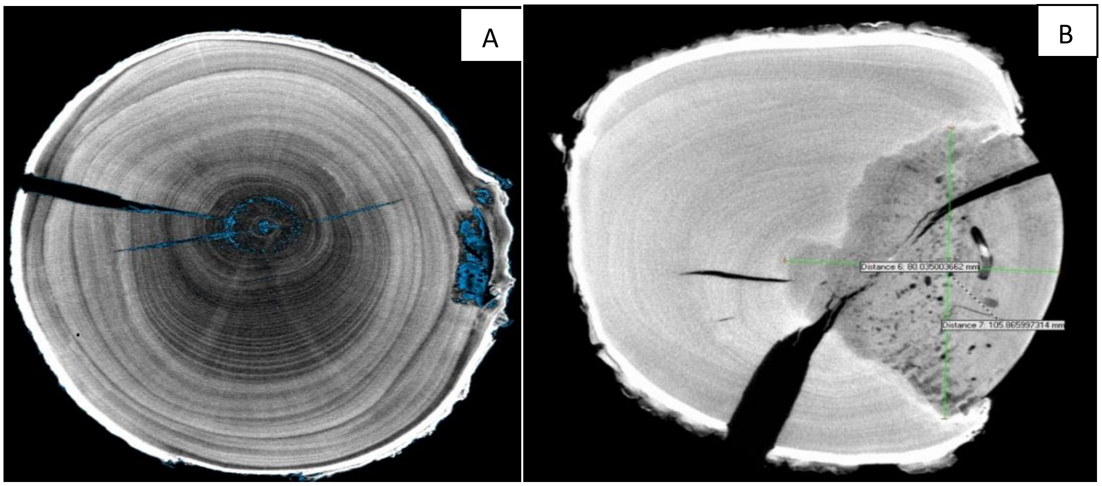

Figure 4.3. Cross-sectional view showing decay in Disc 3 of (A) *Ocotea bullata* and (B) *Curtisia dentata*

Table 4.1. The species differences in terms of sound wood density, density loss, rate of wound occlusion and percentage volume decay.

	Mean	SE
Sound wood density (g/cm³)		
Curtisia dentata	0.925a	±0.117
Ocotea bullata	0.750b	±0.101
relative density loss		
Curtisia dentata	0.133a	±0.032
Ocotea bullata	0.225b	±0.104
Rate of occlusion (mm/annum)		
Curtisia dentata	0.752a	±0.831
Ocotea bullata	7.381b	±4.946
Volume decay (%)		
Curtisia dentata	35.100a	±0.147
Ocotea bullata	5.100b	±0.025

*Different letters indicates significant differences between the species

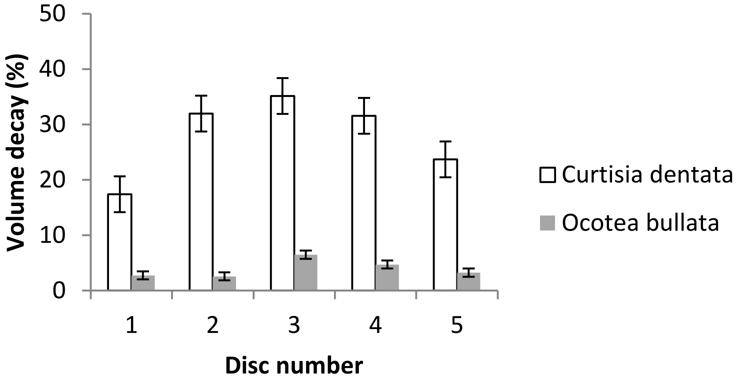

Figure 4.4. The average volume percentage decay on *Ocotea bullata* and *Curtisia dentata* (1= Disc below wound; 2= start of wound; 3 = wound middle; 4 = end of wound; 5 = above the wound).

4.4.3 Ocotea bullata

A strong negative correlation between tree growth rate and sound wood density was found (r= -0.735, n= 10, p <0.05), indicating that faster growing trees have lower wood density (Fig 4.5a). A positive relationship between the rate of wound occlusion and both relative density loss (r = 0.733, n =10, p < 0.05) and percentage decay (r = 0.81, n= 10, p<0.05) were also found (Fig 4.5 b, c). The results indicate that trees with high rates of wound occlusion (and diameter growth rates, see details in Chapter 3) have both higher percentages of decay and higher density losses. However, there was a weak significant correlation between growth rate and density loss (r=0.547, n=10, p>0.05), (Fig 4.5 d). Furthermore, a significant negative relationship was found between density loss and volume of rot (r= -0.66; n=10; p<0.05).

4.4.4 Curtisia dentata

The results indicated weak significant correlation between growth rate and density of the sound wood (r= -0.442; n=10, p>0.05), relative density loss (r= 0.243, n=10, p>0.005), and percentage volume of decay (r= 0.151, n=10, p>0.05), (Fig 4.6 a, b, c). There was also a weak correlation between density loss and volume of decay (r=-0.187; n= 10, p>0.05). However, there was a strong positive correlation between density loss and tree growth rate (0.733, n= 10, p>.0.05). The results indicate that trees with higher growth rates also exhibit high density loss (Fig. 4.6d)). Furthermore, a weak relationship was found between density loss and volume of rot (r= 0.187; n=10; p>0.05).

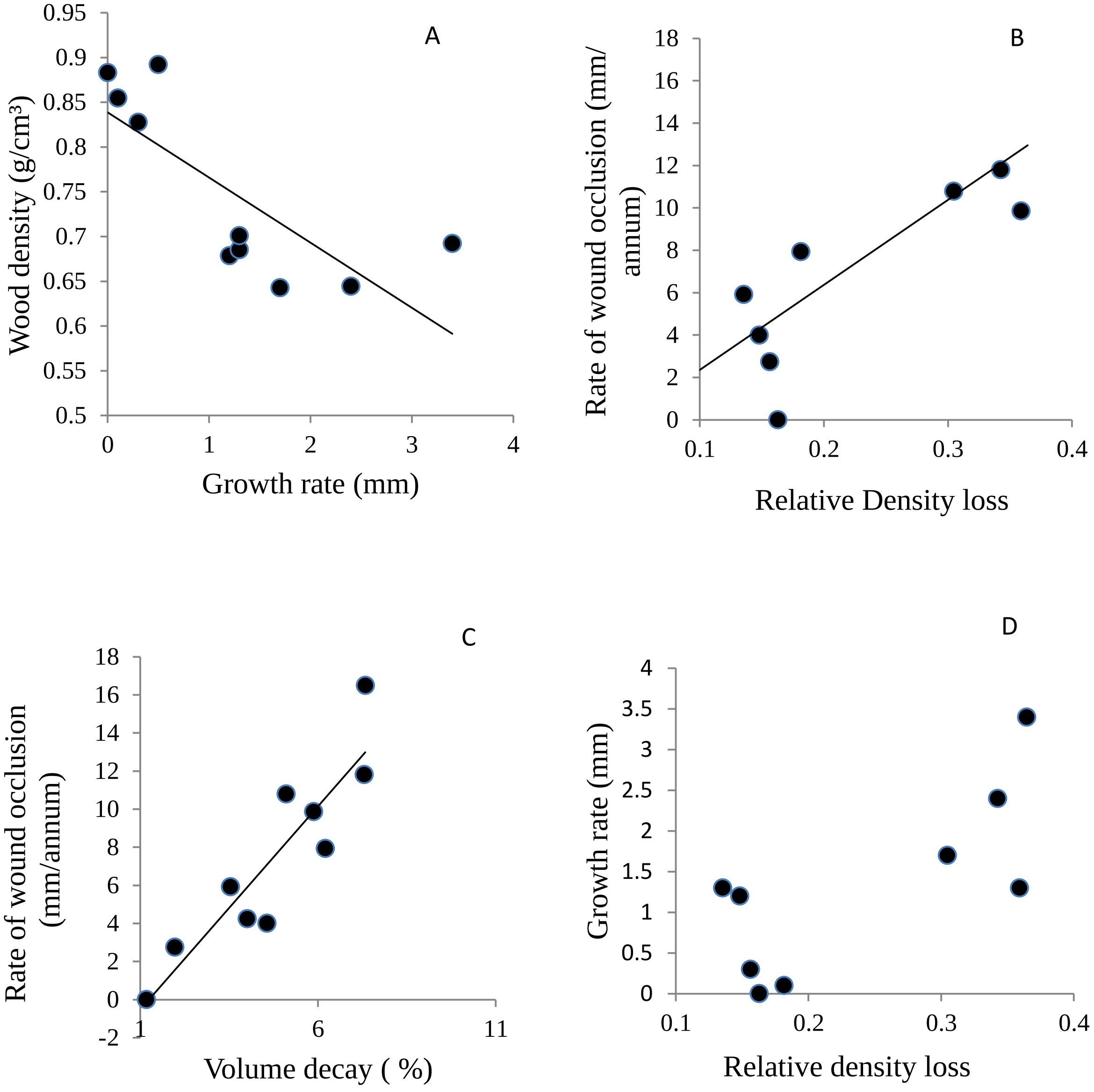

Figure 4.5. The relationship between (A) sound wood density and growth rate, (B) rate of wound occlusion and relative density loss; (C) rate of wound occlusion and percentage volume decay; and (D) relative density loss and tree growth rate, for *Ocotea bullata*

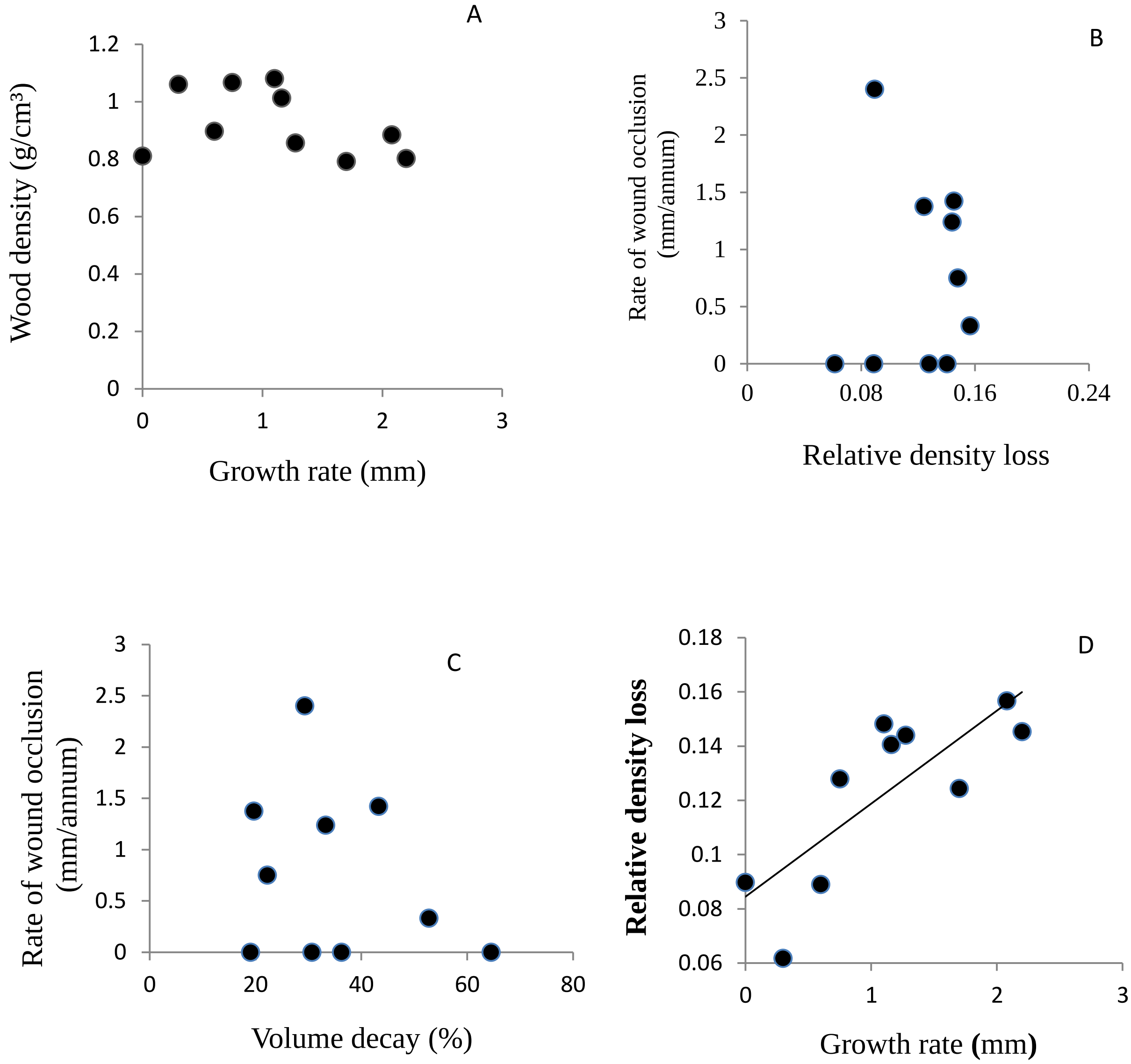

Figure 4.6. The relationship between sound wood density and growth rate (A) rate of wound occlusion and relative density loss (B) rate of wound occlusion and percentage volume decay (C) and relative density loss and tree growth rate (D) for *Curtisia dentata*

4.5 Discussion

4.5.1 Reaction Zone

Using an X-ray CT scanner enabled us to detect the reaction zone that appeared as a thin layer of cells between the sound wood and the affected decayed wood (Fig 4.2). The cell structural changes in the reaction zone were demonstrated by a slightly higher X-ray attenuation rates compared to the sound wood. These results indicate that CT scanning can reliably detect even slight changes in wood densities (as indicated by grey values). This is supported by previous studies (Sarigul et al., 2000; Petutschnigg et al., 2002) that successfully detected lower densities of decayed wood when compared to healthy wood, even in cases where decay was not visually recognizable. Furthermore, Seifert et al. (2010) found no significant difference between branch diameters determined by CT scanner and manual measurements and was also able to accurately determine wood density of decay, all indicating high reliability of measurements from CT scans. However, it should be mentioned that X-ray attenuation is also affected by chemical composition; hence different defense related chemical components might also show an effect, most likely in the direction of higher X-ray attenuation. Since the chemical composition of the reaction zone and the callus zone were not further investigated in this study we cannot finally say how much of the higher X-ray attenuation is indeed a density change of wood and how much is due to impregnation of the respective zones with defensive chemicals, leaving space for further research in the future.

4.5.2 Species differences

The ability of trees to recover from damages is pivotal for tree survival (Romero et al., 2006). Tree response to stem damage has received great attention in the literature, with botanists and horticulturalists describing the anatomical, physiological and chemical changes following stem damage (Romero, 2006). *C. dentata* had a significantly higher sound wood density (0.93 g/cm^3) compared to *O. bullata* (0.75 g/cm^3), the density values comparable to those of Dyer (1989), who indicated mean densities of 900kg/m^3 and 760kg/m^3 (at 10% moisture content dry base) respectively. This research further showed that tree species differ in their ability to close the wound (Chapter 3) and compartmentalize decay. *O. bullata* displayed both good wound occlusion and compartmentalization of decay, with decay mainly confined around the damaged tissues. On the contrary, *C. dentata* showed both poor wound occlusion (Chapter 3) and high volume of decay, with evidence of upward and downward movement of decay within the tree stem (Fig 4.4). The low extent of decay in *O. bullata* and high extent of decay *in C. dentata* is consistent with the findings of Vermeulen et al. (2012) that showed that *O. bullata* was less susceptible to fungal attack compared to highly susceptible *C. dentata*. These results are consistent with the suggestion by Leben (1985) and Vasiliauskas and Stenlid (1998) that species that closed wounds more rapidly should also suffer less spread of decay and vica versa. However, when results were applied inter-specifically, the results from the current study are inconsistent with a trade of theory by Romero and Bolker (2008), which states that species with traits that favour good wound closure would often have traits preventing an effective compartmentalization. The results obtained in this thesis indicated that *O. bullata* has a low volume of decay within the stem but a significantly higher relative density loss compared to *C. dentata*. This could be attributed to *O. bullata* having a relatively lower decayed area for fungi to digest compared to the bigger exposed area in *C. dentata* the effective compartmentalization contained the fungal spread and concentrated the fungal activity in a small zone.

4.5.3 Ocotea bullata

The Romero and Bolker (2008) trade-off theory was found to be inconsistent with the findings in this study when applied inter-specifically. However, it was consistent if applied intra-specifically to *O. bullata*. Trees that exhibited higher rates of wound closure (also higher diameter growth rates) had poor decay containment (high extent of decay) (Fig 4.5c). High growth rates and associated high rates of wound occlusion (Chapter 3) are negatively correlated with healthy wood density (as an indicator of defense investment) and efficient decay containment (high rates of wound occlusion are associated with higher density loss and higher percentage decay indicative of low efficiency of decay containment). The results are consistent with findings of Zycha (1967) that stated that fast growing trees are less efficient in decay containment. High volume of rot in fast growing trees could be attributed to lower density wood of fast growing trees. Romero (2006) further linked low density woods between species to low fiber content, wide dilating rays, and large vessels. The results of Romero (2006) further indicated that, species with low-density wood and wide rays suffered more radial decay penetration compared to other species. It has been demonstrated from previous research that damage on large-diameter vessels exposes larger surface areas, resulting in loss of moisture and air access that stimulate decay propagation (Eckstein et al., 1979). However, a compliant explanation might be found in the Growth Differentiation Balance Theory, which was extended in Herms and Mattson (1992) and states that trees that experience a resource limitation, shift their resources increasingly towards their defense related metabolism, while plants that have a luxurious resource situation invest proportionally more into their growth related metabolism.

4.5.4 Curtisa dentata

This species showed poor performance both in terms of bark regrowth (Chapter 3) and decay containment. Following wounding, decay in this species appears to invade the central portion of the stem and decay expands well above and below the wound, a pattern that has also been observed in other species (Pawsey and Gladman, 1965; Shigo, 1966; El Atta and Hayes, 1987). The poor decay containment and rate of wound occlusion was also reported by Romero (2006) for red oaks (*Quercus. falcata*, *Q. laevis*, *Q. incana*, *Q. nigra*, *Q. hemisphaerica*, *Q. shumardii* and *Q. myrtifolia),* with these species neither proficient at closing wounds nor compartmentalizing decay. Poor decay containment found in *C. dentata* is consistent with the findings of Vermeulen et al. (2012) that reported the species to be highly susceptible to fungal and insect attack. The poor performance of this species is reflected in a significantly higher mortality of treated trees when compared to control trees that were sampled in the same forest type in close proximity to the experimental site (Chapter 3). Poor recovery of *C. dentata* can also partly be explained by site effects, the species not thriving on poorly-drained soils, such as would be expected on flat moist forest sites (Chapter 3). The results from this study highlights that species response to stem damage is complex and therefore there is a need to do further research e.g. on anatomy and structure, chemical composition of wood and defense related wood structures, physiology and phylogeny in order to fully explain and understand species specific response to stem damage.

4.5.5 Management implications in the context of bark stripping for medicinal use

Poor bark regrowth, high extent of decay and high mortality in *C. dentata* renders this species unsuitable for sustainable bark harvesting through bark stripping. Other sustainable bark harvesting methods need to be explored, including harvesting of leaves instead of bark, as previous studies have indicated that healing components found in the bark are also present in the leaves (Shai et al., 2009). Alternatively, full-tree harvesting and the harvesting of bark as a by-product of timber harvesting could be integrated to the SCH (Senility Criteria Harvesting) timber yield regulation system , according to which timber trees are being harvested in the Southern Cape and Tsitsikamma forests (harvesting rates of trees equivalent to natural mortality rates; Seydack et al., 1995).

The good bark regrowth for *O. bullata,* and the species' ability to contain decay indicates that bark stripping from standing trees has some potential in a sustainable harvesting system. The good rate of wound occlusion recorded for *O. bullata*, accompanied by strong links between rates of wound occlusion and tree vigor, allowed for the formulation of a preliminary model that can assist forest managers to determine bark harvest cycles, thereby contributing towards the formulation of sustainable harvest prescriptions for the species. Harvesting of leaves instead of bark, coppice management and full-tree harvesting (as part of the SCH system) The results also indicated relatively poor bark regrowth and high mortality in smaller diameter trees (details in Chapter 3), which further suggest that a minimum tree size (<20cm) for bark-harvested trees needs to be stipulated. The current results indicate that by only considering the potential of wounds to seal, without an understanding of what happens inside the tree, one may misinterpret the long-term implications of bark stripping. Differences in species' responses to bark stripping found in this study highlight that species-specific prescriptions are necessary as different approaches for different species might need to be applied to achieve sustainable bark harvesting in the Afrotemperate forests of the Southern Cape.

4.6 **Conclusion**

Computer tomographic technologies have proven to yield accurate assessments of decay in tree trunks and can contribute immensely in research relating to stem decay and other wood properties. CT scanning seems to offer a good balance between accuracy and user-friendliness, however at comparatively high costs. Good bark regrowth and low volume of decay in *O. bullata* presents potential for sustainable harvesting and integration with indigenous forest management. In contrast, *C. dentata* showed poor bark regrowth and high extent of decay in stems following bark stripping, rendering this species unsuitable for bark stripping as a method of bark harvesting. Therefore alternative bark harvesting strategies need to be explored for this species. No other research has been done on the extent and degree of decay in relation to wound closure in widely used medicinal plants, so this study represents an important first step to addressing this much needed research gap. Further studies are necessary to investigate the decay and bark regrowth of widely used medicinal tree species in order to develop scientifically sound sustainable bark harvesting systems. Studies such as this have important practical implications for forest management and should be extended to other tree species.

4.7 **Acknowledgements**

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5 Chapter 5. Synthesis, conclusion and recommendations for the development of bark harvest system

5.1 Introduction

It is estimated that as many as 80% of the world's population is dependent on traditional medicine for primary health care (Azaizeh et al., 2003). In South Africa, with high diversity of culture and flora, an estimated 3000 plant species are reportedly used for medicinal purposes (van Wyk et al., 1997). With the rise in medicinal plant use, there are concerns over over-exploitation that may result in extinction of widely used plant species. Ecological impacts of plant harvesting have been explored in literature (Ticktin, 2004), with harvesting reportedly having variable effect depending on the parts harvested. Harvesting of bark appears to be more damaging in terms of tree survival (Peters, 1994; Cunningham, 1991; Vermeulen, 2009) compared to harvesting of flowers, which affect regeneration and population viability (Peters, 1994; Gaoue and Ticktin 2008). To avoid over-exploitation of widely used plants from natural vegetation systems, there is a need to explore the cultivation of plants (where practically possible) as an alternative or practiced in conjunction with controlled use of plants from natural systems.

Relevant legislation and policies such as The National Forests Act (Act no. 84 of 1998) makes provision for use of natural resources by local communities for both social and economic development subject to the principles of sustainable harvesting. A conceptual framework for the development of sustainable harvest systems from natural systems was initially proposed by Peters (1996) and extended by Vermeulen (2009); it tailored specifically for medicinal bark harvesting in natural forests. The systematic process entails (a) identification of high- demand species, (b) assessment of species response to bark harvesting, (c) grouping of species based on species response, (d) identification of appropriate harvest system, (e) choice of harvest system for species for each group of species with similar response. The process results in formulation of appropriate harvest system for each species and integration to the multiple-use forest management system (Fig 5.1).

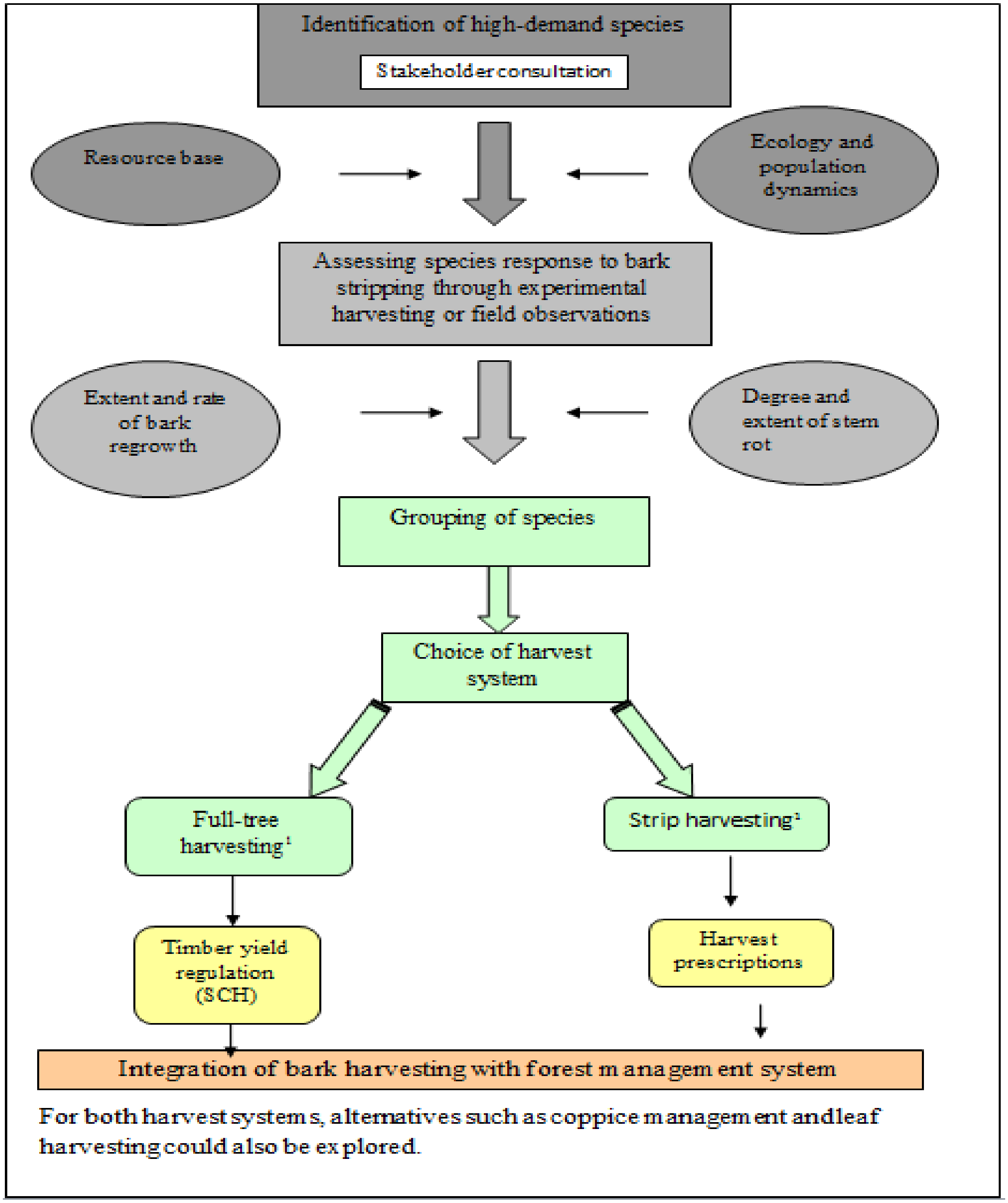

Figure 5.1. Conceptual framework for the development and choice of a harvest system for Medicinal bark in natural forests. Assessing species response to bark stripping through experimental harvesting or field observations (Adapted from Vermeulen, 2009).

This research focused on socio-cultural and ecological components that are pivotal for underwriting species-specific harvest systems for species identified as in high demand for medicinal use within the southern Cape (Identification of high-demand species; Fig 5.1). The social survey was achieved by conducting structured interviews with a group of key informants (Traditional healers). The species-specific response to bark harvesting in terms of bark-regrowth and wood decay consequences was investigated in support of the development of sustainable bark harvesting systems in natural forests (Fig 5.1).

5.2 **Stakeholder needs**

The user-need study found that a total of 69 plant species are used for medicinal purposes in the Southern Cape, however not all mentioned species occurs in the region. The list of species included different plant life-forms, including geophytes, epiphytes, herbs, shrubs and trees. The results from the survey further revealed that most resource users were of the opinion that there is a decline in availability of widely used plants in the wild. Based on this, all respondents indicated a willingness to use cultivated plants as an alternative to wild plants. They attributed the decline to various factors including destructive harvesting methods and increase in demand due to increased number of people that need medical attention. The respondents also predicted a future increase in demand for medicinal plants, which raises concerns for popular species that are already dwindling in most parts of South Africa. However, it is encouraging that respondents are aware of depletion of popular species as this may encourage collaboration with conservation agencies such as SANParks to protect important medicinal species. Cultivation, where practically possible can also be used in conjunction with controlled use of wild plants as a conservation approach that will partly address the challenge of over-exploitation of popular medicinal plants.

5.3 Bark regrowth response to bark stripping

We found the tree response to harvesting to be species-specific. This agrees with similar studies done in South African and Benin (Vermeulen, 2006; Geldenhuys et al., 2007; Guedje et al., 2007; Delvaux, 2009). We reported a significantly better bark regrowth in *O. bullata*, in comparison with *C. dentata.* Season of harvesting and strip width did not influence the bark regrowth of *O. bullata*, however smaller trees (≤ 20cm) had a significantly lower bark regrowth rate and also displayed high mortality. Bark harvesting negatively influenced the survival of *C. dentata* but not that of *O. bullata*. Higher tree growth rates supported higher bark regrowth rates, a relationship that allowed for formulation of a preliminary model that would assist forest managers to determine sustainable bark harvest cycle for *O. bullata*.

5.4 Decay implications following bark stripping

Bark stripping for medicinal use is a common cause of damage in popular medicinal tree species in the natural forests of South Africa. Wounding of trees can facilitate the development of wood decay and affect the long term survival of damaged trees (Vasiliauskas, 2001). Wounds may seal but not heal on the inside (Shigo, 1984) or wounds may never completely close, but they may heal from the inside (Garret & Shigo, 1978). Therefore, by only considering wound occlusion/ bark regrowth, without understanding anatomical pathological consequences, one may misinterpret the long-term impacts of bark stripping on individual tree survival. The results revealed that *O. bullata* had a significantly lower volume of decay, with decay confined within the wounded area, whereas decay in the *C. dentata* was six fold more, with decay extending well above and below the wounded area. Further investigation on *O. bullata* suggests that high diameter growth rate supported better wound occlusion; however it was also linked to high extent of decay. This suggests that facilitating fast tree growth for better wound occlusion and a shorter bark harvesting cycl

eee is not necessary ideal for sustainable harvesting, as fast growing individual trees will be exposed to more decay containment which may compromise the survival of bark stripped trees in the long-term. This study highlights a need to gain an understanding of both the wound occlusion and pathological consequences of bark stripping to understand long-term implications of bark stripping on tree stems.

5.5 Management implications

With the good bark regrowth recorded for *O. bullata* (Chapter 3) and minimal fungal attack (Vermeulen et al., 2012), the species shows potential for the development of a sustainable harvesting system. The good rate of wound occlusion recorded for *O. bullata*, accompanied by strong links between the rate of wound occlusion and tree vigor, allowed for the formulation of a preliminary model that can assist forest managers to determine bark harvest cycles, thereby contributing towards the formulation of sustainable harvest prescriptions for the species. The results also indicated relatively poor bark regrowth and high mortality in smaller diameter trees, which further suggest that a minimum tree size (>20cm) for bark harvest trees needs to be stipulated. The results on *C. dentata* strongly suggest that bark stripping is detrimental to this species. Poor bark regrowth and high extent of wood decay following bark stripping, renders the species unsuitable for bark stripping as a method of bark harvesting, therefore alternative bark harvesting methods need to be explored. Harvesting of leaves instead of bark would be an option, as previous studies have indicated that healing components found in the bark are also present in the leaves of *C. dentata* (Shai et al., 2009). Alternatively, bark harvesting could be integrated with the Senility Harvesting System (SCH), the timber yield regulation system that is practiced in the Southern Cape forests that is based on harvesting of dying trees equivalent to the natural mortality rates (Seydack et al., 1995). Differences in species responses to bark stripping found in this study highlight that species-specific prescriptions are necessary as different approaches might need to be applied to achieve sustainable bark harvesting.

5.6 The contribution of this study to understanding species response to damage

Bark regrowth following bark stripping for medicinal use has been explored for selected species in South Africa (Geldenhuys 2004; Vermeulen 2006; Geldenhuys et al., 2007; Vermeulen 2009, Vermeulen et al. 2012), Zambia and Malawi (Geldenhuys et al., 2007) and Benin (Delvaux, 2009). However this is the first study to report long-term (ten years) results on bark regrowth response on medicinal tree species. Furthermore, this is the first study to provide data on both wound closure and anatomical decay consequences of bark harvesting in relation to tree diameter growth from South African conditions. We report species differences in terms of bark regrowth and decay containment, and report *O. bullata* to be suitable for sustainable harvesting because of its ability to successfully close the wounds and contain decay. Based on our results, we also developed a preliminary model based on a relationship between rate of wound occlusion and tree diameter growth, to help forest managers to determine a bark harvesting cycle for the species. We also report the high extent of decay and poor bark regrowth on *C. dentata*, which renders the species unsuitable for bark stripping technique. The management suggestions provided by this study considers both species response in terms of bark regrowth and decay consequences, so that the recommendations are best fitted to the maintenance of these species in the natural environment. Despite ongoing methodological difficulties with wood decay quantifications, this study further showed the accuracy of the CT scanner in detecting even the slightest change in wood density and other wood properties. Therefore CT Scanners can contribute immensely in research relating to stem decay and other wood properties.

5.7 **Future Directions**

There is a need to generate explanatory and quantitative data in other harvested medicinal tree species in order to define sustainable harvesting strategies. As is often the case, new insight gained with research raises additional questions to be resolved. Further research is required, and is presented below. Addressing these questions will further contribute to the understanding of individual species' response to bark harvesting in natural forests and provide much needed information that will aid in the formulation of sustainable harvest strategies.

Questions to be resolved are:

1. What are the underlying mechanisms that contribute to good bark regrowth in *O. bullata* and poor performance of *C. dentata*? Are they morphological, phylogenic, physiological and environmental characteristics that explain these results?

2. What are some of the factors that favour and/or impede decay containment in *O. bullata* and *C. dentata*?

3. What structural wood formations occur as a result of tree wounding?

4. How efficient are the boundaries (reaction and barrier zones) in stopping the spread of insects and fungi?

Addressing these questions would certainly bring the assessment of the suitability of certain tree species for sustainable bark harvesting forward.

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Appendix 3. User Needs Survey Questionnaire

TRADITIONAL HEALER QUESTIONNAIRE

A. PERSONAL INFORMATION

1. What is your home language?

Xhosa	
Zulu	
English	
Afrikaans	
Other (specify)	

2. How long have you been practicing as a traditional healer?

< 1 year		5 – 10 years	
1 – 2 years		10 – 15 years	
3 – 5 years		> 15 years	

3. How long have you been practicing as a traditional healer in the Southern Cape (George/Knysna/Tsitsikamma area)?

< 1 year		5 – 10 years	
1 – 2 years		10 – 15 years	
3 – 5 years		> 15 years	

4. Which services do you provide?

Traditional healing	
Selling out of hand of medicinal plants or plant parts to customers for personal use (trading)	
Selling of medicinal plants or plant parts to other traditional healers	

5. Approximately how many customers do you have a day or per week? ………..

B. USAGE AND DEMAND

6. Which medicinal plants have you used in treatments or prescribed during the past year, in order of importance?

No.	Name of medicinal plant	Forest	Fynbos
1.			
2.			
3.			
4.			

5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			

7. Which faunal species have you used or prescribed during the past year, in order of importance?

No.	Name of faunal species
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

NOTE: Questions 8 – 17 to be completed for at least three forest plant species- add if not amongst first ten

8. How often do you use or prescribe these medicinal plants in a day/week/month?

No.	Name of medicinal plant	Number of times a day/week/month
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

9. How much of these medicinal plants do you use/prescribe a day/week/month (indicate unit of measure)?

No.	Name of medicinal plant	Volumes/number a day/week/month
1.		
2.		

3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

10. Which times of the year are these medicinal plants in greatest demand?

No.	Name of medicinal plant	Whole year	Spring	Summer	Autumn	Winter
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						

11. In your experience, did the demand for treatment and medicinal plants change in recent years?

	Forest	Fynbos
Demand increased		
Demand remained the same		
Uncertain		

12. Do you think the demand for treatment and medicinal plants will change in future?

	Forest	Fynbos
Demand will increase		
Demand will remain the same		
Demand will decrease		
Uncertain		

Please give reasons for your answer: ……………………………………………………………………….

……….

C. RESOURCE AND AVAILABILITY

13. How do you obtain the medicinal plants that you use?

No.	Name of medicinal plant	Buy	Collect	Place
1.				
2.				
3.				
4.				
5.				

6.				
7.				
8.				
9.				
10.				

14. How much of these medicinal plants do you buy/collect a day/week/month (indicate unit of measure)?

No.	Name of medicinal plant	Volumes/number a day/week/month
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

15. If you buy your plants from gatherers, have you experienced any changes in the availability of these plants during the past two years?

No.	Name of medicinal plant	More common	Scarcer	No change
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

16. If you collect plants, have you experienced any changes in the availability of these plants from the wild during the past two years?

No.	Name of medicinal plant	More common	Scarcer	No change
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Please give reasons why you think there have been changes.

……….

……….

17. If you also provide medicinal plant material to other traditional healers, where are these traditional healers practicing?

Southern Cape		Cape Town area	
Port Elizabeth area		Other (specify)	
Not applicable			

18. Would you be interested to use cultivated plants, by either buying it or growing it yourself?

	Forest	Fynbos
Yes		
No		
If yes:		
Buy		
Grow myself		

If no, what is the reason? ………………………………………………………………………………………

………

……….

Appendix 4. A list of species used in the Southern Cape

Scientific	**Xhosa**	**Common**
Acacia karoo	Umnga	Cape thorn tree
Acalypha glabrata	Mthombothi	False forest nettle
Acorus calamus	Inkalumuzi	Sweet flag, Sweet root
Afzelia quanzensis	Umadlavuza	Mahogany bean
Agathosma betulina	ibushu	Buchu
Aleo aristata	Umathithibala	Long-awned aloe
Alepidea amatymbica	Iqwili	Kalmoes
Aloe ferox	ikhala	bitter aloe
Andrachne ovalis	Umbezo	Devils bush, Bastert lighning bush
Apocynaceae	Itshongwe	Milk bush
Arctotis arctoides	Ubushwa	Botterblom
Artemisia afra	umhlonyane omhlope	African wormwood, Wild wormwood
Asparagus suoveolens	isilawu esimholophe	Wild asparagus
Bulbine natalensis	Ibhucu	Rooiwortel
Cassine aethiopica	Umnqayi	kooboo-berry
Cassipourea flananganii	Mmemezi	Onionwood
Chionanthus foveolatus	Umdlebe	Pock ironwood
Chironia baccifera		Christmas berry
Cinnononum camphora	Roselina	Camphor
Cissampelos capensis	Umathunga	Paintbrush
Clausena anisata	umnukambile	Horsewood
Cliffortia odorata	-	Wild grape
Cnicus benedictus	-	Holy thistle
Cotyledon orbiculata	Iphewula	Pig's ear
Crassula vaginata	Uphuncuka bemphethe	
Croton gratissimus	Mahlabekufeni	Lavender croton
Curtisia salutaris	Mlahleni	Assegai
Cyrtanthus breviflorus	-	Wild Crocus
Dianthus thunbergii	Ngcana	
Dioscorea elephantipes	Nakaa	Elephants's foot
Dioscorea sylvatica	Usikolipati	wild yam
Drimia elata Jacq.	umredeni	Satan squill
Elephantorrhiza elephantina	Indololwane	Elephants root, Elands wattle
Elytropappus rhinocerotis		Rhinoster bush
Encephalartos sp	Umphanga	Tongaland cycad
Eriocephalus africanus	-	Wild rosemary
Eucomiscomosa	-	Pineapple flower
Garderia scabra	Velabahleke	Pink ground-bells

Gasteria sp	Isixhonxo	Ox tongue, Cow tongue
Gunnera perpensa L.	iphuzi	River pumpkin
Helichrysum cymosum	impepho	Gold carped, Straw flower
Helichrysum petiolare	Isibunge	Everlasting
Helichrysum spp	imphepho	Everlasting
Hippobromus pauciflorus	Lwathile	False horsewood
Hypoxis hemerocallidea	ilabatheka	African potato
Hypoxis zeyheri	Labatheka	Broad leaved african potato
Ilex mitis	Isidumo	Cape holly
Kigelia africana	Umvunguthi	Sausage/cucumber tree
Leonotis leonurus	Umfincafincane	Wild dagga
Mentha longifolia	inixina	Wild mint
Mondia whitei	umondi omhlophe z	White's ginger
Ocotea bullata	Mnukani	Stinkwood
Olea europea subsp. africana	Umnquma	Wild olive
Ornithogalum longibracteatum	umrendeni omhlophe	Pregnant onion, False sea onion
Pittosporum viridiflorum	Umkhwenkwe	Cheese wood
Plumbago auricutals	Mabophe	Syselbos
Polygala serpentaria	Nceba	Snake root
Portulacatia afr	Intelezi	Pork bush, Elephants food
Protorhus longifolia	Izintlwa	Red beech, Purple current
Pteaeroxylon obliquum	Umthathi	sneeze wood
Pterocelastrus tricuspidatus	utwina	Candle wood, Cherry wood
Rapanea menalophloes	Umaphipha	Cape beach
Rauvolfia caffra	Umjelo	Quinine tree
Rhoi c'issus digitata	Uchithibhunga	Baboon grape, Dune grape
Rhoi c'issus tomentosa	iphinda bamshaye	Wild forest grape
Rubia petiolaris	Impendulo	Madder
Rutia graveolens	-	Herb of grace
Sarcophyte sanguinea srarrm	umavumbuka	Wolwekos
Siphonochilus eathiopicus	Isiphephetho	Wild ginger
Sutherlandia frutescens	umnwele	Cancer bush, Balloon pea
Talinum caffrum	Uphuncuka bemphethe	Porcupine root, Flame flower
Tetradenia riparia	-	Ginger bush
Thesium hystrix	Klein swart storm	Klein swart storm
Tulbaghia alliaceae	Umwelela	Wild garlic
Warburgia salutaris	Isibharha	pepper-bark tree
Xymalos monospora	Umnonono	Lemon wood
Zanthophyllum capense	Umlungumabele	small knobwood
Zehneria Scabra	Untangazana	Bos aartappel
Ziziphus mucronata	Mphafa	Buffalo thorn