THE SUSTAINABLE HARVESTING OF NON-TIMBER FOREST PRODUCTS FROM NATURAL FORESTS IN THE SOUTHERN CAPE, SOUTH AFRICA: DEVELOPMENT OF HARVEST SYSTEMS AND MANAGEMENT PRESCRIPTIONS

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DECLARATION

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright 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

There is a growing appreciation of the importance of non-timber forest products (NTFPs) and the role they play in the socio-economic wellbeing of rural communities and other stakeholders. Harvest systems to ensure sustainable harvesting are largely still lacking and overutilisation is of growing concern worldwide. In this study the science needed to underwrite management for sustainable use of NTFPs was explored. This was done using case studies of three different products harvested from natural forest in the southern Cape, South Africa *viz.* fern (*Rumohra adiantiformis*) fronds (leaves) as greenery in the florist industry, medicinal tree bark, and the corm (stem) of the geophyte *Bulbine latifolia* for medicinal use. The research approach enabled insight into the complexities of developing harvest systems for NTFPs, the input and expertise required to conduct applied research, and the variation in approach required for different products and plant growth forms.

The study on *R. adiantiformis* showed that the adaptive management approach can be followed effectively with the development of harvest prescriptions for a species. Goal-orientated, long-term monitoring, assessing harvest impact on the resource and natural fluctuations in population dynamics, are essential to verify that harvest prescriptions are sound and ecologically sustainable. However, if all relevant aspects are covered, the input required to develop and refine harvest systems through such monitoring may be extensive.

Experimental stripping of medicinal tree bark showed that species respond differently to wounding, in terms of both bark regrowth and susceptibility to fungal and insect damage. The conceptual model and decision tree developed, demonstrated that tree response to wounding could be used effectively when choosing a management system for bark harvesting, and in informing prescriptions for strip harvesting. The proposed harvest system for the target species, as well as alternative options to meet the demand for bark can be successfully integrated with the existing multiple-use forest management system in the southern Cape.

The study of the ecology and dynamics of *B. latifolia* showed that the species has a complex population dynamics and is abundant on the fynbos/forest ecotone, where it is associated with dry scrub forest communities. Although regeneration is sound, it has a slow rate of renewal in terms of corm diameter and length growth, limiting its harvest potential. The difference between ecotone and forest populations – in terms of population dynamics, plant demography and regeneration phenology – requires that consideration be given to differential harvest prescriptions for ecotone and forest populations.

It was concluded that a simple generic process that provides for research to be focused on the relevant fields can be followed effectively with the development of harvest systems for NTFPs. However, sustainability also has a socio-economic and political dimension, further influenced by institutional arrangements. Considering the wide range of NTFPs used, socio-economic circumstances and the dependence of rural communities on natural resources, a major challenge awaits forest managers in South Africa to develop harvest systems for sustainable use. Policy and decision makers need to appreciate the scientific skills and expertise, and financial resources required to realise this.

OPSOMMING

Die belangrikheid van bosprodukte anders as hout en die rol wat dit in die sosio-ekonomiese welstand van landelike gemeenskappe en ander belanghebbendes kan speel, word toenemend besef. Oesstelsels om standhoudende benutting te verseker is grootliks afwesig en oorbenutting is wêreldwyd ’n toenemende bron van kommer. In hierdie studie word die wetenskaplike insette benodig om oesstelsels vir nie-houtbosprodukte te onderskryf, betrag. Dit is gedoen aan die hand van gevallestudies van drie bosprodukte wat uit natuurlike woud in die Suid-Kaap, Suid-Afrika, benut word, naamlik die blare van die varing *Rumohra adiantiformis* vir blommerangskikkings, medisinale boombas en die stam van die geofiet *Bulbine latifolia* vir medisinale doeleindes. Die navorsingsbenadering laat toe om insig te bekom in die kompleksiteit met die ontwikkeling van oesstelsels vir nie-houtbosprodukte, die insette en kundigheid benodig vir toegepaste navorsing, en die verskillende benaderings met verskillende bosprodukte en plantgroeivorms.

Die studie oor *R. adiantiformis* dui aan dat ’n aanpasbare bestuursbenadering suksevol gevolg kan word met die ontwikkeling van oesvoorskrifte vir ’n spesie. Doelgerigte langtermynmonitering om die impak van inoesting op die bron en natuurlike fluktuasies in populasiedinamika te bepaal, is noodsaaklik om te kan aandui of oesvoorskrifte ekologiese standhoudendheid verseker. Die insette benodig om oesstelsels te ontwikkel en deur langtermynmonitering te verfyn, kan egter aansienlik wees.

Eksperimentele basstroop dui aan dat boomspesies verskillend reageer op basverwydering in terme van bashergroei en vatbaarheid vir insek- en swamskade. ’n Konsepmodel en vloeidiagram vir besluitneming is ontwikkel en dui aan dat ’n boomspesie se reaksie op basverwydering effektief aangewend kan word in die keuse van ’n oesstelsel en die ontwikkeling van voorskrifte vir strookbenutting. Die voorgestelde oesstelsel vir die teikenspesies en ander alternatiewe om in die behoefte vir bas te voorsien, kan doeltreffend geintegreer word met die bestaande meervoudige-benutting woudbestuurstelsel in plek in die Suid-Kaap.

Die studie oor die ekologie en dinamika van *B. latifolia* dui aan dat die soort goed verteenwoordig is in die fynbos/woud-ekotoon, dat dit geassosieer is met droë struikwoud, en ’n komplekse populasiedinamika het. Alhoewel dit goed verjong, het dit, gemeet aan stamdeursnee- en -lengtegroei, ’n lae groeitempo wat die benuttingspotensiaal van die spesie beperk. Die verskille tussen ekotoon- en woudpopulasies – in terme van populasiedinamika, demografie en reproduksiefenologie – vereis dat oorweging geskenk word aan verskillende oesvoorskrifte vir ekotoon- en woudpopulasies.

’n Eenvoudige, generiese proses wat verseker dat navorsing gefokus is op die toepaslike velde kan suksesvol gevolg word met die ontwikkeling van oesstelsels vir nie-houtbosprodukte. Standhoudendheid het egter ook ’n sosio-ekonomiese en politieke komponent wat verder beinvloed word deur institusionele strukture. Inaggenome die wye verskeidenheid van nie-houtbosprodukte wat benut word, sosio-ekonomiese omstandighede en die afhanklikheid van landelike gemeenskappe van natuurlike hulpbronne, is die ontwikkeling van oesstelsels vir standhoudende benutting ’n groot uitdaging vir woudbestuursinstansies. Beleidmakers en besluitnemers moet ’n waardering ontwikkel vir die wetenskaplike kundigheid en kennis, en finansiële hulpbronne, wat benodig word om dit te bewerkstellig.

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CHAPTER 1: GENERAL INTRODUCTION AND RESEARCH JUSTIFICATION

1.1 INTRODUCTION

Forests are complex ecosystems capable of providing a wide range of economic, social and environmental benefits, and are essential for human life (FAO 1995a). The numerous roles they are expected to play in local, national and global development continue to change and, in 1992, concerns about this evolving role triggered an intense debate at the United Nations Conference on Environment and Development in Rio de Janeiro (FAO 1995a). This resulted in 178 countries adopting a set of non-legally binding principles on the management, conservation and sustainable development of all types of forests (Heissenbuttel *et al.* 1992, revised UNFF 2007), with the overarching principle that forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations (Bethlehem 2002).

In recent years, there has been a growing appreciation of the importance of non-timber forest products (NTFPs) and the role they play in the socio-economic wellbeing of rural communities and other stakeholders (Falconer 1990, FAO 1995b, 1997, Peters 1996, Mahapatra & Mitchell 1997, Neumann & Hirsch 2000, Shackleton & Mander 2000, Shackleton *et al.* 2000, Cunningham 2001, Van On *et al.* 2001, Walter 2001, Du Toit 2002, Chipeta & Kowero 2004, Clarke & Grundy 2004, Hiremath 2004, Lawes *et al.* 2004a, Shackleton & Shackleton 2004, Sunderland *et al.* 2004, Ticktin 2004, Vedeld *et al.* 2004, Delang 2006, Sheil & Liswanti 2006, Croitoru 2007, Mudekwe 2007, Shackleton *et al.* 2007, Akhter *et al.* 2008, Hembram & Hoover 2008). However, harvest systems to ensure the sustainable harvesting of NTFPs from the wild are largely still lacking, and overutilisation is of growing concern, (Cunningham 1993, 1997, Hall & Bawa 1993, Peters 1996, Balick & Cox 1997, Ngulube 1999, Ouédraogo 2001, Walter 2001, Grace *et al.* 2002, Lawes *et al.* 2004b, Ticktin 2004, Ndangalasi *et al.* 2007)). Also, despite the Rio declaration and meaningful efforts of forest planting and landscape restoration, deforestation continues at the alarming rate of about 13 million hectares per year, with the largest net loss in Africa and South America (FAO 2005). Degraded forest further adds to a decline in the capacity of the world's forest resources to supply goods and services (FAO 2001, 2003), and an integrated management approach is required to ensure that these services are sustained in the long term.

1.2 LEGISLATIVE FRAMEWORK FOR FOREST MANAGEMENT IN SOUTH AFRICA

The birth of a new political dispensation in South Africa in 1994 (Constitution of the Republic of South Africa, Act No. 108 of 1996) triggered the revision of legislation that affects the lives of its citizens. In terms of resource use, the revision and promulgation of new laws largely provide for and facilitate access to natural resources where it has been restricted in the past, but subject to the principle of sustainability. Relevant legislation includes the National Environmental Management Act (Act No. 107 of 1998), National Environmental Management: Biodiversity Act (Act No. 10 of 2004), National Forests Act (Act No. 84 of 1998), National Protected Areas Act (Act No. 57 of 2003), as well as Provincial legislation.

In addition, to protect indigenous knowledge and to promote the sharing of benefits, draft regulations on bioprospecting, access and benefit sharing were published in Government Gazette (Notice 329 of 2007).

The development of a new national forest policy for South Africa (DWAF 1995) gave rise to a White Paper on sustainable forest development (DWAF 1996) and the National Forestry Action Programme (DWAF 1997), culminating in the National Forests Act (NFA). The NFA provides the legal framework for the protection and sustainable management of natural forest in South Africa, but also promotes access to forest resources, the equitable distribution of benefits accruing from natural forests, and greater stakeholder participation in forest management. To realise this, the Department of Water Affairs and Forestry (DWAF), responsible for administrating and enforcing the NFA, formulated a policy of participatory forest management (PFM) (DWAF undated, 2004) for State Forest land to facilitate a sustained flow of benefits to key stakeholders (DWAF 2005a).

In line with global thinking on forest management, the focus has shifted away from timber exploitation and strict conservation to a more holistic, multiple-use, ecosystem-based management approach (Gilmore 1997, Schlaepfer & Elliott 2000). The NFA, however, binds forestry operations to the principles of sustainable forest management. This has resulted in the development of Principles, Criteria, Indicators and Standards (PCI&S) for sustainable forest management, to be adopted into forest management practices in South Africa (DWAF 2005b).

1.3 ECOLOGY AND MANAGEMENT OF THE SOUTHERN CAPE FORESTS

The natural forests in the southern Cape, the largest forest complex in southern Africa, form the southern end of the chain of Afromontane forests along the eastern escarpment and the Indian Ocean Coastal Belt forests along the east coast of South Africa (White 1978, Geldenhuys 1991). Management of these forests has a rich history, from destructive timber exploitation in the 1700s to participatory, multiple-use conservation management that culminated in Forestry Stewardship Council (FSC) certification in 2002 (Kok & Vermeulen 2002), meeting national and international standards for sustainable forest management.

1.3.1 Description of the southern Cape forests

Location

These natural forests cover a total area of about 60 500 ha between 22°00' and 24°30'E at approximately 33°45'S latitude (Figure 1.1), of which 35 765 ha are managed by South African National Parks (SANParks). They lie scattered on the narrow coastal strip south of the Outeniqua and Tsitsikamma mountain ranges where climatic conditions allow for forest development (Geldenhuys 1991).

Physiography

The E-W trending mountains, coastal foreland with coastal scarp, and frequent north-south orientated river incisions are the outstanding physiographic features of the southern Cape (Geldenhuys 1991, Schafer 1992). The crests of the mountain ranges are over 1000 m high,

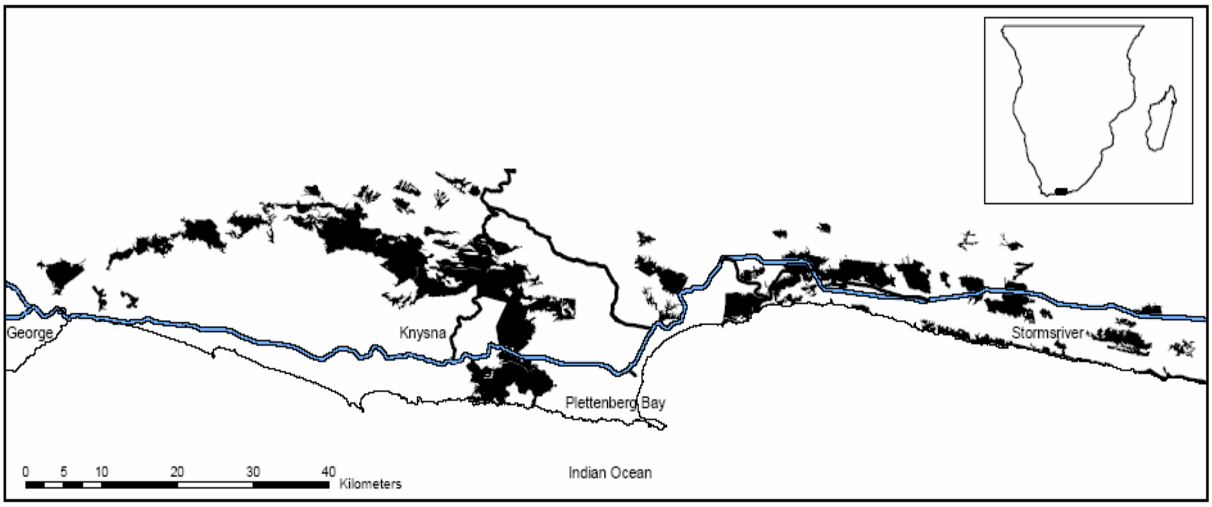


Figure 1.1. The distribution of natural forests in the southern Cape and their location in southern Africa (insert).

and vary between 10 and 40 km in distance from the Indian Ocean in the south (Geldenhuys 1991). There are three forest zones (Geldenhuys 1991, 1993a, Von Maltitz *et al*. 2003):

- Mountain forests occur on the mountain slopes and foothills, at altitudes ranging from 600 to 840 m on steep slopes, footslopes above streams and sheltered gullies in fire refugia, on a predominantly southern aspect.
- Coastal platform forests occur on the undulating landscape of the dissected plateau north of Knysna and the coastal plateau in the Tsitsikamma to the west, with altitudes ranging from almost sea level to 650 m, on predominantly south to southwest-facing slopes.
- Coastal scarp forests occur along river valleys and coastal scarps, with altitudes ranging from almost sea level to 380 m on predominantly southeast to southwest slopes.

Geology and Soils

Rocks of the Cape Supergroup underlie most of the area, while PreCape and Cretaceous rocks and unconsolidated deposits of recent age occupy smaller areas (Toerien 1979, Scriba 1984). Soils are generally acid, leached, low in nutrients, shallow and with poor internal drainage, depending on the geological substrates (Toerien 1979, Geldenhuys 1991, 1993a, Von Maltitz *et al*. 2003).

- Mountain forests occur almost exclusively on the Peninsula Formation of the Table Mountain Sandstones, with the soils generally moist to wet with pH ranging between 3.9 and 4.6.
- Platform forests occur on quartzitic sandstones and shales of Peninsula, Goudini, Skurweberg, Baviaanskloof, Cederberg and Gydo Formations (i.e. on geological formations of the Cape Supergroup), the Knysna Sands (old dunes) and parts of the Kaaimans Formation (shales, schists and phyllites). The soils are shallow to deep with relatively high water tables, and the pH ranges from 4.3 to 5.6.
- Scarp forests occur on the Kaaimans Formation, recently stabilised dunes, Enon conglomerates, and quarzitic sandstones and shales of Peninsula, Goudini, Skurweberg and Gydo Formations. Sites are well-drained or physiologically dry because of a high

clay content, and generally have a high nutrient status with relatively high pH ranging from 5.4 to 6.9.

Climate

The climate is described as moist, warm temperate (Scriba 1984, Von Maltitz *et al*. 2003, Schafer 1992). The mountains have a profound effect on the weather pattern by acting as a barrier to the inland penetration of shallow weather systems, invoking typical orographic precipitation (Tyson 1971 cited in Scriba 1984). Rain falls throughout the year, but with definite peaks during autumn (March to April) and early summer (September to October), ranging from 500 mm in the west and at the coast to 1 200 mm in the mountains (Scriba 1984, Geldenhuys 1991, 1993a, Schafer 1992).

Mean daily maximum temperature ranges from 23.8°C in February to 18.2°C in August, with the mean daily minimum between 19.7°C and 8.9°C (Geldenhuys 1991). Frost, confined to depressions, and hail occur infrequently, with one to a few snowfalls per year on the mountain peaks and very infrequent incidences of these events lower down (Geldenhuys 1991). Thunderstorms are rare, but occasionally portions of the forest are struck by lightning which may ignite a fire (Geldenhuys 1991). The most significant prevailing winds are the southwesterly rain-bringing winds (spring and autumn) and the dry, fair-weather southeasterly winds in summer (Scriba 1984, Geldenhuys 1991). In winter, the prevailing winds blow from the southwest or as "berg winds" from the northwest (Geldenhuys 1991). These climatic variables cause steep moisture and temperature gradients from the coast to the mountains.

Forest types

The forests have been classified as Knysna Forest and Afromontane Forest by Acocks (1988) and Low & Rebelo (1996) respectively, and more recently as Southern Cape Afrotemperate Forest (Von Maltitz *et al.* 2003), forming part of the Southern Afrotemperate Forest vegetation type (Mucina & Rutherford 2006). The three distinct forest zones are described as follows:

- Mountain forests are mostly wet, with typically Afrotemperate species, occur in relatively small patches and are species poor as a result of more frequent disturbance by fire.
- Coastal platform forests are relatively large in extent and rich in species. They are typically moist and medium-moist managed for timber production, and include mainly species of Afrotemperate affinity.
- Scarp forests consist of dry and scrub forest, are relatively large in extent and species rich, including many coastal belt species.

The forest types, based on the classification by Phillips (1931) and Laughton (1937), are described as follows (after Von Breitenbach 1968a and Geldenhuys 2000a; species names after the nomenclature of Germishuizen & Meyer 2003):

Very very dry Scrub (vvd-S) is found on sites with a relatively very hot and dry climate, and where soil formation occurs in patches only and remains at an initial stage over a sandy, rocky or stony substratum. The scrub is about 2-5 m high and consists of smaller or larger groups of shrubs and occasional, stunted, bushy trees, with low ground vegetation. The shrub flora is rich in species with *Allophylus decipiens, Buddleia saligna, Cassine peragua, Chrysanthemoides monilifera* and *Osyris compressa* among the most common. The shrubs are often intertwined, or overgrown by scramblers such as *Rhoicissus tomentosa* and *Scutia myrtina*. The ground between the scrub groups is covered with dwarf shrubs and herbaceous plants among which species of *Agathosma* and *Cliffortia* are prominent.

Very dry Scrub-Forest (vd-SF) occurs on shallow soils and on hot, dry aspects and is characterised by a dense mixture of shrubs (3 to 6 m) and stunted trees (up to 9 m). Tree regeneration is infrequent and ground flora is sparse. Thorny shrubs such as *Gymnosporia buxifolia, Carissa bispinosa* and *Scutia myrtina* are common. Occasional large trees, in particular *Podocarpus falcatus*, occur. Many species of the dry and medium-moist forest types also occur.

Dry High-Forest (d-HF) occurs on well-drained or shallow soils with warm aspects and especially on steep slopes. The forest is relatively dense with an irregular canopy, 10 to 18 m high. Tree regeneration is poor, but there is an abundance of ground and shrub flora species, many spinescent. *Trichocladus crinitus*, a tall shrub with a fairly thick stem, has scattered occurrence. Characteristic species are *Cassine peragua, Rhus chirindensis, Maytenus acuminata, Canthium inerme, Tarchonanthus camphoratus, Pittosporum viridiflorum, Sideroxylon inerme* and *Lachnostylis hirta.*

Medium-moist High-Forest (mm-HF) is found on a variety of (but generally poorly-drained) soils. The main canopy is 16 to 22 m high. A very dense shrub layer, composed mainly of *Trichocladus crinitus* with relatively thin stems, grows up to 6 m. Ground flora is abundant while tree regeneration is good to poor. Dominant species in the upper canopy include *Olea capensis* subsp. *macrocarpa, Podocarpus latifolius, Pterocelastrus tricuspidatus, Apodytes dimidiata*, *Curtisia dentata and Psydrax obovata.* A lower canopy consists of species such as *Gonioma kamassi, Canthium mundianum*, *Elaeodendron croceum, Robsonodendron eucleiformis, Diospyros whyteana* and *Burchellia bubalina.*

Moist High-Forest (m-HF) occurs on moist, deep loamy soils on southerly aspects; the upper canopy reaches 20 to 30 m. Most species of the medium-moist forest occur but the density is lower and the mean diameter larger. Additional species in the main canopy are *Ocotea bullata*, *Maytenus peduncularis, Ilex mitis* and *Platylophus trifoliatus. Halleria lucida* and *Olea capensis* subsp. *capensis* are the most common subcanopy tree species. *Trichocladus crinitus* is less dense and often absent from the shrub layer. *Plectranthus fructicosus* and *Rumohra adiantiformis* become important understorey species.

Wet High-Forest (w-HF) occurs on cooler aspects with wet soils, often shallow, but with relatively good drainage. Canopy height ranges from 12 to 30 m. Relatively few species occur. *Cunonia capensis* and *Ocotea bullata* form the main canopy. Other occasional species of the main canopy are *Podocarpus latifolius, Platylophus trifoliatus* and *Nuxia floribunda. Olea capensis* subsp. *capensis, Halleria lucida* and *Gonioma kamassi* are common intermediate trees. The tree fern *Cyathea capensis* is characteristic and attains a height of up to 6 m. There is a variety of ferns, particularly *Blechnum* spp. and tree regeneration is poor. *Sparrmannia africana* occurs sporadically in the understorey. *Virgilia divaricata* is common in the forest fringe adjoining fynbos.

Very wet Scrub-Forest (vw-SF) is found on steep, wet slopes with shallow soils. The general canopy is 6 to 9 m in height. *Cunonia capensis* is the dominant species, while *Ocotea bullata*, *Podocarpus latifolius, Rapanea melanophloeos, Platylophus trifoliatus* and *Virgilia divaricata* also occur. Shrub species include *Sparrmannia africana, Diospyros glabra and Laurophyllus capensis*. *Blechnum capense* and *Todea barbara* are prominent ferns.

A more detailed floristic classification of the southern Cape forests was conducted by Geldenhuys (1993a) but was not yet adopted in the forest management classification. The results show that a particular tree community may have different understorey communities and, likewise, a ground flora community may occur in different tree communities. A total of 470 species were identified, belonging to 280 genera and 106 families (Geldenhuys 1993b), including a number of disjunct species or species that reach their westernmost distribution limit in the region (Geldenhuys 1992).

Fynbos

The forests are surrounded by or occur in association with fire-adapted fynbos vegetation. This largely consists of South Outeniqua Sandstone Fynbos and Tsitsikamma Sandstone Fynbos, as well as smaller areas of lowland fynbos, e.g. Knysna Sand Fynbos and Garden Route Shale Fynbos (Mucina & Rutherford 2006). Fire in fynbos is a natural disturbance agent on the forest edge (Geldenhuys 1994a, Von Maltitz *et al*. 2003) and maintains the forest/fynbos boundary. The absence of fire results in forest expansion, while the opposite occurs during intense fires (Watson & Cameron 2001).

1.3.2 Forest management

Policy and objectives

Subject to scientific principles, the forests are managed in accordance with a multiple-use management system, with conservation, resource use (timber and NTFPs) and ecotourism as important land-use types (Seydack *et al*. 1982, Durrheim & Vermeulen 1996). The primary management objective is nature conservation, which entails the maintenance of the present distribution of the forest, the conservation of biological diversity, the maintenance of natural ecological processes and landscape intactness, as well as soil and water conservation. In compliance with national legislation and forest policy that promote access to forest resources for consumptive and non-consumptive use (DWAF 2004), a policy of participatory forest management (PFM) is followed to ensure local participation in decision making and the sharing of economic, social and environmental benefits from the forests.

Management classification

Five management classes, with the forest types as the ecological basis for management, were distinguished (Table 1.1) (Durrheim & Vermeulen 2006):

Management class A: Timber utilisation
These are moist and medium-moist High-Forest compartments where timber exploitation is practically feasible (regarding slope and accessibility); the timber growing stock potential is favourable; and timber exploitation is reconcilable with the overriding management objective of conservation (i.e. the ecologically less sensitive compartments). Timber yield regulation evolved over the years (Seydack *et al*. 1982, 1990) culminating in the "senility criteria harvesting" (SCH) system, which is aligned with natural disturbance patterns in the forest (Seydack *et al*. 1995). Harvest methods and guidelines have been implemented to minimise damage to the residual stand (Stehle 2000a, Kok 2002). Other activities, such as outdoor recreation and harvesting of NTFPs, are also permitted.

Table 1.1. Management and forest type classification for the southern Cape forests under South African National Parks jurisdiction

Forest type	Management class (ha)						
	Timber utilisation	Protection	Nature Reserves	Recreation	Research	Total	Percentage of total
vd-SF[1]		294.6	1380.6	40.7		1715.9	4.8
d-HF[2]		5962.7	2991.3	13.0	14.2	8981.2	25.1
mm-HF[3]	6891.5	4839.9	2766.8	37.0	205.5	14740.7	41.2
m-HF[4]	2384.6	806.1	909.4	36.3	176.0	4312.4	12.1
w-HF[5]		3643.5	1606.6		24.9	5275.0	14.7
vw-SF[6]		486.2	233.2		20.8	740.2	2.1
Total	9276.1	16033.0	9764.9	127.0	441.4	35765.4	100.0
% of Total	25.9	44.8	27.3	0.4	1.2	100.0	

[1] Very dry Scrub-Forest; [2] Dry High-Forest; [3] Medium-moist High-Forest; [4] Moist High-Forest; [5] Wet High-Forest; [6] Very wet Scrub-Forest

Management class B: Protection

These compartments are not suitable for timber utilisation because of ecological sensitivity and the nature of the growing stock. They are mainly of the drier and wetter forest types, but also include moist and medium-moist compartments that are too steep or are inaccessible. The harvesting of NTFPs, and outdoor recreation are permitted, provided their impacts are minimal.

Management class C: Nature Reserves
The aim with this class is to ensure that representative areas of all forest types are afforded enhanced conservation status and protection, with their legal status entrenched in the NFA. These areas serve as control for management activities in timber utilisation and other management categories; and offer opportunity for both the scientific study of undisturbed ecological processes and for outdoor recreation in natural, unspoilt environments. No harvesting of forest products is permitted.

Management class D: Recreation
These are compartments of any forest type where high-intensity outdoor recreation activities are concentrated, e.g. some picnic sites and view sites. Special steps are taken, where required, to reduce the impact of high visitor numbers; and harvesting forest products is usually avoided.

Management class E: Research
These are compartments of any forest type used exclusively for long-term ecological or silvicultural research. Monitoring and research, however, also take place in compartments of other management classes.

Apart from the harvesting of timber and NTFPs, management practices include invader plant control; forest rehabilitation; the management of cultural/historical assets, endangered plant species, and outdoor recreation facilities; as well as law enforcement and the maintenance of infrastructure.

Participatory forest management (PFM)

The NFA, which provides the legal basis for forest management in South Africa, recognises the links between communities, conservation and commercial forestry, and attempts to balance access to and use of forests with protection and sustainability. It allows access to forests for environmental, economic, educational, recreational, cultural, health and spiritual purposes, as well as greater participation of stakeholders in forest management.

The Department of Water Affairs and Forestry (DWAF) subsequently implemented a policy of PFM (DWAF undated), aimed at ensuring shared responsibility of forest management between stakeholders and forest management authorities, and a sustained flow of benefits to key stakeholders (DWAF 2005a). To realise this PFM forums were established on each forest estate in the southern Cape, with a specific focus on community development, and on ensuring the equitable distribution of benefits through Community Forestry Agreements (CFAs), Public Private Partnerships (PPPs), licences, etc. A concerted effort was made to identify stakeholder needs through a range of stakeholder workshops, and a number of potential projects (both ecotourism-based and of a consumptive resource-use nature) were identified by stakeholders for economic development (Anon. 2000).

The management system in place thus not only provides for sustainable timber harvesting and biodiversity conservation, but also ensures that local communities and other stakeholders have fair access to forest resources, recognising the importance of NTFPs.

1.4 THE CONCEPT OF SUSTAINABILITY

If forests, including commercial timber plantations, are to deliver their full potential to sustainable development, they must be considered from a broad, holistic viewpoint and managed accordingly (Harcharik 1997). This requires a conceptual framework that unites science with social consciousness (Harcharik 1997). Therefore, the concept of sustainable forest management includes "an environmental dimension that aims at the perpetual maintenance of the resource; an economic dimension that includes the production of commodities and services; and a social dimension that involves people in decision-making processes concerning forest management and the distribution of forest benefits" (Harcharik 1997). This is supported by Cunningham (2001), who argues that achieving sustainable use of resources is cross-disciplinary and should be addressed at the confluence of the social, economic and ecological spheres, within a political framework. According to Goodland *et al*. (1990), sustainability has to be pursued within three externalities, *viz*. human population pressure, national resource policies and sustainability of effective management institutions. Sustainability thus relies on favourable combinations of political, social, cultural, economic and ecological factors, and incentive systems which harness positive human motivations (IUCN 2000).

The concept of sustainability has been widely debated and various definitions exist (Harcharik 1997, Higman *et al*. 2000, IUCN 2000, Shackleton & Mander 2000, Wong *et al*. 2001, Dobbertin & Prüller 2002, Watts 2002). According to IUCN (2000), sustainable use could be defined as "the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations". Goodland *et al.* (1990) further expand and define the sustainable use of natural forest as use "which indefinitely maintains the forest substantially unimpaired both in the environmental services which it provide, and the biological quality". More explicitly, sustainable harvesting implies that "similar amounts and types of products (dimensions, quality, species) continue to be harvested at periodic intervals in perpetuity" (Seydack 2000a). Sustainable yield has been defined by Gilpin (1996) cited in Wong *et al*. (2001) as "living off the interest rather than the capital, of a resource base". IUCN (2000) formulated the following criterion for sustainability: "Provided biological diversity and key ecological functions are maintained, and the population of any target species remains above thresholds for long-term viability and at levels where it remains a significant resource for people, then the use can be regarded as generally sustainable".

The likelihood that a use will be sustainable into the future requires consideration of social and economic factors in addition to ecological factors (IUCN 2000). Harcharik (1997) considers the socio-cultural dimension the greatest challenge in modern sustainable forest management, as local communities (and other stakeholders) demand participation in forest management and how forest benefits are shared. Fabricius (2004) concludes that for sustainability we need to maintain the ecological capacity (i.e. the capacity of populations and ecosystems to renew themselves), the institutional capacity (i.e. the capacity to manage), as well as the adaptive capacity (i.e. the capacity of the socio-ecological system to adapt to change). As advocated in the Addis Abba principles for sustainable use of biodiversity, sustainability will be enhanced if provisions are made for mitigation, remediation, compensation and / or rehabilitation when biodiversity loss results from overuse (CBD 2004).

1.5 IMPORTANCE OF NON-TIMBER FOREST PRODUCTS

Although rural people have relied on NTFPs for centuries, the importance of such products in rural livelihoods and for economic development has only recently been fully appreciated by forest managers and decision makers (Falconer 1990, Godoy & Bawa 1993, Harcharik 1997, Mahapatra & Mitchell 1997, Hiremath 2004, Sheil & Liswanti 2006). Harvesting of NTFPs has been overshadowed by the demand for, and economic potential of timber (FAO 1993, Harcharik 1997, Prance 1998, Seydack & Vermeulen 2004, Adam *et al*. 2006). Management and yield regulation systems for timber harvesting, therefore, seldom made provision for the protection of utilisable NTFPs, or an integrated approach to accommodate such uses.

With a growing appreciation of the importance of NTFPs and their potential role in the socio-economic well-being of especially rural communities (Homma 1992, Peters 1996, FAO 1995b, 1997, Mahapatra & Mitchell 1997, Lawes *et al*. 2004a, Neumann & Hirsch 2000, Shackleton & Mander 2000, Shackleton *et al*. 2000, Van On *et al*. 2001, Walter 2001, Du Toit 2002, Chipeta & Kowero 2004, Clarke & Grundy 2004, Hiremath 2004, Shackleton & Shackleton 2004, Sunderland *et al*. 2004 p1, Ticktin 2004, Vedeld *et al*. 2004, Delang 2006, Sheil & Liswanti 2006, Dlamini 2007, Hembram & Hoover 2008), the harvesting of NTFPs is now recognised as an important aspect of the sustainable management of natural forests (Mahapatra & Mitchell 1997). This is further supported by an ecosystem approach with forest management (Covington & DeBano 1994, Gilmore 1997, Isik *et al*. 1997, Morris 1997, Phillips & Randolph 1998, Schlaepfer 1997, Schlaepfer & Elliott 2000). However, although the increasing discovery of new commercial uses for NTFPs is a major change in forestry in recent years (Harcharik 1997), others caution against the overestimation of potential economic and other benefits that can be derived from NTFPs and forests at large (Godoy & Bawa 1993, Pearce 1998, Neumann & Hirsch 2000, Marshall *et al*. 2003, Laws 2004, Kusters *et al*. 2006, Gubbi & MacMillan 2008).

The different uses and demand for NTFPs have been well researched and documented. Use categories include foods, medicine, handcrafts and household items, fuelwood, fencing and housing, as well as animal products (Cunningham *et al*. 1988, Prance 1998, Wong *et al*. 2001, Van Wyk 2002, Lawes *et al*. 2004a, Shackleton & Shackleton 2004, Dlamini 2007, Mudekwa 2007). The harvesting of medicinal plants is of particular importance, as the most valued traditional medicines come from natural forests (Cunningham *et al*. 1988, Mander 1998, Lawes *et al.* 2004a, Williams 2003). The value and importance of resources from woodlands and forest are difficult to quantify (Balance *et al*. 2001), but are significant, both at local and national level (Shackleton & Mander 2000, Lawes *et al*. 2004a, Shackleton 2004). The HIV/AIDS epidemic has resulted in changes in rural household livelihood strategies, further increasing the use of medicinal plants and other forest products (Gelman *et al*. 2005).

1.6 RESEARCH JUSTIFICATION

In South Africa, case studies in different forest areas have largely focused on user needs, especially in terms of species and products used (e.g. Everard & Hardy 1993, Evans *et al*. 1995, Park 1997, Ngulube 1999, Nomtsongwana 1999, Shackleton *et al*. 2000, Botha *et al*. 2001, Grundy & Cocks 2002, Mander 1998, Cruz 2002, Du Toit 2002, Dold & Cocks 2002, Pakia & Cooke 2003a,b, Williams 2003, Anon. 2004, Cocks 2006, Cawe & Geldenhuys 2007), and the impact of harvesting on the resource (Milton & Moll 1988, Obiri 1997, Cawe 1999, Obiri & Lawes 2000, Venter 2000, Geldenhuys 2004a, Cawe & Geldenhuys 2007). As harvesting of NTFPs has become increasingly commercialised, so has research into the commercial value of, especially, medicinal plants, user needs and demands on the resource (e.g. Shackleton & Shackleton 1997, Mander 1998, Steenkamp 1999, Botha *et al*. 2001, Dold & Cocks 2002, Williams 2003, Cocks *et al*. 2004, Shackleton & Campbell 2007).

Considering the importance of NTFPs, research aimed at the development of systems for their sustainable use has been widely neglected (Pearce 1998, Lawes & Obiri 2003, Endress *et al*. 2004, Pfab & Scholes 2004, Ticktin 2004, Bitariho *et al*. 2006), while there is generally a lack of basic ecological knowledge at both species and ecosystem level (Neumann & Hirsch 2000) to inform sustainable use. The result is that sustainable harvest strategies and management systems for NTFPs are largely still lacking, and overutilisation is of growing concern, locally and abroad (Cunningham 1993, 1997, Hall & Bawa 1993, Balick & Cox 1997, Ngulube 1999, Ouédraogo 2001, Walter 2001, Grace *et al*. 2002, Lawes *et al*. 2004b, Ticktin 2004). In South Africa, this is exemplified by the fact that species that are harvested for medicinal use e.g. *Siphonochilus aethiopicus*, *Warburgia salutaris*, *Ledobouria hypoxidoides* and *Mystacidium millaria* are fast becoming extinct in certain areas in the wild (Walter 2001). However, the need for applied research to inform harvest systems for NTFPs has been recognised by Cunningham (1985) and, for example, in more recent work by Venter (2000) on *Secamone* sp. used for basket baking, Geldenhuys (2004a) on medicinal bark harvesting, and McKean (2004) on the sustainable use of the palm *Hyphaene coriacea*. Research relating to the sustainable management of the resource has also been identified as priority in Southern and East Africa (Pérez *et al*. 1997).

The southern Cape forests have a history of continuous timber harvesting over two-and-a-half centuries, and are important in the economic development of the region (Heyl 1999, Seydack & Vermeulen 2004). Although *Rumohra adiantiformis* fern fronds have been harvested on a commercial scale for florist markets since the 1980s, the harvesting of NTFPs only gained momentum in recent years with the formulation of new forest policy and legislation that promote access to forest resources. With the recognition of traditional healthcare practices - Traditional Health Practitioners Act (Act No. 35 of 2004) (Richter 2003) - there is a growing demand for access to medicinal plants from natural forests in the southern Cape. This is exacerbated by a fast-changing population demography (Reuther & Gebhardt 2005, Anon. 2007) and more people who traditionally use forest resources moving into the region. Access is now provided for the conservative harvesting of medicinal plants such as *Bulbine latifolia* and is being considered for medicinal tree bark (Vermeulen 2005, Vermeulen & Geldenhuys 2004). Initiatives which contribute to the socio-economic development of communities through the harvesting of NTFPs have also been taken. For example, tree seedlings are harvested from timber utilisation areas for establishment in community nurseries; timber offcuts are made available for carving projects (Vermeulen & Van der Merwe 2004); and the fronds of the fern *Gleichenia polypodioides* (as well as *R. adiantiformis*) are harvested on a commercial scale.

While the focus in the past was on sustainable timber harvesting, the demand for NTFPs has brought new management challenges. Systems for sustainable harvesting and experience in addressing this in a scientifically sound manner are limited. In addition, harvesting of NTFPs needs to be integrated with the existing forest management system, in such a way that other management objectives are not compromised. These issues need to be addressed as a matter of urgency to ensure compliance with revised legislation in providing access to forest resources, while upholding the principles of multiple-use, sustainable forest management.

1.7 RESEARCH RATIONALE AND OBJECTIVES

The systematic process of sustained yield determination for forest products and the development of harvest systems and management strategies have been well documented (Van Daalen 1988a, FAO 1995b, Peters 1996, Geldenhuys 2000b, Cunningham 2001, DWAF 2005b,c). This systematic process, with the focus on ecological sustainability, entails (a) defining the product, (b) delineation of the resource area, studies on (c) population dynamics and (d) demography of the target species, as well as (e) continued monitoring and system refinement, once the harvest system has been developed and implemented (Figure 1.2). The **overall objective of this study** is to explore the science needed to underwrite management for the sustainable use of NTFPs by scrutinising this process and requirements for its successful implementation, while also considering the socio-economic and political dimensions of sustainable use. This is done using case studies of three different products harvested from natural forest in the southern Cape, *viz.* fern (*Rumohra adiantiformis*) fronds (leaves) as greenery in the florist industry, medicinal tree bark, and the corm (stem) of the geophyte *Bulbine latifolia* for medicinal use. The study was motivated by the **management objective** of ensuring optimum, sustainable harvesting of NTFPs from natural forests in the southern Cape under management of South African National Parks, with due consideration of other management objectives and land-uses.

1.7.1 Case study 1: *Rumohra adiantiformis* (seven-weeks fern)

The first NTFP formally harvested from natural forest in the southern Cape on an economic scale were fronds of the fern *R. adiantiformis* (seven-weeks fern) used in florist greenery. This continued for more than 20 years (Geldenhuys & Van der Merwe 1988, Geldenhuys

1994b, Kok 1998, 2004). The fronds have a long vase life and are extensively used in flower arrangements, both locally and abroad (Milton & Moll 1987, Geldenhuys & Van der Merwe 1988, Burrows 1990, Kok 2004). The economic importance of the species is reflected by the fact that when fern harvesting was at its peak, the income generated from *R. adiantiformis* exceeded that of indigenous timber. However, when commercial harvesting of *R. adiantiformis* on State Forest land started in 1982, little was known about its ecology, dynamics and productivity and applied research was initiated at different levels to advise managers on the sustainable harvesting of the species (Milton & Moll 1987, 1988, Milton 1987a, 1991, Geldenhuys & Van der Merwe 1988, 1994, Geldenhuys 1994b). The yield regulation system and harvest prescriptions that are currently in place for *R. adiantiformis* were developed over a period of almost two decades. An adaptive management approach based on long-term monitoring was followed (Geldenhuys 1994b) and provided an opportunity to evaluate and scrutinise the approach followed.

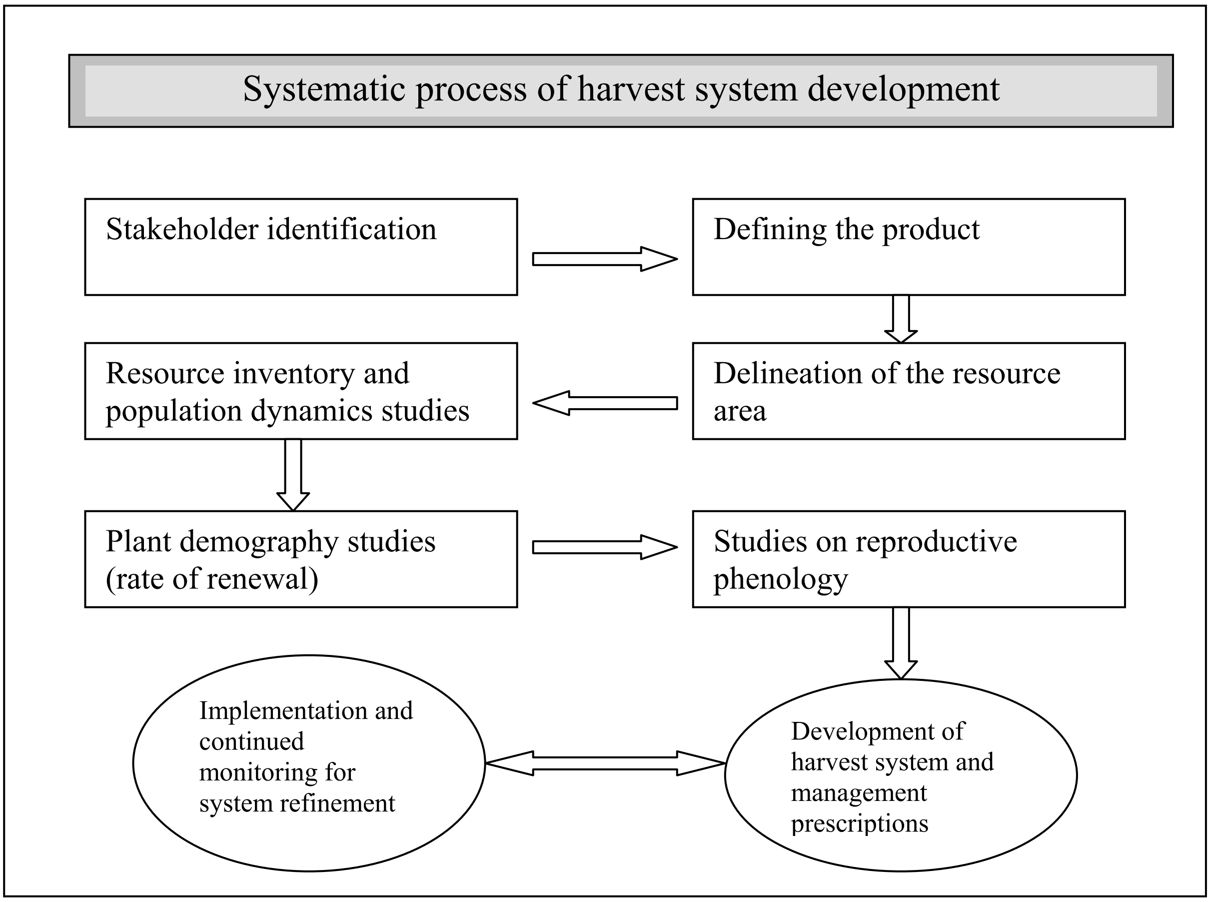


Figure 1.2. Flow diagram indicating the generic process for the development of harvest systems and management prescriptions for NTFPs (adapted from Peters 1996).

1.7.2 Case study 2: Medicinal bark

In South Africa millions of people, especially in rural areas, depend on forest and woodland resources for their daily livelihoods (Lawes *et al*. 2004a). The harvesting of medicinal plants poses a major management challenge as thousands of rural people still use traditional medicines, often in a highly commercialised environment. Of the important medicinal plant species on the market, the most valued come from natural forest (Lawes *et al*. 2004a), with bark being the plant part most commonly used (Mander 1998, Williams 2003). Considering the importance of the medicinal plant industry and the dependence of communities on traditional medicines, there is a growing concern about the uncontrolled, destructive harvesting of tree bark (Cunningham 1993, Mander 1998, Grace 2002, Grace *et al*. 2002, Stewart 2003, Guedje *et al*. 2007). There is also increasing demand in the southern Cape for medicinal bark, and numerous requests have been received to formally make this forest resource available to user groups. The medicinal bark study is an expansion of the approach with fern harvesting, with detailed studies on selected species to inform best practice for bark harvesting (Geldenhuys 2004b, FRP-DFID 2003). It should result in a more holistic approach with forest management and the incorporation of bark harvesting in management systems.

1.7.3 Case study 3: *Bulbine latifolia* for medicinal use

In addition to medicinal bark, there is a growing demand, especially from the Rastafarian community, to harvest the corm of the geophyte *Bulbine latifolia*, a species well represented on the fynbos/dry Scrub-Forest ecotone in the region. It is used to treat wounds, burns, convulsions, venereal diseases, diabetes, rheumatism, urinary complaints and blood disorders, and to quell vomiting and diarrhoea (Van Wyk *et al*. 1997). One result of this increased demand is illegal and uncontrolled harvesting (Vermeulen 2005). In the spirit of the PFM policy adopted for the management of natural forests in the southern Cape (DWAF undated, 2005a), an interim arrangement was made with the Rastafarian community for limited, controlled access while applied research is conducted to develop harvest prescriptions for its sustainable use (Vermeulen 2005). The process to develop harvest systems for NTFPs is taken forward and tested on *B. latifolia*, for which little information exists that could inform harvest prescriptions to ensure sustainable use.

Specific research objectives are as follows and are expanded on in terms of research questions and hypotheses in the relevant chapters:

- Specific objective 1: To review the adaptive management approach followed with the development of harvest prescriptions for *R. adiantiformis*, and to present lessons learnt of relevance to the development of harvest systems for NTFPs.
- Specific objective 2: To assess whether harvest prescriptions developed for *R. adiantiformis* provide for the sustainable harvesting of the species, and to review the importance of long-term monitoring in informing harvest prescriptions for NTFPs.
- Specific objective 3: To assess, through experimental research, the response of different species to bark stripping of relevance to the sustainable harvesting and management of medicinal bark species.
- Specific objective 4: To develop a conceptual framework and decision tree based on experimental research; to identify the most appropriate harvest options for the sustainable supply of medicinal bark for target species; and to guide the formulation of harvest prescriptions.
- Specific objective 5: To assess and demonstrate how sustainable medicinal bark harvesting could be integrated with the existing forest management system in the southern Cape, with due consideration of other management objectives and land-uses.
- Specific objective 6: To gain a better understanding, through applied research, of the habitat and distribution, community association and population dynamics of *B. latifolia* and their relevance to the sustainable harvesting of the species in the southern Cape.

- Specific objective 7: To gain insight, through applied research and monitoring, into the demography and reproductive phenology of *B. latifolia*, to inform the development of a harvest system and management prescriptions for the species.
- Specific objective 8: To develop and present, based on applied research results, a management system for the sustainable harvesting of *B. latifolia* from natural forests in the southern Cape, and a planning approach for its successful implementation.

1.8 THESIS STRUCTURE

The thesis has been divided into eight chapters: an introductory chapter; two chapters each dealing with the three case studies (*R. adiantiformis*, medicinal bark and *B. latifolia*); and a concluding chapter (Figure 1.3).

In Chapter 1, the current chapter, global trends in forest management as well as the revision of forest policy and legislation in South Africa that impacts on resource use are presented as an introduction to the chapters that follow. Specific reference is made to the growing appreciation of NTFPs and the role they could play in the socio-economic wellbeing of especially rural communities, concerns of their overutilisation, and the importance of developing harvest systems that would ensure sustainability, that justify this study. The characteristics of the southern Cape forests and the current management system are described to provide the background for exploring management options for harvesting the different NTFPs dealt with in this study, and how these could be integrated with the forest management system. The research rationale is discussed and broad study objectives presented.

Specific objectives 1 and 2 are addressed in Chapters 2 and 3 respectively. The process of developing and implementing a sustainable harvest system for *R. adiantiformis* through an adaptive management approach is described and scrutinised in Chapter 2. Long-term, goal-orientated monitoring (both in terms of expanding baseline data on population dynamics and demography of the species and the impact of harvesting on the resource) formed an integral part of fern-picking operations. Chapter 3 is an overview of the monitoring programme. Results are presented, and their relevance and contribution to the optimum, sustainable harvesting of *R. adiantiformis* are discussed.

Chapters 4 and 5 deal with sustainable harvesting of tree bark for medicinal use, addressing Specific objectives 3, 4 and 5. There is a good resource base for bark harvesting from the southern Cape forests if this can be done in a sustainable and controlled way. To ensure sustainability, harvest prescriptions need to be developed and best practices formulated for bark stripping. This is best achieved through controlled, experimental harvesting and long-term monitoring of tree response to bark stripping. Lessons learnt from experimental bark harvesting of the high-demand species *Ocotea bullata, Rapanea melanophloeos* and *Curtisia dentata* – initially part of the Innovation Fund Project: Commercial Products from the Wild (Geldenhuys 2004b, Vermeulen & Geldenhuys 2004) – provided some insight into the differential response of tree species to bark stripping, and best practices for experimental research (Vermeulen & Geldenhuys 2004). The original experimental layout and research methodology were revised and the project expanded to include *Ilex mitis*, *Rhus chirindensis* and *Prunus africana* (Vermeulen & Geldenhuys 2004). Results of the two studies are presented and discussed in Chapter 4.

<table>
<tr><td colspan="2">THE SUSTAINABLE HARVESTING OF NON-TIMBER FOREST PRODUCTS FROM NATURAL FORESTS IN THE SOUTHERN CAPE, SOUTH AFRICA: DEVELOPMENT OF HARVEST SYSTEMS AND MANAGEMENT PRESCRIPTIONS</td></tr>
<tr><td colspan="2">Chapter 1. General introduction and research justification

Overall study objective: To explore the science needed to underwrite management for the sustainable use of NTFPs by scrutinising the systematic process for the development of harvest systems and the requirements for its successful implementation, also considering the socio-economic and political dimensions of sustainable use.
Management objective: Ensuring optimum, sustainable harvesting of NTFPs from natural forests in the southern Cape, with due consideration of other management objectives and land-uses.</td></tr>
<tr><td colspan="2">CASE STUDY 1. RUMOHRA ADIANTIFORMIS FERN FRONDS</td></tr>
<tr><td>Chapter 2. Twenty years of harvesting of the fern Rumohra adiantiformis from natural forests in the southern Cape: Sustainable use through adaptive management</td><td>Chapter 3. Twenty years of harvesting of the fern Rumohra adiantiformis from natural forests in the southern Cape: The importance of long-term monitoring</td></tr>
<tr><td colspan="2">Specific objective 1: To review the adaptive management approach followed with the development of harvest prescriptions for R. adiantiformis, and to present lessons learnt of relevance to the development of harvest systems for NTFPs.
Specific objective 2: To assess whether harvest prescriptions developed for R. adiantiformis provide for the sustainable harvesting of the species, and to review the importance of long-term monitoring in informing harvest prescriptions for NTFPs.</td></tr>
<tr><td colspan="2">CASE STUDY 2. MEDICINAL TREE BARK</td></tr>
<tr><td>Chapter 4. Response of selected tree species to strip harvesting of medicinal bark from natural forest in the southern Cape</td><td>Chapter 5. Management options and potential for medicinal harvesting from selected forest species in the southern Cape</td></tr>
<tr><td colspan="2">Specific objective 3: To assess, through experimental research, the response of different species to bark stripping of relevance to the sustainable harvesting and management of medicinal bark species.
Specific objective 4: To develop a conceptual framework and decision tree based on experimental research; to identify the most appropriate harvest options for the sustainable supply of medicinal bark for target species; and to guide the formulation of harvest prescriptions.
Specific objective 5: To assess and demonstrate how sustainable medicinal bark harvesting could be integrated with the existing forest management system in the southern Cape, with due consideration of other management objectives and land-uses.</td></tr>
<tr><td colspan="2">CASE STUDY 3. BULBINE LATIFOLIA FOR MEDICINAL USE</td></tr>
<tr><td>Chapter 6. The distribution, population structure and community association of Bulbine latifolia (L.F.) Schult. & Schult.F. harvested for medicinal use form natural forest in the southern Cape</td><td>Chapter 7. The demography and reproductive phenology of Bulbine latifolia (L.F.) Schult. & Schult.F. harvested for medicinal use from natural forest in the southern Cape, and guidelines for sustainable harvesting</td></tr>
<tr><td colspan="2">Specific objective 6: To gain a better understanding, through applied research, of the habitat and distribution, community association and population dynamics of B. latifolia and their relevance to the sustainable harvesting of the species in the southern Cape.
Specific objective 7: To gain insight, through applied research and monitoring, into the demography and reproductive phenology of B. latifolia, to inform the development of a harvest system and management prescriptions for the species.
Specific objective 8: To develop and present, based on applied research results, a management system for the sustainable harvesting of B. latifolia from natural forests in the southern Cape, and a planning approach for its successful implementation.</td></tr>
<tr><td colspan="2">Chapter 8. Synthesis, conclusion and recommendations for the development and implementation of harvest systems for non-timber forest products</td></tr>
</table>

Figure 1.3. Schematic overview of the thesis chapters and study objectives.

In Chapter 5, the demand for medicinal bark, especially from natural forest species in the southern Cape, is assessed. This is essential to address uncontrolled harvesting and to determine how best to make medicinal bark available to users in a way that would meet the demand of local stakeholders while also protecting the resource. This was achieved by conducting a literature survey and by scrutinising records of illegal bark harvesting in the region, as well as through interviews with traditional healers. The response of a species to bark stripping, especially in terms of bark regrowth and susceptibility to fungal and insect attack, determines management options for sustainable bark harvesting. A conceptual framework and procedure to match species with harvest options and prescriptions, based on tree response to bark stripping, are presented. Management options and potential for the selected species are discussed, and ways are explored to integrated sustainable bark harvesting with the existing forest management system applicable to natural forests in the southern Cape under management of South African National Parks (SANParks).

Chapters 6 and 7 address Specific objectives 6, 7 and 8, i.e. the results of research into the community association, population dynamics, demography and reproduction phenology of *B. latifolia* as a methodology to develop harvest prescriptions. Management options and the resource potential for sustainable harvesting of the species from natural forest in the southern Cape are also explored.

In Chapter 8, the concluding chapter, the study approach followed and the achievement of specific and overall study objectives are reflected on. The process to develop systems and management prescriptions for the sustainable harvesting of NTFPs, based on lessons learnt from the three case studies, is discussed, and requirements and restrictions for its successful implementation are elaborated on. This includes aspects of ecological, social and economic sustainability, with due consideration of management constraints within a changing socio-political environment in South Africa, and the integration of NTFP harvesting with traditional practices for sustainable forest management.

1.9 CONCLUDING REMARKS

The value and importance of NTFPs is widely recognised, as is the need to develop harvest systems for sustainable use that can be integrated with forest management systems dominated by timber harvesting. Concerns, however, are growing regarding the overutilisation of forest resources, including NTFPs.

Research into the sustainable harvesting of NTFPs is complex, considering the wide range of forest species and products harvested and the ever-changing socio-political sphere within which this needs to be addressed. The approach adopted with this thesis, using case studies of different species and products, should provide good insight into the complexities of developing harvest prescriptions for NTFPs, the input and expertise required to conduct applied research and challenges with implementing harvest systems and their integration with existing forest management systems. Furthermore, the case studies selected would allow for interrogation of the adaptive management approach often advocated for the sustainable management of natural resources. This is especially important considering the long-term nature of the development of harvest systems for resource use, the long-term monitoring required to support the adaptive management approach, and socio-economic circumstances that often do not allow for the formulation of scientifically based harvest prescriptions before access to resources is granted.

The research approach and scope of the study not only provide for scientific, ecological research of the forest resource, but also put strong emphasis on the implementation of harvest systems and integration thereof into the existing forest management system in the southern Cape. The research is taken to its conclusion to be reflected in future forest management plans for the region.

CHAPTER 2: TWENTY YEARS OF HARVESTING OF THE FERN *Rumohra adiantiformis* FROM NATURAL FORESTS IN THE SOUTHERN CAPE: SUSTAINABLE USE THROUGH ADAPTIVE MANAGEMENT

2.1 INTRODUCTION

Until fairly recently the importance of non-timber forest products (NTFPs) in rural livelihoods and for economic development was not fully appreciated by resource managers and decision makers. In many areas it was overshadowed by the demand for and economic potential of timber (FAO 1993, Harcharik 1997, Prance 1998, Adam *et al*. 2006). Management and yield regulation systems for timber harvesting seldom make provision for the protection of utilisable NTFPs or an integrated approach to accommodate such uses.

The southern Cape forests have a rich history of timber harvesting (Seydack & Vermeulen 2004) and are of major economic benefit to the region (Heyl 1999). In recent years, non-consumptive use in the form of forest-based ecotourism has become increasingly important, as has the need for NTFPs, especially plant products for medicinal use. The fronds (leaves) of *Rumohra adiantiformis* (seven-weeks fern) have, however, been harvested on an economic scale since 1982 (Geldenhuys & Van der Merwe 1988, Geldenhuys 1994b, Kok 1998, 2004). They have a long vase life and are extensively used in flower arrangements, both locally and abroad (Geldenhuys & Van der Merwe 1988, Milton & Moll 1987, Burrows 1990, Kok 2004). The approach of allowing controlled harvesting, while applied research is conducted to develop scientifically sound harvest prescriptions, has been cited as a good example of the adaptive management concept (Geldenhuys 1998).

2.2 STUDY OBJECTIVES

In this chapter, Specific study objective 1 is addressed, namely "to review the adaptive management approach followed with the development of harvest prescriptions for *R. adiantiformis*, and to present lessons learnt of relevance to the development of harvest systems for NTFPs". The process followed with the development of harvest prescriptions for the species is scrutinised; a historical overview of *R. adiantiformis* harvesting from the natural forests in the region is provided; and research results that informed harvest prescriptions are presented and discussed within the context of the adaptive management approach.

Associated research questions:

- How did applied research inform the development, implementation and refinement of harvest prescriptions for *R. adiantiformis*?
- Was the adaptive management approach effective in ensuring sustainable harvesting and what lessons were learnt for wider application?
- What is the economic importance of the commercial harvesting of *R. adiantiformis* as NTFP in the region, compared to commercial timber?
- How did fern frond yield and economic revenue vary over the two decades of harvesting?

2.3 THE SPECIES AND HISTORICAL BACKGROUND TO FERN HARVESTING

Rumohra adiantiformis (G. Forst.) Ching (Family: Aspidiaceae) is described by Jacobsen (1983) and Burrows (1990). It has a creeping rhizome, densely clothed in papery, rusty-red scales and is up to 25 mm in diameter with spaced, coriaceous, erect fronds. It is a widespread, polymorphic fern species occurring from Polynesia through Australasia and some Indian Ocean islands to southern Africa, across the Atlantic to South and Central America. In southern Africa it occurs in forests extending from the southwestern Cape, through the Eastern Cape and KwaZulu-Natal to the mistbelt forests along the north-eastern escarpment and Zimbabwe. Despite its wide distribution, viable populations for large-scale commercial harvesting are confined to the southern Cape, the centre of its distribution in southern Africa.

Harvesting of fronds of *R. adiantiformis* – a protected species in terms of the Cape Provincial Ordinance (No. 19 of 1974) – from natural forests in the southern Cape started as far back as 1970 when private landowners were issued permits to harvest small quantities of ferns on their land for the local flower market (Milton & Moll 1988) (Appendix 1). However, these suppliers could not meet the increasing demand for fronds and, undeterred by prosecution and fines because of the economic value of the product, illegal harvesting on State Forest land escalated (Geldenhuys & Van der Merwe 1986, 1988).

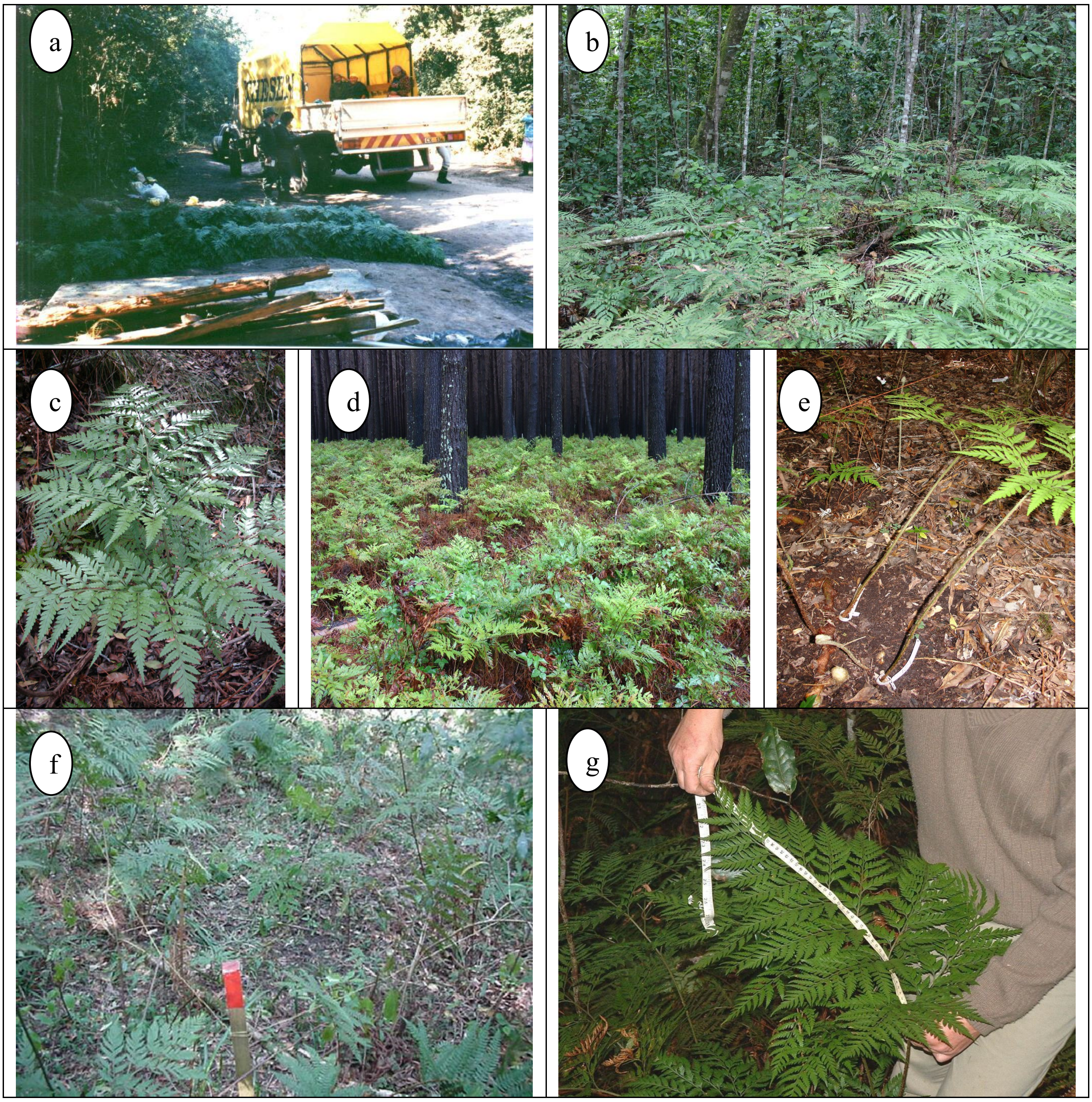
In 1982, approximately 4 000 ha of indigenous State Forest land was released for commercial harvesting of *R. adiantiformis* for the local and European markets, and tenders were invited for harvesting for a one-year period (Geldenhuys & Van der Merwe 1988, Milton & Moll 1988) (Plate 2.1a, Appendix 1). The following year the tender was renewed for a further two years and the harvest area expanded to 7 000 ha (Geldenhuys & Van der Merwe 1988) on the argument that a larger area would contribute to the control of illegal picking, thereby protecting the resource area (Geldenhuys & Van der Merwe 1986). The rapid growth of the industry and the employment opportunities it created resulted in major economic benefits for the region (Milton & Moll 1988). Due to growing demand and the dwindling supply of fronds from harvest areas, the Department of Forestry came under pressure to open up additional areas (Milton & Moll 1988) and, by 1989, 20 000 ha of State Forest land was subjected to commercial fern harvesting. As applied research results became available, harvest prescriptions were developed and refined through an adaptive management approach.

However, the enormous potential of *R. adiantiformis* as a source of foreign revenue and the low productivity of natural forest resulted in suppliers looking for alternative sources (Kok 2004). By 1998, less than 25% of fronds exported came from State Forest forests; the bulk were grown and harvested from commercial pine plantations and in shade houses (Kok 1998). This resulted in a waning interest in tenders for fern harvesting in natural forest, with the last tender allocated in the Tsitsikamma in 2001. In 2002, a small fern-harvesting community project was initiated as part of the policy of participatory forest management (PFM) and the equitable distribution of benefits from forest areas (Vermeulen *et al*. 2005). The project, however, proved not to be economically viable and has since been phased out.

2.4 THE ADAPTIVE MANAGEMENT APPROACH

To optimally reap the benefits from natural resources, resource use should be ecologically, economically and socially sustainable. To achieve this, harvest systems must be developed, taking into consideration ecological constraints and resource-use potential, as well as market

Plate 2.1. (a) Fern fronds harvested from natural forest; (b) *Rumohra adiantiformis* fern stand with mature forest in the background; (c) a pickable fern frond; (d) ferns commercially grown under pine plantations; (e), (f) and (g) long-term population dynamics monitoring.



demands and social dynamics. However, the pressing demand for access to forest resources for consumptive use (Lawes *et al*. 2004a, Shackleton & Shackleton 2004) often does not allow for scientifically sound harvest systems to be developed before such access is permitted. To delay access is often counter-productive, and could have serious socio-economic implications, especially for poverty-stricken rural communities dependent on natural resources for their daily livelihood. This could lead to indiscriminate, uncontrolled, destructive harvesting, and management conflict. The solution therefore is an adaptive management approach whereby conservative, interim harvest prescriptions based on existing knowledge are implemented together with applied research and monitoring.

Adaptive management is defined as a systematic process for continually improving management policies and practices by learning from the outcomes of operational programmes (Anon. 1999). In terms of resource use, harvest prescriptions are refined as research results become available. The concept of adaptive management has been widely accepted by forest managers since its development in the early 1970s (Nyberg & Taylor 1995, Oglethorpe 2002, Singh & Nayak 2003, Udell 2003, CBD 2004, Zhou *et al*. 2008). It has been advocated as a management approach for the sustainable harvesting of forest produce from natural forest in the Eastern Cape where many communities are dependent on forests for their daily livelihood but where information on the resource is limited (Michell 2000).

When commercial harvesting of *R. adiantiformis* on State Forest land started in 1982, little was known about the species' ecology, dynamics and productivity. Initially, fern populations were picked every five weeks with no restrictions on the number of fronds harvested. State-funded research was initiated at different levels to advise managers on sustainable harvesting (Geldenhuys & Van der Merwe 1986) and, concurrently, the industry (fern-harvesting contractors) commissioned additional research and studies on the ecology and dynamics of the species (Dean 1984 cited in Geldenhuys & Van der Merwe 1986, Milton & Moll 1987). As research results became available, harvest prescriptions for the species were refined.

2.5 APPLIED RESEARCH AND HARVEST SYSTEM DEVELOPMENT

The generic process of sustained yield determination for forest products and the development of harvest prescriptions have been well documented (Van Daalen 1988a, FAO 1995b, Peters 1996, Geldenhuys 2000b, Grundy 2000, Cunningham 2001, DWAF 2005c; see Chapter 1). This systematic process, with the focus on ecological sustainability, entails:

- defining the product;
- delineating the potential resource area following studies on the habitat and distribution of the target species; and
- studying the population dynamics, demography and reproductive phenology of the species, to inform harvest prescriptions.

When the harvesting of *R. adiantiformis* commenced, research focused on these aspects. The first preliminary results (Milton & Moll 1987) were presented at *Rumohra* Research Committee meetings in 1984 and 1985 (Stehle 1987), followed by formal reports and publications *viz*. Geldenhuys & Van der Merwe (1986, 1988, 1994), Milton (1987a,b, 1991) and Milton & Moll (1987, 1988).

The section that follows is a summary and review of research results as they became available and how these impacted on the formulation of management prescriptions (see Appendix 1) through a process of adaptive management.

2.5.1 Defining the product

The first step towards optimum, sustainable use is to define the product, taking into consideration user needs and market demands (Van Daalen 1988a, Geldenhuys 2000b, Peters 1996, Cunningham 2001). The industry dictates the minimum requirements for commercial harvesting. Only fully matured, hardened fronds without necroses or other blemishes are considered utilisable for the florist trade, with frond size, form and colour other important criteria for product quality (Geldenhuys & Van der Merwe 1988). Initially this was not clearly defined and fern pickers were allowed to harvest all fern fronds they considered pickable, which resulted in indiscriminate harvesting and wastage, and made proper management control difficult.

Subsequently, in consultation with the industry, a pickable fern frond was defined as "a normally shaped mature fern leaf, longer than 250 mm, measured from the base of the leaf to the apex of the leaf, with not more than 10% of the surface of the leaf damaged through discolouration, wilting or any other defect" (Plate 2.1 c). This clear definition proved to be an important management tool in controlling picking operations and enforcing harvest prescriptions (see Chapter 3), not only to prevent overpicking, but also to ensure that underpicking by the successful tenderer and subsequent financial losses to the State did not occur (Baard & Wannenburg 1998). However, declining interest in the available fern tenders on State Forest land and the implementation of a small-scale, community fern-harvesting project (Vermeulen *et al*. 2005) demanded that a pickable frond be redefined to accommodate changes in market demands. Currently (2008), fronds longer than 40 cm are preferred.

2.5.2 Habitat, community association and delineation of harvest area

To identify and accurately map the potential harvest area for a species, knowledge of its habitat and distribution and insight into its community association are required. When fern harvesting commenced in 1982, only basic information for *R. adiantiformis* was available. The species has a patchy distribution (Milton & Moll 1987) which made the accurate mapping of the potential harvest area difficult. On the coast it is found on the plateau and southern mountain slopes while limited to kloofs and river valleys at higher altitudes (Milton & Moll 1987); it occurs sporadically in wet fynbos and in scrub forest on dunes and ridges (Milton & Moll 1987); it grows densely on moist, well-drained sites such as near ridgetops or hill crests on southern slopes, and close to streams lower down (Geldenhuys & Van der Merwe 1988); in wet and moist High-Forest it occurs in fairly dense clusters (Von Breitenbach 1974) where it is often associated with *Ocotea bullata* and *Platylophus trifoliatus* (Van Dijk 1987, Geldenhuys & Van der Merwe 1988). Based on the then existing forest type classification (Von Breitenbach 1968a, 1974, Seydack *et al*. 1982), and tapping into local knowledge, a forest area of 4 000 ha with potential for commercial fern harvesting was identified and mapped, and eventually extended to approximately 20 000 ha.

A detailed phytosociological study of the forest vegetation of the region was only concluded in 1993 with a description of both tree and ground flora communities (Geldenhuys 1993). *Rumohra adiantiformis* was found to be an important component in four ground flora communities in the area, described in detail by Geldenhuys (1993). It occurs in scarp, platform and mountain forests. On the scarp it is found in scrub forest communities and is associated with species such as *Putterlickia pyracantha, Secamone alpinii*, *Dioscorea mundtii* and *Ornithogalum longibracteatum* in the understorey, and *Euclea schimperi*, *Sideroxylon inerme* and *Cassine aethiopica* in the higher strata. On the platform, it occurs in tall to high forest, associated with understorey species such as *Gerbera cordata*, *Galopina circaeoides*, *Angraecum pusillum* and *Protasparagus setaceus*. Depending on community, tree species include *Pterocelastrus tricuspidatus*, *Olea capensis* subsp. *macrocarpa*, *Cassine papillosa*, *Podocarpus latifolius*, *Psydrax obovata*, as well as *Olea capensis* subsp. *capensis* and *Platylophus trifoliatus*.

What proved to be of major significance was that *R. adiantiformis* is frequently associated with specific understorey communities in tall to high, moist regrowth forest, on a variety of sites in mountain, foothill, platform and coastal scrub situations. It grows with species such as *Ficinia complex*, *Ehrharta calycina* and *Blechnum punctulatum*. Dominant tree species include *Pterocelastrus tricuspidatus*, *Olea capensis capensis*, *Platylophus trifoliatus* and *Podocarpus latifolius.* Charcoal was collected in many stands of the regrowth forest communities, indicating that these forests are in a successional stage of development (Geldenhuys 1994b) (Plate 2.1b). The association of *R. adiantiformis* with regrowth forest following disturbance was also confirmed by Geldenhuys & Van der Merwe (1994), studying the relationship between fern variables and tree stands. This is further supported by the fact that sites where *R. adiantiformis* is abundant are also sites prone to disturbance by berg wind fires and lightning (Geldenhuys 1994a).

2.5.3 Population structure

Knowledge of the population structure together with demography of the target species is critical in the development of a system for sustainable use and in assessing potential yield (Van Daalen 1988a, Peters 1996, Cunningham 2001). For *R. adiantiformis*, population structure is determined by site and season (Geldenhuys & Van der Merwe 1988), but is also strongly influenced by the characteristics of the shrub and tree layers. Dense fern stands are usually associated with a sparse to absent shrub understorey and a relatively open tree canopy (Geldenhuys & Van der Merwe 1988), while an inverse relationship exists between fern abundance and tree canopy height (Milton & Moll 1987). Geldenhuys & Van der Merwe (1994) found no clear relationship between tree communities and fern stand structure and argue that the density of *R. adiantiformis* represents a phase in the regrowth of different forest communities after relatively recent disturbance (50 to 100 years).

The density of stands varies greatly within and between stands (Milton & Moll 1987, Geldenhuys & Van der Merwe 1988, 1994). Plant density ranges between 0 and 14 plants m^{-2} with an average of 4.0 plants m^{-2}. Average frond density (all fronds) varies between 3.8 and 8.0 fronds m^{-2}, and 1.2 and 7.3 fronds m^{-2} for mature, harvestable fronds, with the densest fern stands on footslopes. The number of fronds per plant for *R. adiantiformis*, which proved to be an important variable in the formulation of harvest prescriptions for the species, varies between 2.40 ± 0.14 and 3.1 ± 0.2, depending on site and season.

Frond size is affected by various factors (Milton & Moll 1987, Geldenhuys & Van der Merwe 1988, 1994). Frond (lamina) length is correlated with rainfall in winter and spring, is affected by site factors and also varies considerably within a stand. Plants in stands of average density tend to have larger fronds than those in either very high or low density stands. Larger fronds are produced by buds appearing during winter and spring. An average frond length of 47.8 ± 1.6 cm was recorded for floodplain populations compared to 26.9 ± 1.6 cm for ridgetop populations. Stalk length varies between 63 and 80 cm, depending on site. With a positive relationship between stalk length and frond size (lamina length), stalk length could be used as an indicator of harvest impact or the production potential of a site. Geldenhuys & Van der Merwe (1988) recommended that an area be withdrawn from harvesting if the average frond stalk length is less than 40 cm, i.e. an average lamina length of healthy mature fronds of 25 cm (which is the minimum frond length for harvesting).

2.5.4 Plant demography and reproductive phenology

Apart from population structure, information on frond development, rate of production and frond longevity, and how it is affected by season was essential in refining harvest prescriptions, especially as regards the harvest cycle. Furthermore, by studying reproductive phenology, the optimum harvest season or periods sensitive to harvesting could be identified. This required medium- to long-term monitoring.

An annual frond production of 1.3 ± 0.1 (Milton 1987b) and 1 to 3 fronds per plant (Milton & Moll 1987) has been documented. In terms of bud production, Geldenhuys & Van der Merwe (1994) reported a rate of 1.8 buds/m^2/year, with an eventual mature (harvestable) frond production of 1.6 fronds/m^2/year. The time of bud formation, number of buds formed and rate of bud growth to maturity vary seasonally (Geldenhuys & Van der Merwe 1988). Geldenhuys & Van der Merwe (1994) found that bud initiation starts during July and August, although it could occur earlier (Geldenhuys & Van der Merwe 1988). Bud numbers peak between September and November (Geldenhuys & Van der Merwe 1988, 1994). Considering the above, the period January to March i.e. before the onset of bud formation, could be regarded as the least sensitive to harvesting, with September to November the most. Milton (1987b) postulated that winter bud formation and the spring and summer peak in frond expansion are triggered by temperature, but the time and quantity of rain in a particular year could affect frond size.

The length of the immature stage (bud, unfolding and young stages) depends on the season of bud initiation. The entire immature stage averages 15.3 weeks, ranging from 8.5 weeks for September buds to 24.8 weeks for buds initiated during April (Geldenhuys & Van der Merwe 1988). Consistent with seasonal variation, this is slightly shorter than the 23 to 32 weeks recorded by Milton (1987b) as the total age of mature fronds. From November, mature fronds increase in proportion to dominate from January to March (Geldenhuys & Van der Merwe 1988), with a peak between December and January and the lowest number in July (Geldenhuys & Van der Merwe 1994). This is of critical importance when assessing the potential yields and scheduling harvest operations. Fronds remain largely unblemished, and thus harvestable, for 40 to 52 weeks after reaching maturity before developing necrotic spots, and then remain partially green for more than a year before withering completely (Milton 1987b).

Spore production is related to frond size, with plants with fronds > 40 cm in length accounting for more than 60% of spore production (Milton & Moll 1987). The creeping tip of a mature rhizome extends at 10.9 ± 1.6 cm/annum, multiplying occasionally by lateral branching (Milton & Moll 1987).

2.5.5 Impact of harvesting

Assessing the impact of harvesting on individual plants and the resource as a whole (Cunningham 2001) is an essential part of developing a harvest system or refining harvest prescriptions. With a huge industry dependent on the *R. adiantiformis* resource, research into the impact of frond harvesting began as a matter of priority after commercial harvesting commenced. Experimental harvesting at different intensities and schedules were subsequently initiated by Geldenhuys & Van der Merwe (1986, 1988), Milton (1987a,b, 1991) and Milton & Moll (1987).

The biggest negative impact of overharvesting is on frond size. Both Geldenhuys & Van der Merwe (1988) and Milton & Moll (1987) recorded a decline in mature frond size for a harvest frequency of less than six months. In terms of harvest intensity, both partial and total defoliation (12-month harvest cycle) could result in a significant decline in the size of fronds produced after harvesting (Milton 1987a, 1991). Geldenhuys & Van der Merwe (1988) recorded a decline in frond size to 51% of the control for five-monthly harvesting, while Milton (1987a) found that fronds produced after total defoliation were only 40% as large as the fronds they replaced. The reduced size was also associated with malformed lamina and leaflets (Geldenhuys & Van der Merwe 1988).

Apart from the reduction in frond size, harvesting could also impact on plant survival, rhizome growth and phenological events. Milton (1987b) found that continual total defoliation of *R. adiantiformis* resulted in a mortality of 55% of the plants, while a decrease in rhizome diameter was recorded following two consecutive years of total defoliation (Milton 1991). Also, the harvesting of all utilisable fern fronds at monthly and five-monthly intervals (over a three-year period) changed the timing of bud initiation and reduced the density of buds and mature fronds (Geldenhuys & Van der Merwe 1986, 1988). Spore production and sporogensis are also reduced by overutilisation (Milton 1987b).

Plant recovery after total defoliation is slow. Milton (1987a) found no significant increase in the average length of fronds on defoliated plants (two cycles; nine-month interval) during a 22-month rest period. Although the number of fronds on defoliated plants returned to the pre-harvest level or even increased, frond size and quality often remained below that required for the export flower market (Milton & Moll 1987, Milton 1987b).

Concerns were raised that the reduction in fern cover through harvesting could increase competition by woody plants in the understorey and suppress the ability of fern populations to recover (Milton & Moll 1988, Geldenhuys 1994b), but Geldenhuys & Van der Merwe (1994) found no significant difference in the growth rate of tree seedlings for harvested and unharvested fern stands. It was also postulated that the decline in frond production after intensive harvesting resulted from the depletion of phosphorus and potassium resources stored in the plant (Geldenhuys & Van der Merwe 1986). The complexities of nutrient cycling and its relevance to resource use are reflected in the significant spatio-temporal variation in phosphorus and nitrogen levels stored in mature fronds reported by Geldenhuys & Van der Merwe (1994). They suggested that future research in this field focuses on the nutrient levels in the humus layer and A-horizon, as this layer is the nutrient source for the fern.

Geldenhuys & Van der Merwe (1994) concluded that at the existing harvest intensity (50% of fronds/plant on 15-month rotation) frond density is not negatively affected by harvesting; neither is the production of buds and mature fronds. This is largely supported by Kok (1998).

2.6 FERN YIELD AND ECONOMICS

When fern-picking areas on State Forest land in the Southern Cape were first opened up for commercial harvesting, large numbers of ferns were harvested unsustainably due to the lack of scientifically based harvest prescriptions. For example, in the 1983/84 financial year 231 091 bundles of fern fronds (50 fronds per bundle) were harvested from an area of about 7 000 ha (Unpublished Departmental data). As stricter harvest prescriptions were implemented, the yield gradually declined (Figure 2.1) despite the increase in harvest area (Appendix 1). This can largely be attributed to the impact of the initial overharvesting and an increasingly longer harvest cycle implemented as research results became available (Geldenhuys & Van der Merwe 1988, 1994, Milton & Moll 1988). From 1992/93, harvest numbers stabilised somewhat after harvest prescriptions were fixed and a harvest cycle of 15 months was implemented (Figure 2.1, Appendix 1). However, numbers continued to decline into the late 1990s as alternative fern sources were developed and market demands shifted towards larger fronds, resulting in a waning interest in fern tenders (Kok 1998, 2004, Vermeulen *et al*. 2005).

Despite this decline, up until 1991/92 there was a steady increase in the income generated (Figure 2.1), indicating the value of and demand for the product. For example, in 1991/92, 3.95 million fern fronds were harvested in the Southern Cape (fronds harvested in the Tsitsikamma region excluded), generating an income of more than R900 000 (Unpublished Departmental data). By 2001/02, twenty years after natural forest on State land was opened up for commercial fern harvesting, income was negligible. The last formal commercial tender was awarded in 1999/2000, and since then only a small number of ferns have been harvested as part of a community development project (Vermeulen *et al*. 2005).

The economic importance of *R. adiantiformis* harvesting over the years, compared to indigenous timber, is reflected in Figure 2.2. For the periods 1988/89 and 1994/95, when fern harvesting was at its peak, income from harvesting exceeded that of indigenous timber, contributing between 51.1 and 68.6% of the income generated from consumptive resource use from natural forests in the Southern Cape (excluding the Australian blackwood, *Acacia melanoxylon*). The harvesting of fern fronds thus not only contributed to economic development in the region (Kok 2004), but was also an important source of income to the Forestry Department. By 1998, though, less than 25% of fronds exported came from natural forest on State land – the bulk was grown and harvested on commercial pine plantations and in shade houses (Kok 1998) (Plate 2.1d).

2.7 DISCUSSION

The primary purpose of this chapter was to provide an overview of *R. adiantiformis* frond harvesting over a period of almost 20 years and to review the process of developing harvest prescriptions for the species through an adaptive management approach. The findings demonstrate the socio-economic importance of *R. adiantiformis* as NTFP for the region, especially when harvesting was at its peak, and that the adaptive management approach was followed effectively in the development of harvest prescriptions for the species.

2.7.1 Importance and value of fern harvesting

The success of commercial fern harvesting demonstrates the potential value of forest products other than timber for the region. This is supported by the fact that when fern harvesting was at its peak, the income exceeded that of indigenous timber. It is of even more significance when the huge operational cost of timber harvesting (Heyl 1999) is compared to that of fern harvesting. It was initially argued that fern harvesting would add to the intrinsic value of forest, also on private land, and indirectly contributes to its conservation (Geldenhuys 1983). Of greater significance, though, is the fact that a whole industry with huge socio-economic benefits developed around this forest species.

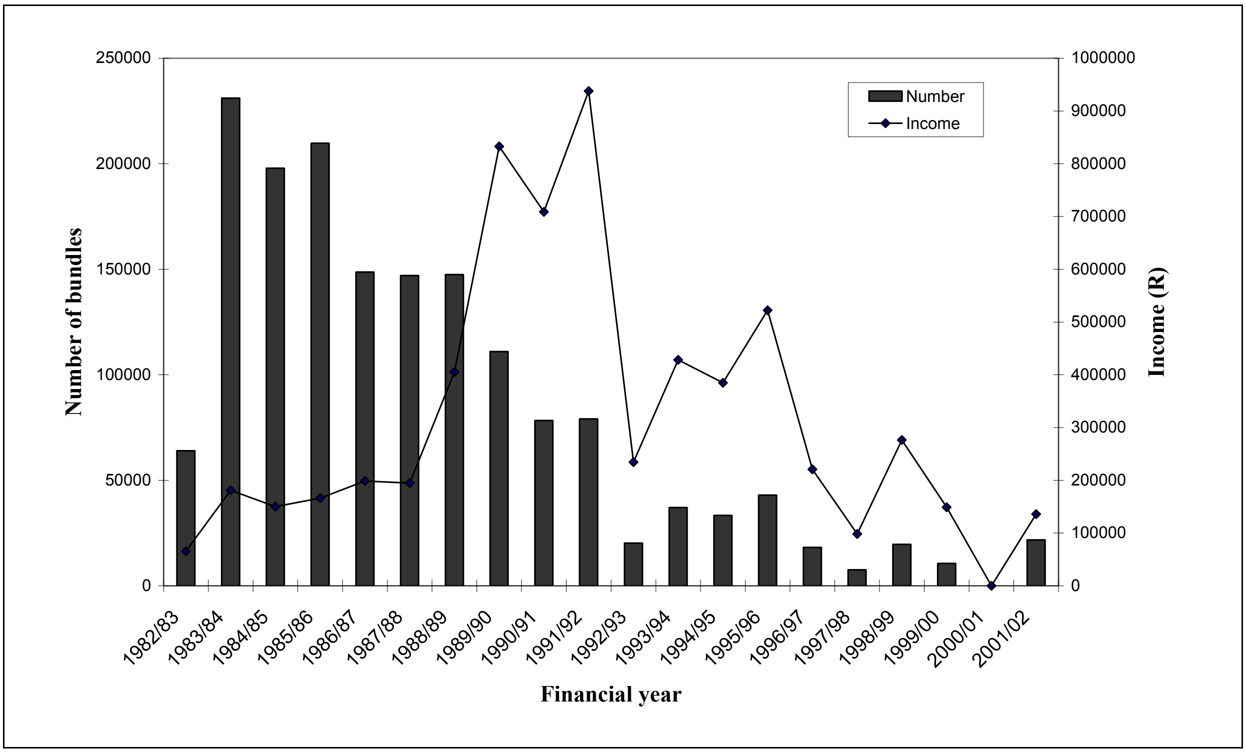


Figure 2.1. Number of *Rumohra adiantiformis* fronds (bundles of 50) harvested from the Southern Cape forests 1982/83 – 2001/02.

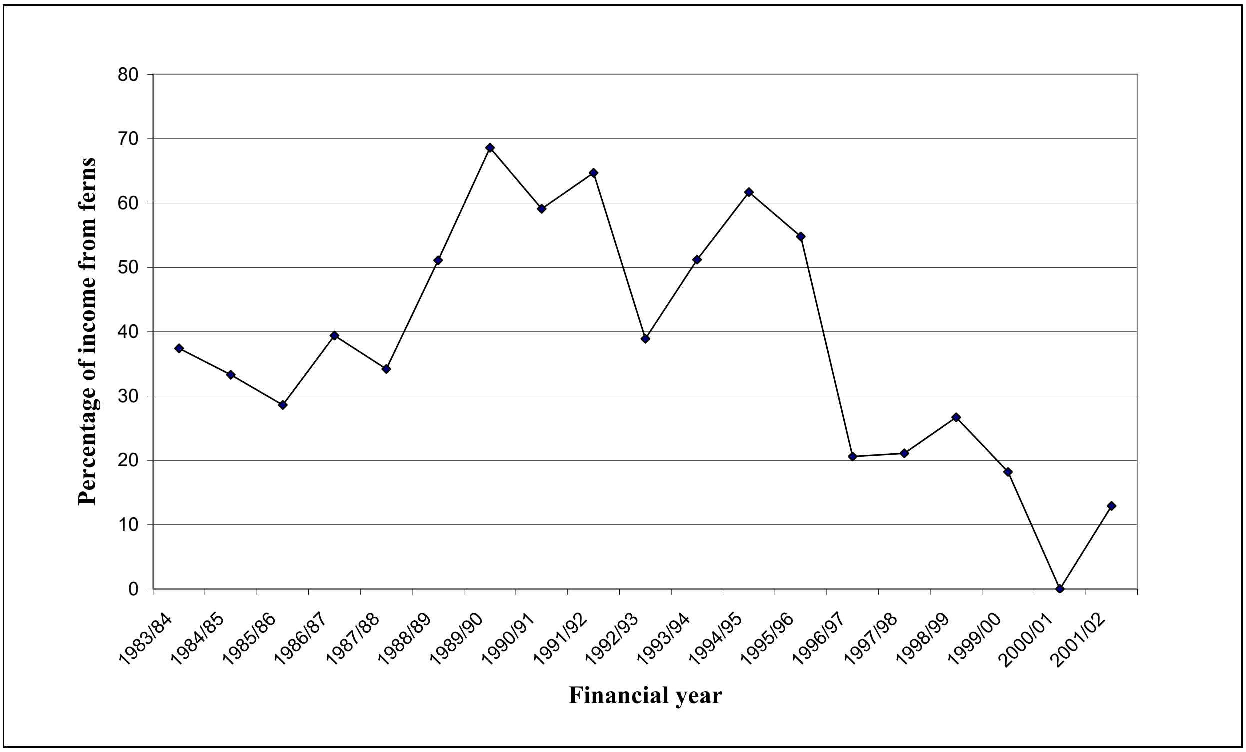


Figure 2.2. Income from *Rumohra adiantiformis* frond harvesting as percentage of total income from ferns and indigenous timber 1983/84 – 2001/02.

While they were initially only harvested from their natural habitat, most fronds destined for the export market are now grown under commercial pine plantations or in shade houses (Kok 1998). The considerable cost of establishing these stands is justified by the much higher production of 250 000 and 60 000 to 100 000 frond/ha/annum for nursery and pine stands respectively (Gerber pers. comm. 1998 cited in Kok 1998). The maintenance of these fern beds created about 60 permanent jobs in addition to the almost 50 people employed for fern picking in natural forest and pine plantations (Kok 2004). Furthermore, the *R. adiantiformis* trade opened up opportunities for the sale of other forest greenery such as *Gleichenia polypodioides*, *Blechnum punctulatum* and the leaves or stems of a number of other indigenous plant species, creating at least an additional 200 jobs for the region (Kok 2004).

The evolution of the fern harvesting industry in the southern Cape largely fits the economic model presented by Homma (1992). As recorded during the first ten years of *R. adiantiformis* harvesting, this includes an "expansion phase" with a growth in extraction and the existence of untapped resources, followed by a "stabilisation phase" with an equilibrium between supply and demand. This was followed by a "decline phase of extraction", with shrinking resources and increased cost of harvesting, and a "domestication phase" during which alternatives were developed to meet demand and maintain economic sustainability.

2.7.2 Adaptive management

This review demonstrates that an adaptive management approach can be followed effectively where the demand for NTFPs does not allow for sound research before access to resources is granted. As pointed out by Salleh & Ng (1994), research expands the scientific basis for management and gives managers the information they need, but management itself should be ongoing and effective, not suspended "pending research". Despite the initial lack of knowledge on the ecology and dynamics of *R. adiantiformis*, the adaptive management approach permitted access to the resource and secured socio-economic benefits to stakeholders while applied research was initiated. This, together with the close cooperation between researchers and forest managers, could be considered as ground-breaking for natural forest management in the region at the time. By allowing legal access to the resource, there was more effective law enforcement and a decline in illegal harvesting, which added to securing the ecological sustainability of the resource.

Harvest prescriptions

The interpretation of research results and the refinement of harvest prescriptions were complicated by spatio-temporal variation in the research, as well as drought during parts of the research period (Geldenhuys & Van der Merwe 1994). The disturbance of some research sites due to uncontrolled fern picking added to this, and demonstrated the importance of setting aside unharvested areas for control purposes. Formal studies, though, confirmed the cluster-like distribution of *R. adiantiformis* and the difficulties in accurately mapping the harvest area and defining the resource-use potential. Furthermore, the population structure and dynamics of the species are complex and vary spatially (within and between populations) and temporally (Geldenhuys & Van der Merwe 1988). These are also affected by the density of the tree and shrub layers (Geldenhuys & Van der Merwe 1988, Milton & Moll 1987), which presented a challenge in terms of defining harvest prescriptions.

Of most relevance, though, in the development of harvest prescriptions is the rate of recruitment or turnover. The rate of frond production for *R. adiantiformis* is low, limiting the potential sustainable yield. However, the sensitivity of the species to overutilisation, as reflected in especially the decline in frond size and the slow recovery rate, could be regarded as the most important trigger in the revision of the harvest prescriptions. *Rumohra adiantiformis* seems to be less attractive to mammalian herbivores than fern species such as *Blechnum giganteum* and *B. punctulatum* (Milton & Moll 1987), which might indicate that it is not adapted to herbivory and therefore more prone to damage when harvested. The long-term implications for the industry, should harvest rates not be aligned with the natural rate of production for the species, were therefore realised. Through the adaptive management approach, the initial harvest cycle of five weeks was increased to eight weeks, then to 16, 26 and 52 weeks, and eventually fixed at 15 months. Total defoliation was prohibited and harvest intensity restricted to 50% of mature fronds per plant, with a minimum frond length of 25 cm. This enabled some fronds to grow through to the old stage to recycle some of the nutrients, partly addressing the concern raised by Geldenhuys & Van der Merwe (1986) that harvesting could lead to the depletion of phosphorus and potassium stored in the plant.

Uprooting and trampling during harvesting were also identified as potential concerns, especially with a short harvest cycle (Milton & Moll 1987). Through phenological research, the period that the species would be most sensitive to harvesting (e.g. during bud initiation) was identified. Phenological events are, however, synchronised with rainfall and temperature fluctuations, which are not always predictable. For socio-economic sustainability, a steady flow of the product throughout the year is also required, so a moratorium on harvesting during certain times of the year was not a viable management option. However, the problem has partly been addressed through the longer harvest cycle of 15 months, which will also ensure that a particular area is not harvested consistently during the same time of year.

Practical considerations with the actual harvest operation also need to be taken into account. It is often difficult to distinguish between individual *R. adiantiformis* plants in dense stands, and the prescription of 50% of pickable fronds *per plant* is difficult to apply. Restrictions on harvest intensity for the population as a whole rather than per individual plants would be preferable, and this approach was followed when a new interim system for fern harvesting was implemented in 2003 as part of a community project (Vermeulen *et al*. 2005). Prescriptions were simplified by describing the potential harvest as all fronds ≥ 40 cm in a picking area. In line with the adaptive management approach, harvest frequency still needs to be established through experimental harvesting and harvest impact assessed through long-term monitoring.

Long-term sustainability

Of major importance to long-term, economic sustainability of *R. adiantiformis* harvesting is that the species is often associated with regrowth forest. It represents an early regrowth phase and should eventually be suppressed by shrub understorey and tree regeneration (Geldenhuys 1993, Geldenhuys & Van der Merwe 1994). The potential harvest area can therefore not be fixed for the long term, but should be looked at a landscape level, taking into consideration natural ecological processes and disturbance regimes. This further emphasises the relevance of an adaptive management approach with *R. adiantiformis*. However, considering that regeneration and succession in the ground flora and shrub layers are also dependent on disturbance or growth in the sub- and canopy layers (Midgley *et al*. 1995), it is unlikely that fern harvesting at current levels will have any significant effect on forest succession and development – a concern raised by Milton & Moll (1988) and Geldenhuys (1994b) – and negatively affect fern stands.

Another complication with the formulation of harvest prescriptions is that of irretrievable mortality (Seydack *et al*. 1990), which refers to additional natural mortality than that which prescriptions provide for. However, insect herbivory, although occasionally severe, is very patchy (Milton & Moll 1987) while damage by baboon and bushpig (uprooting and eating the rhizome) appears to be seasonal (Milton & Moll 1987). Also, Milton (1987b) reported that *R. adiantiformis* seems to be better defended against browsers than are e.g. *Blechnum* spp. by a foetid odour particularly strong in immature fronds. In terms of sustainable use, this is a positive as few fronds are removed through browsing in addition to harvesting.

To accommodate all the different variables and research findings in harvest prescriptions and procedures proved to be difficult, if not impossible. Therefore, although the current prescriptions are scientifically sound and should provide for sustainable harvesting, long-term sustainability in terms of quantity and quality of the product is difficult to guarantee.

Some of the key lessons learnt from the adaptive management approach taken with the development of a harvest system for *R. adiantiformis* include the following:

- The precautionary principle (Cooney 2004) should be followed. Considering the negative impact of harvesting on the resource in accordance with initial prescriptions (especially in terms of harvest frequency), it is apparent that the precautionary principle was not applied effectively and that the productivity of the resource was overestimated. This was exacerbated by a slow recovery rate following overharvesting, as recorded through experimental harvesting (Milton 1991).
- Knowledge gaps need to be identified and research objectives clearly set. This allowed for focused research and goal-orientated, long-term monitoring over a period of more than a decade.
- Close cooperation between the different role players, and knowledge sharing, is essential. The *R. adiantiformis* Research Committee that was set up as a platform for feedback and discussions between researchers, planners and managers proved to be indispensable.
- Where for commercial use, the entrepreneur should be prepared to contribute to scientific studies on the target species to inform management prescriptions, especially where they (the entrepreneurs) are pressurising for access to resources. In the case of *R. adiantiformis*, research was conducted in a complementary way, funded and initiated by both the resource owner (State) and commercial harvester (business).
- The needs of the different role players in the adaptive management process need to be understood. In the case of *R. adiantiformis*, resource managers had to appreciate the economic potential of the resource and the loss of potential business opportunities should access to resources be delayed. At the same time, business had to appreciate the importance of ecological and economic sustainability, and the complexities and time span associated with the development of scientifically based harvest prescriptions.
- The development and refinement of harvest prescriptions is ongoing. Considering the complexities of plant populations and the dynamic nature of forest ecosystems, it is difficult to foresee long-term impact of resource use. Continued monitoring is thus indispensable.

2.8 CONCLUDING REMARKS

In this chapter the adaptive management approach followed with the development of harvest prescriptions for *R. adiantiformis* in the southern Cape, was reviewed. In line with the study objective, lessons learnt in applying the adaptive management approach were also presented. Through addressing the research questions, it has been demonstrated that the adaptive management approach was followed effectively in the development and implementation of a harvest system for *R. adiantiformis*. The approach can be applied wider with the development of harvest prescriptions for NTFPs, provided that the precautionary principle is applied and that goal-orientated monitoring programmes are in place. When commercial fern harvesting was at its peak, the species made a significant contribution to the income generated from natural forest in the region. However, of greater significance is the fact that a whole sustainable industry with huge socio-economic benefits developed around this forest species, with the bulk of fern fronds now being harvested from plants grown in shade houses and commercial pine plantations. The opening up of natural forests on State land in 1982 for commercial fern harvesting could be regarded as the first step towards a new approach in the management of natural forest in the region. Until then the focus was very much on commercial timber harvesting and forest conservation (Grewar 1982, Von Breitenbach 1974, Darrow 1975, Seydack & Vermeulen 2004) with little emphasis on other uses. The success of commercial fern harvesting thus emphasised the importance of forest products other than timber, for the region.

The need for continued monitoring, to assess the impact of harvesting and to gather further information on fern stand development, was stressed by Geldenhuys & Van der Merwe (1988) and Geldenhuys (1994b). To this end and to further refine harvest prescriptions, various goal-orientated monitoring projects were initiated in the southern Cape (Heyns 1993a, Kok 1998, 2001). These include long-term monitoring to gather baseline data on natural fern growth and population development in unharvested (control) areas, monitoring in picking areas to assess harvest impact on the resource, as well as further experimental harvesting at different harvest intensities. Through daily monitoring, mechanisms were implemented to control over- and underpicking by contractors responsible for fern picking. Data were analysed on a regular basis and, where required, monitoring programmes were revised (e.g. Baard 1992, 1998, 2001, Botha 1992, Heyns 1994, 1998, Kok 1993, 1998, Baard & Wannenburg 1998). This is reported on in Chapter 3.

CHAPTER 3: TWENTY YEARS OF HARVESTING OF THE FERN *Rumohra adiantiformis* FROM NATURAL FORESTS IN THE SOUTHERN CAPE: THE IMPORTANCE OF LONG-TERM MONITORING

3.1 INTRODUCTION

The State-owned natural forests in the southern Cape are managed in accordance with a multiple-use management system, with conservation, resource use (timber and non-timber) and ecotourism important land-use types (see Chapter 1). A policy of participatory forest management (PFM) is followed to ensure local participation in decision making and the sharing of economic, social and environmental benefits from the forests (Durrheim & Vermeulen 2006). The harvesting of *Rumohra adiantiformis* (seven-weeks fern) has been practised on an economic scale since 1982 (Geldenhuys 1994b, Kok 1998, 2004). The fronds have a long vase life, an attribute reflected in the name "seven-weeks fern" and are extensively used in flower arrangements, both locally and abroad (Geldenhuys & Van der Merwe 1986, Milton & Moll 1987, Burrows 1990, Kok 2004). An historical overview of the harvesting of *R. adiantiformis* from the southern Cape forests and research on the dynamics and demography of the species to ensure sustainable use through an adaptive management approach, are provided in Chapter 2.

Monitoring, defined as the long-term, goal-orientated, systematic observation of environmental components and processes potentially or actually affected by management action (Seydack 1991), is an integral part of sustainable forest management (Higman *et al.* 2000, DWAF 2005b). Being able to account for the degree and type of response of a resource to harvesting is particularly important in the context of multi-purpose management with its competing objectives (Seydack 1991). To assess harvest impact on the resource, impacts on plants at the larger spatial scales of plant populations and landscapes, and the response of individual plants to harvesting must be considered (Hall & Bawa 1993, Cunningham 2001). Continued monitoring is, furthermore, a critical component of an adaptive management approach where the relevant information to develop harvest prescriptions is lacking when resource use commences (Anon. 1999).

3.2 STUDY OBJECTIVE

In this chapter, Specific study objective 2 is addressed, namely "to assess whether harvest prescriptions developed for *R. adiantiformis* provide for the sustainable harvesting of the species, and to review the importance of long-term monitoring in informing harvest prescriptions for NTFPs."

This was done by reviewing the monitoring conducted over a period of almost two decades in support of initial applied research on *R. adiantiformis*, by presenting monitoring results, and by discussing their relevance and importance to ensure the sustainable, optimum harvesting of the species.

Associated research questions:

- What monitoring programmes were put in place to broaden baseline knowledge of the population dynamics, demography and reproduction phenology of *R. adiantiformis*?
- What monitoring programmes were put in place to assess the long-term impact of fern harvesting on the resource at the prescribed harvest intensity?
- How important were the results in revising harvest prescriptions and assessing the sustainability of harvesting at the prescribed rates?
- What lessons were learnt in terms of the development and implementation of monitoring programmes for long-term monitoring of NTFPs?

3.3 MONITORING PROGRAMME[1]

Within the SANParks-managed natural forests in the southern Cape, an extensive monitoring programme is in place, aimed at management accountability, the expansion of baseline ecological and resource data, and at obtaining a better understanding of forest disturbance and succession processes (Geldenhuys & Van Daalen 1992, Vermeulen 2000, Durrheim 2006).

Geldenhuys & Van der Merwe (1988) and Geldenhuys (1994b) stressed the importance of continued monitoring of *R. adiantiformis* following the formulation of harvest prescriptions. To this end, and to refine harvest prescriptions further, various goal-orientated monitoring projects were initiated in the southern Cape. They included (a) long-term monitoring to gather baseline data on natural fern growth and population development and (b) continued monitoring in picking areas to assess harvest impact on the resource. Lastly, (c) through a programme of daily monitoring, mechanisms were implemented to control over- and underpicking by contractors responsible for fern harvesting. Data were regularly analysed and monitoring programmes revised where required (Botha 1992, Baard 1992, 1998, 2001, Kok 1993, 1998, Heyns 1994, 1998, Baard & Wannenburg 1998).

(a) Baseline monitoring: For the purpose of developing or refining harvest systems for sustainable resource use or to assess harvest impact on the resource, baseline information from natural, undisturbed populations is indispensable (Peters 1996, Cunningham 2001). For *R. adiantiformis* in the southern Cape, this entailed (a) monitoring fern growth and population development through permanent plots in nature reserves and (b) long-term studies on fern phenology (see Plate 2.1e-g). Although basic studies on the population dynamics and demography of the species were conducted by Milton & Moll (1987) and Geldenhuys & Van der Merwe (1988) (Chapter 2), the purpose of continued monitoring is to provide further information and to follow long-term changes in natural, undisturbed populations. In terms of fern phenology, information on the seasonal variation in bud production and frond development is provided by Geldenhuys & Van der Merwe (1988, 1994). This provided the basic information to be considered with the implementation of a harvest system and control measures. However, as these studies were conducted over a period of less than two years, the

[1] As Manager of the Scientific Services Section since 1989, the author was overall responsible for the development and implementation of the monitoring programme. Although various aspects of the monitoring programme were delegated to different co-workers over the years (see Acknowledgements) the author has been involved with the programme at all levels, including fieldwork and support with data analyses and report-writing where it was not done as part of this thesis.

need was identified for further baseline information on fern phenology over a longer period of climatic variation.

(b) Impact of harvesting: When the harvesting of *R. adiantiformis* on State Forest land commenced in the early 1980s priority was given to research to determine the impact of fern picking on the resource at different harvest levels (Geldenhuys & Van der Merwe 1988, Milton 1987a,b, 1991, Milton & Moll 1987; Chapter 2). As these studies were conducted over a relatively short period (less than three years), the need was identified for additional long-term monitoring in selected harvest areas. Two approaches to determine the impact of harvesting on the resource could be followed, *viz*. monitoring (a) quality and quantity of the product that is harvested and (b) the health of the population after harvesting (Cunningham 2001). In terms of (a), accurate records of the number and size of fronds harvested from picking areas are kept through a programme of daily monitoring (Heyns 1993b, Kok 2001). Regarding (b), when contracted research subsided, a departmental monitoring programme (semi-permanent plots) was initiated in harvest areas to assess the long-term impact on the resource (Heyns 1993b) at the prescribed harvest intensity (50% of pickable fronds per plant; harvest cycle of 15 months). The need, however, was also identified for long-term monitoring under more controlled conditions (through experimental harvesting) in addition to semi-permanent plots in harvest areas.

(c) Management control: A major responsibility rests with resource managers to ensure that harvest prescriptions are honoured by contractors once they have been developed and implemented. Should proper control mechanisms not be in place, all efforts to develop systems for sustainable use would be futile. Management control is not only about overutilisation, but also, where it is for commercial purposes, to ensure optimum use of the resource in accordance with the harvest prescriptions developed for the species or product. Contracts with commercial *R. adiantiformis* harvesters on State Forest land in the southern Cape include a penalty clause should underutilisation occur. A monitoring programme was developed and implemented to exercise the necessary control over fern pickers.

3.4 METHODS

3.4.1 Baseline monitoring

Population dynamics (Permanent plots in nature reserves)[2]

Monitoring was conducted in medium-moist High Forest (see Chapter 1 for description) in three nature reserves (Sinclair, Jubilee Creek and Petrus Brand) representative of the fern harvest areas in the Southern Cape (Figure 3.1). Sinclair Nature Reserve lies on the seaward margin of the southern Cape coastal platform on podzolised sands and shallow, duplex soils closer to the coast. The Jubilee Creek (230 metres a.m.s.l.) and Petrus Brand (380 metres a.m.s.l.) Nature Reserves are located further inland underlain by the Peninsula and Kouga geological formations respectively, with Table Mountain Sandstone the dominant parent

[2] The plots were established by members of the Scientific Services Section. Plots are still maintained and remeasurements annually by various members of the Section, including the author, as part of a continued fern monitoring pragramme. Kok (1998) reported on the results for the first three remeasurements. Results presented here are up to 2006.

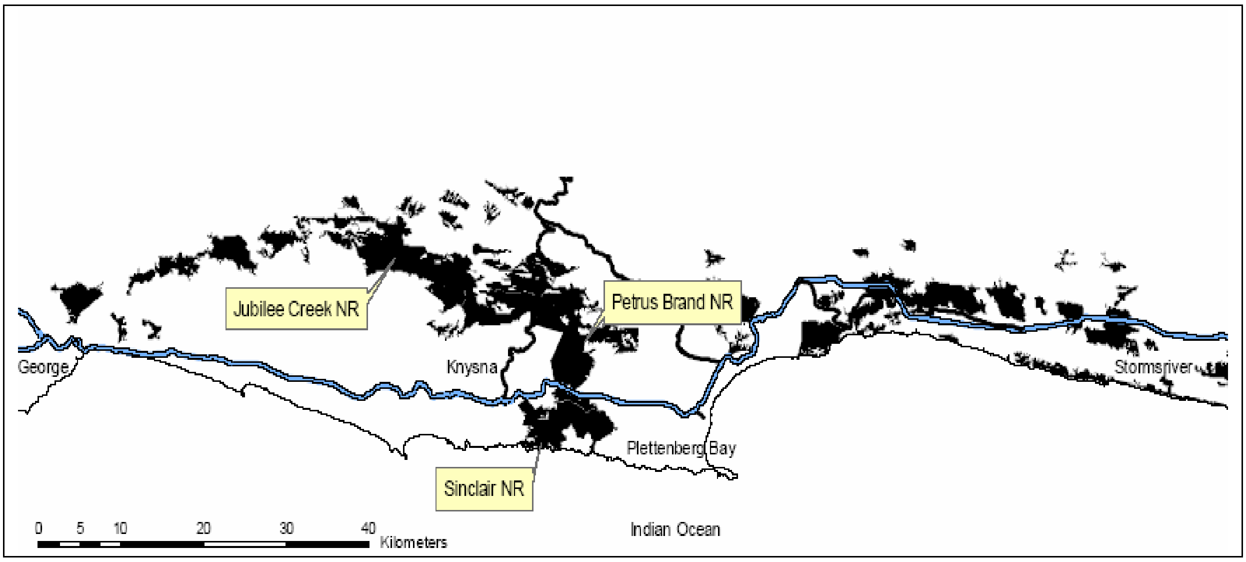


Figure 3.1. Distribution of natural forest in the southern Cape and location of nature reserves where permanent plots for the long-term monitoring of *Rumohra adiantiformis* population dynamics were established.

material. Annual average rainfall is 822 (recorded at Goudveld 216 metres a.m.s.l.), 958 (recorded at Fisantehoek 358 metres a.m.s.l.) and 977 mm (recorded at Harkerville 242 metres a.m.s.l.) for Jubilee Creek, Petrus Brand and Sinclair respectively. For all study sites rainfall is evenly distributed throughout the year but with slight peaks in spring and autumn. Mean daily maximum temperature for the bigger study area (recorded at George airport, 220 metres a.m.s.l.) varies between 18.7ºC (August) and 24.7ºC (February) with the mean daily minimum between 7.9ºC (July and August) and 15.5ºC (February).

Two 5x10 m permanent plots (wooden corner poles connected with rope defined the plot area) were established in each reserve in medium to dense fern stands that were never subjected to harvesting. The plots were established in 1992/93 and are re-measurements annually (biennial before 2000) during June and July. The following data are recorded for each plot: number of plants with pickable fronds (≥ 25 cm frond length, < 10% blemish), number of pickable fronds per plants, frond length (measured from the base of the leaf to the apex), presence of spores (absent or present). Since 2000, following recommendations after a preliminary analysis of data (Kok 1998), all plants with at least one pickable frond are tagged (tag attached to the youngest leaf) and numbered and the number of buds, young fronds and small plants recorded (Vermeulen 2007a).

The non-parametric Spearman rank correlation analysis (Zar 1996) was conducted for plot variables, and the repeated measures ANOVA and Benferroni test for plant and frond variables, to assess population health over time, using Statistica Version 7.1.

***Fern phenology*[3]**

The fern phenology monitoring project was initiated in January 1994 and lasted until February 2000. Data were collected in a permanent plot of 5x10 m (limited to one plot and

[3] Monitoring was conducted by members of the Scientific Services Section (including the author). A report on results was compiled by Baard (2001).

study site due to labour constraints) in the Petrus Brand Nature Reserve that had never been subjected to fern harvesting. The plot was located subjectively in a medium to dense fern stand. All fronds in the plot were permanently marked and given a unique number. Information on bud stage (partly unfolded, completely unfolded, mature leaf) and insect or fungal damage, was recorded monthly to monitor frond development from bud formation to death. Newly appeared buds were also recorded, tagged and numbered.

3.4.2 Impact of harvesting

Quality and quantity of yield (daily monitoring)[4]

The harvest area has been divided into a number of picking areas, and accurately mapped to a scale of 1: 10 000. Contractors responsible for fern picking are accompanied by a forest guard, who is responsible for the daily monitoring programme. The number of fronds (bundles of 50 fronds) harvested during the day in a picking area is recorded, and fifty of those fronds selected at random and their length recorded. Using Statistica Version 7.1, a Spearman rank correlation analysis was conducted to assess the change in the number of fronds harvested over the eight harvest cycles monitored. In terms of frond length data were not analysed statistically as only one mean value for a harvest cycle was available from historical records.

Population health of harvest areas (semi-permanent plots)[5]

The project ran from 1989/90 to 1996/97 and covered six harvest cycles. Sampling was done in 1 m^2 (radius = 0.564 m) semi-permanent (plots are not permanently fixed but the same sampling technique is used during successive years), circular plots located 4 m apart on transects distributed systematically through the picking area, 10 m apart. The length of transects depended on the size of the harvest area. At least 70 plots were sampled in a picking area, and sampling was done within seven days after picking. For each plot the number of plants with pickable fronds (≥ 25 cm; < 10% damage), number of pickable fronds per plant (remaining and harvested), length of remaining pickable fronds and presence of spores on remaining pickable fronds were recorded. The repeated measures ANOVA was conducted (using Statistica Version 7.1) to detect trends over harvest cycles. Significant differences between harvest cycles (in terms of number of fronds per plant, percentage of plants with only one pickable frond, percentage of fronds with spores and frond length) were separated applying a post hoc Bonferroni test.

Population health (experimental harvesting)[6]

Monitoring was conducted from 1991 to 2001. Sixteen plot groups, consisting of three plots of about 5x6 m (allocated at random to a 100%, 50% and 0% harvest of pickable fronds per plant on a 15-month cycle), were located in fern-picking areas using different block designs (see Kok 1998). In each plot at least 50 plants were initially permanently marked and

[4] This monitoring is conducted by forest guards, accompanying fern pickers, when and where fern harvesting takes place. Data is send to the Scientific Services Section for analyses to assess long-term trends in yield.
[5] This monitoring was conducted jointly by management staff (responsible for overseeing picking operations) and Scientific Services staff (including the author).
[6] This monitoring was conducted by members of the Scientific Services Section (including the author). Monitoring results are reported on by Kok (1998).

numbered. Data recorded for each plant on a 15 month cycle included the number of plants with pickable fronds, number of pickable fronds/plant, frond length and the presence of spores.

3.4.3 Management control[7]

Forest guards accompany commercial harvesters during picking operations and ensure that harvesters not only stay within the allocated picking area, but also that the full picking area is covered. For each picking area, 100 plants are selected in the daily harvest area as picking progresses. Monitoring is conducted behind the line of pickers during pre-determined times of the day, following a point sampling technique (plant closest to shoe-tip sampled every four steps along a transect perpendicular to the direction in which the fern pickers are moving). For each plant the number of freshly picked fronds and the number of remaining pickable fronds are recorded. Measured against the harvest prescription of 50% of pickable fronds on a plant, this provides area-specific data on over- or underpicking. For practical considerations it was agreed arbitrarily between managers and contractors that a maximum of 10% underpicking and 5% overpicking (of plants picked) would be allowed. Data are analysed daily to ensure prompt management intervention where required.

3.5 RESULTS

3.5.1 Baseline monitoring

In terms of **population dynamics** the Spearman rank correlation results show a general decline in the resource-use potential of undisturbed fern populations, as reflected by the number of plants with pickable fronds (Figure 3.2a). These findings are also reflected in the consistent increase in the percentage of plants with only one pickable frond (which renders a plant unharvestable, as only 50% of fronds may be picked) (Figure 3.2b), and a decrease in the number of pickable fronds in the monitoring area (Figure 3.2c). With the exception of Petrus Brand, the results represent a significant decline for all the variables at $P < 0.05$. Spore production, however, fluctuated with no clear trends (Figure 3.2d), with the Jubilee Creek site consistently producing the lowest percentage of fronds with spores.

These findings are further supported by the results of the repeated measures Anova and Bonferroni test, showing a significant decline in the number of pickable fronds per plant (Figure 3.3a) for all study sites except Petrus Brand at $P < 0.05$. Frond length varied significantly between years but with no clear trends (Figure 3.3b).

For the **phenology monitoring**, a descriptive analysis of data was conducted by Baard (2001). From a harvesting perspective, key findings from the study and from research conducted by Geldenhuys & Van der Merwe (1988, 1994) include the following:

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[7] Monitoring is conducted by forest guards accompanying fern pickers. Data are analysed daily by Managers to identify over- or under-picking and Scientific Services to identify long-term trends in adherence to harvest prescriptions.

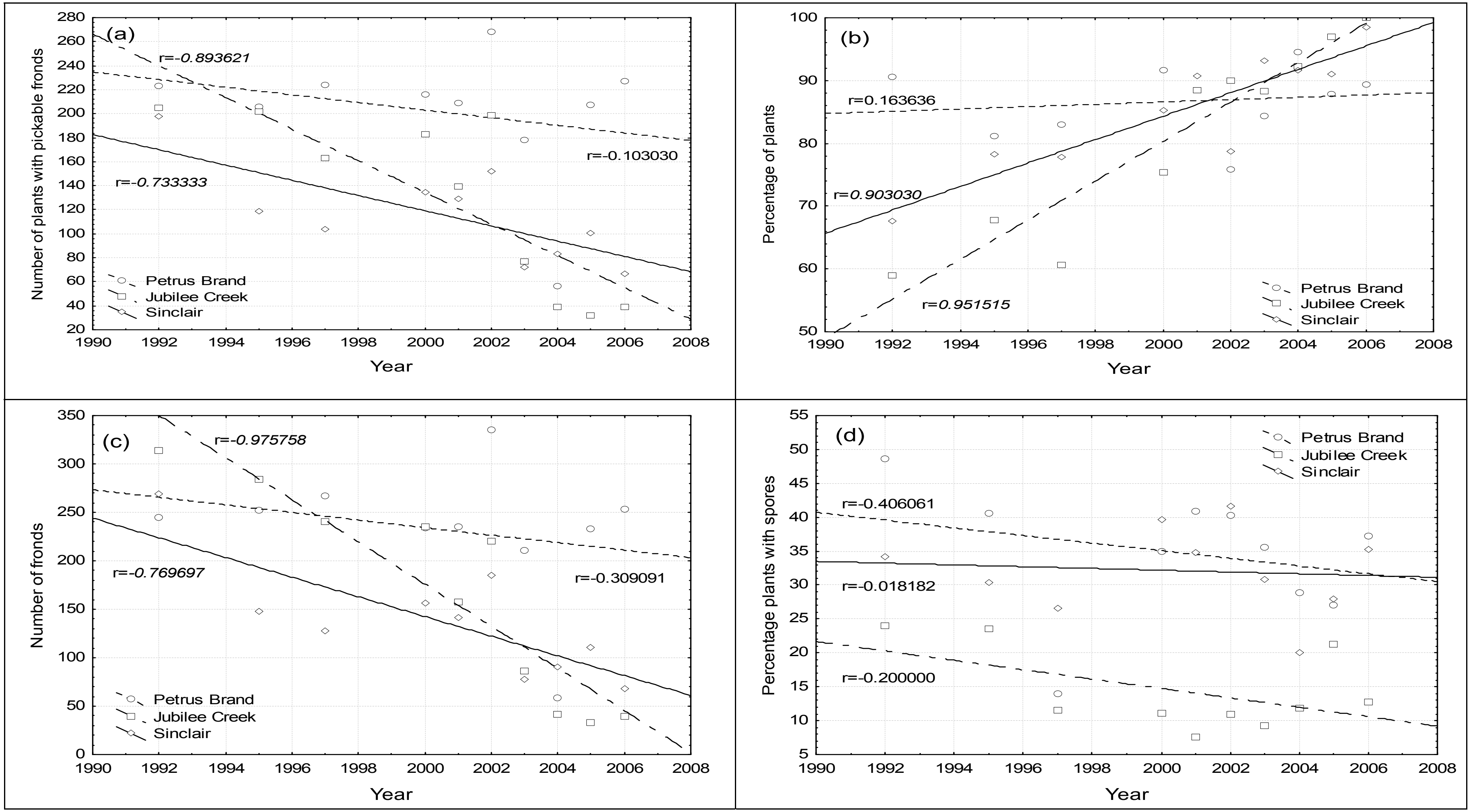

Figure 3.2. Results of Spearman Rank Correlation analysis indicating change in (a) number of plants with pickable fronds, (b) percentage of plants with only one pickable frond, (c) number of pickable fronds and (d) percentage of plants with spores over time, for *Rumohra adiantiformis* for the three monitoring sites. Correlations in italic are significant at $P < 0.05$.

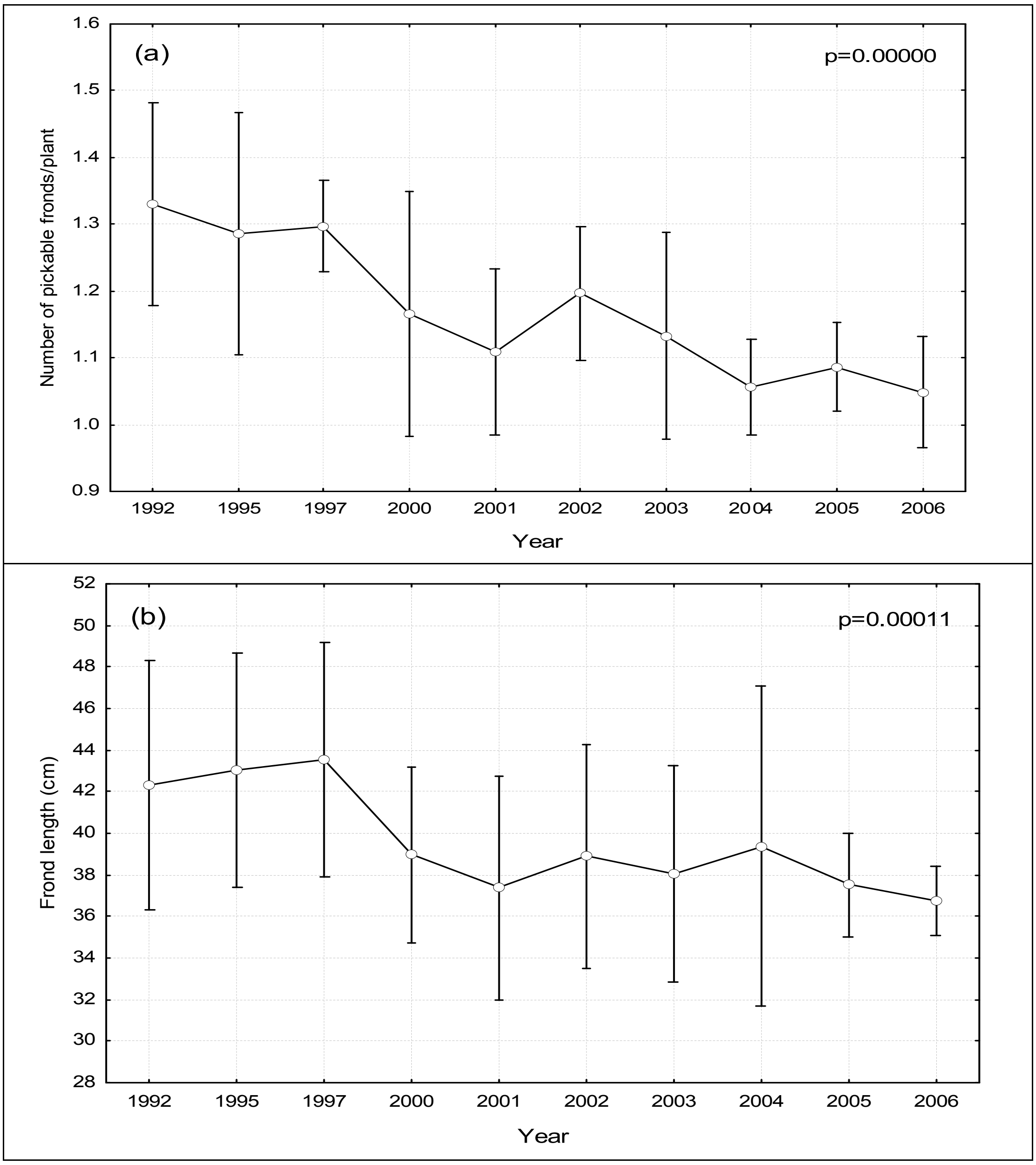

Figure 3.3. Results of repeated measures ANOVA indicating variation in (a) number of pickable fronds per plant and (b) frond length over time for *Rumohra adiantiformis* in nature reserves never subjected to resource use.

- Bud formation rises sharply from July and peaks towards September, which coincides with a turn in the low daily maximum and minimum temperatures and roughly coincides with the higher rainfall months.
- The largest number of harvestable fronds occurs between the months November and May, although these peaks are not clearly defined and pickable fronds are available throughout the year.
- It takes, on average, 12 weeks for a bud to develop to maturity and become a harvestable frond. Fronds remain alive for an average of 23 months, with those from buds produced from May to August surviving the longest. Fronds remain harvestable (less than 10% damage or blemish) for 32 weeks on average.

3.5.2 Impact of harvesting

In terms of **quality and quantity of yield**, the results show a consistent and significant decline ($r = 0.833$) in the number of fronds harvested from the same picking areas over eight consecutive harvest cycles (15-month rotation) (Table 3.1). The number of ferns harvested declined from 99 893 bundles (of 50 fronds) in the 1990/91 harvest cycle to a mere 17 339 bundles for the 1997/98 cycle. The average length of harvested fronds varied between harvest cycles, ranging from 37.5 cm in 1990/91 to 41.6 in 1997/98.

Table 3.1. Fern yield and length of harvested fronds as recorded from the same harvest area over eight harvest cycles

Harvest cycle	Year	No of bundles (50 fronds per bundle)	Length of harvested fronds (cm)
1	1990/91	99893	37.5
2	1991/92	88425	40.9
3	1992/93	49882	38.5
4	1993/94	42051	38.0
5	1994/95	55748	38.4
6	1995/96	14004	39.2
7	1996/97	14612	41.2
8	1997/98	17339	41.6

In terms of **population health** (semi-permanent plots in harvest areas) the results show a significant interaction between different harvest areas and harvest cycle in terms of all the variables. Results, though, were still interpreted to find general patterns over time, and indicate a decline in population health over the six harvest cycles (Table 3.2). There was a significant decrease in the number of pickable fronds per plant (Figure 3.4a) over harvest cycles, which is also reflected in the significant increase in the percentage of plants with only one pickable frond (Figure 3.4b). The percentage of fronds with spores varied significantly between harvest cycles but with no clear trends (Figure 3.4c, Table 3.2). In terms of frond length, harvesting at the prescribed intensity had no negative effect on the resource. The length of remaining pickable fronds in the harvest area increased significantly (Figure 3.4d) over harvest cycles.

Table 3.2. Results from the Bonferroni test indicating trends over harvest cycles. Values in italic indicate a significant difference from the first harvest cycle ($P < 0.05$)

	P-values			
Harvest cycle	Number of fronds/plant	% of plants with only one pickable frond	% fronds with spores	Frond length
1	-	-	-	-
2	0.148316	0.069452	*0.000021*	0.054857
3	0.362498	*0.020462*	0.142752	0.450437
4	*0.000000*	*0.000000*	0.066130	*0.018707*
5	*0.000000*	*0.000000*	*0.000013*	*0.002700*
6	*0.000000*	*0.000000*	*0.016277*	*0.000000*

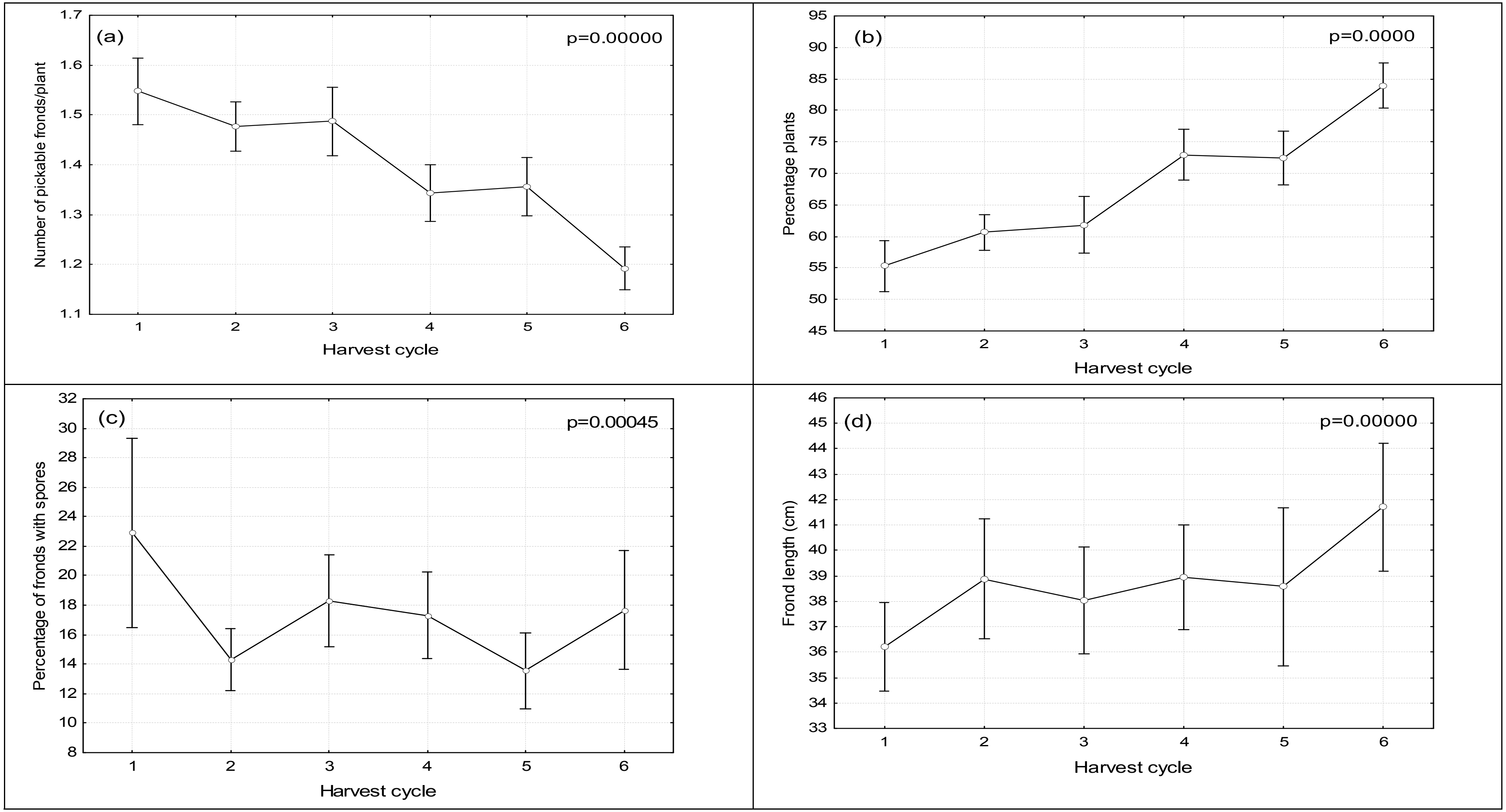

Figure 3.4. Results of repeated measures Anova indicating variation in (a) number of pickable fronds, (b) percentage of plants with only one pickable frond, (c) percentage of fronds with spores and (d) frond length in *Rumohra adiantiformis* harvest areas, over six harvest cycles.

Results of **experimental harvesting** (impact on population health at different harvest intensities) are presented by Kok (1998). Important variables such as frond length, number of plants with pickable fronds, number of pickable fronds per plant, and spore production show no significant difference between the prescribed 50% harvest intensity and the control plots (0% harvest). A harvest intensity of 100% of pickable fronds had a significant negative impact the resource.

3.5.3 Management control

The results of six harvest cycles for the period 1989 to 1997 showed underpicking, rather than overpicking, to be the bigger problem (Figure 3.5), being consistently above the cut-off of 10%.

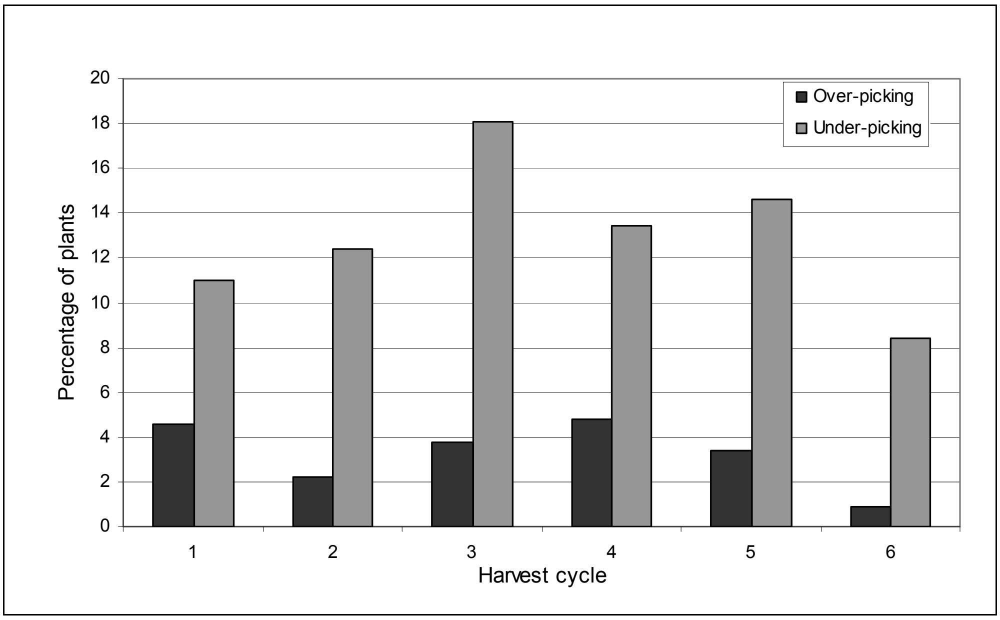

Figure 3.5. Over- and underpicking of *Rumohra adiantiformis* fern fronds in harvest areas in the southern Cape over six consecutive harvest cycles (1989-1997).

3.6 DISCUSSION

Research conducted by Geldenhuys & Van der Merwe (1986, 1988), Milton & Moll (1987, 1988) and Milton (1987a,b, 1991) provided a sound scientific basis for the development of harvest prescriptions, following an adaptive management approach, to put the harvesting of *R. adiantiformis* on the path of sustainable use (Chapter 2). Considering conservation requirements, the vulnerability of the species to overutilisation and the economic value of the resource, continued monitoring was considered essential for guidance and control of harvesting activities in the long term (Geldenhuys & Van der Merwe 1988, 1994, Geldenhuys 1994b). The results support previous findings that current harvest prescriptions are scientifically sound and provide for sustainable harvesting, while it also gave further insight in the population dynamics of the species

3.6.1 Population trends in harvest areas *versus* undisturbed populations

Harvest prescriptions provide for the harvesting of 50% of pickable fronds (≥ 25 cm, < 10% blemish) per plant on a 15-month cycle (Chapter 2). The results from long-term monitoring in fern-picking areas revealed a consistent decline in the harvest potential of the resource, measured against the number of pickable fronds per plant and the percentage of plants with pickable fronds but not harvestable (i.e. plants with only one pickable frond) (Figure 3.4). An increase in the length of the remaining pickable fronds in the harvest area was recorded, but with no significant effect on the number of plants with pickable fronds and spore production. Geldenhuys & Van der Merwe (1988) and Milton & Moll (1987) reported a reduction in frond size where overutilisation takes place, while a reduction in spore production could also occur (Milton 1987b). However, the increase in frond length (compared to a decline in Sinclair and Jubilee Creek Nature Reserves not subjected to harvesting) could reflect a reduction in harvest impact as Geldenhuys & Van der Merwe (1994) reported that fern populations subjected to overharvesting in the past (as is the case with most of the Southern Cape harvest areas) recover by producing fewer but larger fronds. It is postulated that this could be attributed to a higher investment of resources in growth and longevity, compared to reproduction, as a strategy for the population to recover, similar to what is found with organisms with a k-selected life history pattern (Barbour *et al.* 1987).

Of great significance is that the same trends as those for fern-picking areas were recorded for populations in nature reserves never subjected to harvesting, i.e. a decline in the harvest potential of the resource (Figures 3.2 & 3.3). For Sinclair and Jubilee Creek Nature Reserves, this is reflected in a significant decline in the number of plants with pickable fronds, the number of pickable fronds per plant, total number of pickable fronds in the population and the length of pickable fronds; the Petrus Brand population remained stable. The highest average length of pickable fronds recorded for Jubilee Creek correlated with lower spore production, which could indicate a trade-off between growth and reproduction (Barbour *et al*. 1987).

The results indicate that *R. adiantiformis* populations are dynamic with a long-term spatio-temporal variation in population structure and productivity. These long-term changes are synchronised with natural disturbance patterns and forest succession. The species is often associated with wet and moist regrowth forest (Geldenhuys 1993, Geldenhuys & Van der Merwe 1994). This is further confirmed by the fact that dense stands of *R. adiantiformis* in high forest are usually associated with a relatively open tree canopy and a sparse or absent shrub understorey of *Trichocladus crinitus* (Geldenhuys & Van der Merwe 1988, Vermeulen pers. obs.), a species associated with near-climax forest (Geldenhuys & Van Laar 1980) (see Chapter 2). These forests are regarded to be in a successional stage of development following disturbance by fire, evident from the presence of charcoal in the soil (Geldenhuys 1994b, Vermeulen 1995a). This include ground fires in the forest interior (caused by lightning or sparks flying from fires outside the forest during strong berg winds – see Vermeulen *et al*. 2006) and fynbos fires scorching the forest edge, or burning deeper into the forest interior during berg wind conditions (Geldenhuys 1994a, Watson & Cameron 2001, 2002). The abundance of *R. adiantiformis* in these forests thus depends on the successional phase of the tree community. The decrease at the Sinclair and Jubilee Creek monitoring sites could be the result of a late successional phase, compared to Petrus Brand where forest regrowth has not suppressed fern growth as yet. This process could be accelerated where fern populations are also subject to drought.

The above demonstrates that *R. adiantiformis* harvest areas are not static and have to be continuously redefined as the harvest potential of populations declines through natural succession (except for more stable populations outside regrowth forest areas) and as new populations establish following disturbance. This is consistent with the recommendation by Geldenhuys (1994b) that fern density and performance should be considered in relation to its temporary phase in the development of forest towards maturity. The identification and assessment of potential harvest areas should therefore be conducted at a landscape level, while natural disturbance patterns in the larger forest area should be maintained. This would provide a continuous flow of fern fronds to the market, ensuring that fern harvesting is also economically sustainable.

3.6.2 Fern phenology

Results of fern phenology monitoring conducted as part of the long-term monitoring programme and reported on by Baard (2001), largely support the findings by Geldenhuys & Van der Merwe (1988) that the time and number of bud formation and frond development varies seasonally. The insight gained into the phenology and growth of *R. adiantiformis* enables managers to identify peak periods for fern production as well as periods when populations are most sensitive to harvesting. November to May gives the biggest yield, with the stands most vulnerable to harvesting from July to September when the peak for bud initiation is reached. To accommodate market demands and to ensure a steady flow of fronds during the whole of the harvest cycle, though, a total prohibition of harvesting during the sensitive months would not be a viable management option. However, partly to accommodate phenological events, the harvest prescriptions were amended in the early 1990s from a 12-month harvest cycle to 15 months that would prevent the same population being exposed to harvesting consistently during the same season (see Chapter 2).

3.6.3 Fern yield and harvest impact

The decline in fern yield (Table 3.1) and harvest potential (Figure 3.4) from the same harvest area cannot be attributed to overutilisation at prescribed harvest levels, as it is consistent with trends in populations never subjected to harvesting (Figures 3.2 & 3.3). It ties in with the conclusion by Geldenhuys & Van der Merwe (1994) that frond density is not negatively affected by harvesting at the prescribed harvest intensity; neither is the production of buds and mature fronds. This is further supported by results of the experimental harvesting conducted as part of the long-term monitoring programme and reported on by Kok (1998). In terms of variables such as frond length, number of plants with pickable fronds and number of pickable fronds per plant, the results showed no significant difference between the 50% harvest intensity and the control plots (0% harvest). Although Geldenhuys & Van der Merwe (1988) reported that harvesting could affect timing of bud initiation and therefore also fern production, this could not be confirmed through long-term phenology monitoring reported on by Baard (2001).

In addition to a natural decline in the resource potential, the decline in the number of ferns harvested could also partly be attributed to the recorded underpicking by contractors (Table 3.5). Similarly could the increased length of harvested fronds (Table 3.1) partly be the result of harvesters giving preference to larger fronds, while underpicking smaller fronds. The underpicking resulted in additional financial losses to the State and a penalty clause in the harvest contract was put into effect to compensate for the losses. It not only showed the importance of sound management control but also of proper supervision during harvest operations.

3.6.4 Importance of long-term monitoring, and lessons learnt

Monitoring is primarily concerned with the detection of change, involving time-series of observations made in a standardised way (Van Hensbergen 1993), with yield studies a prerequisite to economic planning and forest valuation (Peters 1996). As plant populations change over time (Barbour *et al*. 1987) continued sampling is essential to determine patterns of natural change in population structure and the effects of harvesting on natural population dynamics (Hall & Bawa 1993, Cunningham 2001).

NTFPs such as ground flora species are affected by short-term environmental fluctuations (e.g. drought) (Meilleur *et al*. 1992), and long-term monitoring is essential to explain long-term trends in population dynamics and succession, of relevance to the development of sustainable harvest systems. The results of 15 years of monitoring of undisturbed *R. adiantiformis* populations in nature reserves were of great significance as a control in interpreting trends in picking areas, as it catered for short-term fluctuations and long-term, natural changes in fern populations. As pointed out by Hall & Bawa (1993), the impact of harvest pressure could be a response measurable over a relatively short period (e.g. less harvestable fronds), or it could be reflected in long-term trends (e.g. spore production). For example, Geldenhuys & Van der Merwe (1994) reported that fern populations that were subjected to overharvesting, recover by producing fewer but larger fronds, but this would be a short-term reaction until the populations have stabilised. Long-term monitoring programmes as implemented *for R. adiantiformis* are thus essential to accommodate both short-term reactions to harvesting and long-term trends in population dynamics.

Long-term monitoring is expensive and absorbs resources that could be used in other spheres of forest management. From this perspective, lessons learnt with the development, implementation and maintenance of the long-term *R. adiantiformis* monitoring programme, include the following:

- A comprehensive literature review of the topic, especially in terms of applied research already conducted, is critical in preventing duplication and defining the boundaries of the envisaged monitoring programme.
- Monitoring must be goal orientated and needs-driven. Also, there is a trade-off between the extent of monitoring that can be conducted and justified, and available resources. Monitoring projects should be prioritised, also considering other forest management needs and objectives, and must be sustainable in the long term in terms of available resources to take projects to a conclusion.
- Projects must be scientifically sound. The development phase of the project and experimental lay-out is critical to ensure that data collected are relevant, reliable and sufficient to provide the required results in achieving long-term monitoring objectives.
- Detailed descriptions of the different projects that form part of the monitoring programme are required and should include the setting of monitoring objectives, description of plot lay-out, survey and re-measurement protocols, re-measurement schedules, etc. This is not only essential to ensure consistency of data collection in the long-term, but also that monitoring objectives do not fade over time.

- Where long-term monitoring projects are in place, data should be analysed regularly and results scrutinised to assess whether the project, as set up, is effective in achieving the objectives. This would allow for the early identification of shortfalls and the adjustment or phasing out of projects where required. Also, where interim harvest prescriptions for resource use have been implemented, regular data analysis to allow for the refinement of harvest prescriptions is an integral part of the adaptive management approach.
- A high staff turnover could result in long-term monitoring projects falling behind schedule; different interpretations of certain variables and how data should be recorded; lack of commitment or appreciation of accuracy required with the re-measurement of monitoring plots; etc. A committed programme manager who can ensure continuity and consistency with the different projects in the long-term is thus indispensable.
- Where resource use is allowed according to certain harvest prescriptions and control measures, the roles and responsibilities of different role players should be clearly defined. The fern-monitoring programme in the southern Cape followed initial research by internal and external scientists; it was conducted in liaison with management staff responsible for enforcing control measures; and aligned with daily monitoring during harvest operations. Also, the importance of regular feedback of monitoring results to management staff responsible cannot be overemphasised.

3.6.5 Future research and monitoring

Despite the vast amount of research conducted on *R. adiantiformis* (Geldenhuys 1994b; see Chapter 2) and the long-term monitoring programme implemented knowledge gaps still exist:

- The role and importance of natural disturbance patterns on the maintenance of *R. adiantiformis* populations and the forest succession processes that affect the longevity of populations require further investigation. In this regard, Geldenhuys (1994b) raised concerns that disturbance through fern harvesting could stimulate the growth of woody plants and suppress fern growth in competition for light. Also, fire is an important mineralisation agent and enriches nutrients such as Ca, Mg and P on the forest soil surface (Louw 2007). Studies of the importance of enriched soils in the establishment of *R. adiantiformis* after fire, and the impact on population health as nutrient levels decline again with natural succession, should provide further insight into the spatio-temporal variation of the species.
- Heyns (1998), Kok (1998) and Baard & Wannenburg (1998) reported on differences between fern populations in the Southern Cape and Tsitsikamma forest regions in terms of long-term yield, population dynamics trends and harvest potential. Seydack (pers. comm. 2007) hypothesises that *R. adiantiformis* populations in the Southern Cape possess characteristics of r-selected species with rapid growth, a short lifespan and a relatively large energy allocation to sexual reproduction, compared to the k-selected characteristics of slow growth and a long lifespan of the Tsitsikamma populations (Barbour *et al*. 1987). This requires further investigation to ensure optimum use of the resource in the combined forest area.
- There are practical considerations that justify the revision of the current harvest system. Prescriptions require the identification of individual plants, which is, especially in dense stands, difficult and time consuming as a result of the growth form (rhizome often underground) of the species. It not only presents problems for harvesters who must abide by prescriptions, but also impacts negatively on the accuracy of monitoring data collected by managers. A more “user-friendly”, market-driven system of harvesting of all pickable

fronds in the population ≥ 40 cm (doing away with individual plant-based prescriptions) could be explored (Vermeulen *et al*. 2005). This would require monitoring to assess the impact of harvesting on the resource and recovery rate, allowing for refinement of prescriptions (especially in terms of harvest frequency) in an adaptive way (Vermeulen & Herd 2004). As the system could result in total defoliation of individual plants, the importance of allowing for recycling of some of the plant nutrients before harvesting (Geldenhuys & Van der Merwe 1986) would be an important research focus area.

- Since 1986, drought has been mentioned from time to time (by contractors, management staff and the *Rumohra* Research Committee) as having a negative impact on fern population health and long-term sustainability (Unpublished Departmental Records, Stehle 1998). The extent to which extended dry periods enhance the natural decline of *R. adiantiformis* populations – considering that ground flora species are more affected by short-term environmental fluctuations (Meilleur *et al*. 1992) – deserves further investigation, especially within the context of global climate change (Von Maltitz *et al*. 2006).

Despite the fact that the commercial harvesting of *R. adiantiformis* fronds from natural forest in the southern Cape ceased in the early 2000s (see Chapter 2), the permanent monitoring plots in nature reserves should be maintained. Their value not only lies in a better understanding of *R. adiantiformis* population dynamics, but they could also provide insight into successional changes of ground flora and other understorey communities should data on this be recorded. This would be important to develop indicators of change which could be assessed in harvest areas. Addressing specific research needs, though, would depend on future demand for fern fronds from wild populations.

3.7 CONCLUDING REMARKS

The research questions were effectively answered, indicating the importance of goal-orientated, long-term monitoring in assessing long-term sustainability of harvesting - also considering natural fluctuations in population dynamics. The monitoring results indicate that the current harvest prescriptions for *R. adiantiformis* are scientifically sound and provide for the sustainable harvesting of the species. As the lessons learnt from the monitoring programme implemented in the southern Cape are generic, they have wider application and should contribute to avoiding pitfalls where new monitoring programmes for NTFPs are established.

Achieving sustainable use of a resource is not only dictated by ecological considerations, but it also has economic and social dimensions (Harcharik 1997, Cunningham 2001). The costs for developing harvest systems to ensure sustainable use and the implementation of monitoring programmes should therefore be absorbed by the harvester, if of a commercial nature. This could render many commercial resource-use ventures economically unviable. However, as stipulated by Cunningham (2001), resource use operates within a policy and political framework. A policy of participatory forest management has been adopted for State Forest land (DWAF undated) with – as entrenched in the National Forests Act (Act No. 84 of 1998) – strong emphasis on community development and the equitable distribution of benefits from forest areas (DWAF 2005a). The costs of developing harvest systems and continued monitoring to refine prescriptions should therefore not only be weighed up against direct economic benefits to commercial harvesters, but also against downstream social benefits to communities at large. To this end, the social responsibility of management agencies and how this could be met through consumptive resource use need to be clearly defined. These aspects will be highlighted further in the chapters that follow.

3.8 ACKNOWLEDGEMENTS

The contribution of my colleagues in the Indigenous Forest Planning section (now Scientific Services) and management staff in the establishment and maintenance of different components of the *R. adiantiformis* monitoring programme over many years is greatly acknowledged. My appreciation also to Prof Daan Nel from the Center for Statistical Consultation at the University of Stellenbosch and Dr Armin Seydack (SANParks) for their guidance with the statistical analysis of data.

CHAPTER 4: RESPONSE OF SELECTED TREE SPECIES TO STRIP HARVESTING OF MEDICINAL BARK FROM NATURAL FOREST IN THE SOUTHERN CAPE

4.1 INTRODUCTION

The harvesting of non-timber forest products (NTFPs) is an important aspect of the sustainable management of natural forests, and that of medicinal plants particularly so, as the most valued traditional medicines come from natural forest (Lawes *et al.* 2004a). Tree bark is a commonly used traditional medicine in South Africa (Mander 1998, Botha *et al*. 2001, Grace *et al.* 2002, Williams 2003, Cocks *et al*. 2004) and, due to increasing urbanisation, has become highly commercialised (Mander 1998, Williams 2004, Mander & Le Breton 2006). This has resulted in the overexploitation of some target species (Cunningham 1993, Mander 1998, Grace *et al*. 2002, Guedje *et al*. 2007), posing a major challenge to resource managers to develop mechanisms for sustainable resource use and forest protection. The need was identified to develop a strategy and to explore different options for the sustainable harvesting of bark for medicinal use from the southern Cape forests (Lübbe *et al.* 1991).

The development of yield regulation systems and best practices for bark harvesting can best be achieved through controlled, experimental harvesting and the long-term monitoring of tree response to bark stripping. In 2001, an experimental bark-harvesting project (initially part of the SA Innovation Fund Project: Commercial Products from the Wild or CPWild[8]) (Geldenhuys 2000c,d) was initiated at two study sites in the southern Cape. Three species were selected for this study, *viz*. *Ocotea bullata*, *Curtisia dentata* and *Rapanea melanophloeos*. The CPWild study was supported by further studies as part of the FRP-DFID (Forestry Research Programme – UK Department for International Development) project[9] "Developing biometric sampling systems and optimal harvesting methods for medicinal tree bark in southern Africa" (FRP-DFID 2003). The study was designed to determine bark response patterns for trees with different ecophysiological profiles (Vermeulen & Geldenhuys 2004) in Zambia (miombo woodland), Malawi (miombo woodland and evergreen forest), and South Africa (evergreen forest). Five species were selected in the southern Cape i.e. *O. bullata, R. melanophloeos* (also treated as part of the CPWild project), *Ilex mitis*, *Rhus chirindensis* and *Prunus africana*. Vascular cambium shows great seasonal variation in intensity of activity (Fahn 1985), while phellogen development, and thus wound recovery, are also influenced by environmental factors such as light intensity, photoperiodicity, temperature, relative humidity, etc. (Borger 1973, Fahn 1985). This requires that species response to bark stripping for different seasons also be explored.

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[8] The experimental design of the project was done by C.J. Geldenhuys. The author (of this dissertation) was actively involved with the implementation of the project and the initial remeasurements, and took full responsibility for further remeasurements and all data analysis reported on in this dissertation. Although reference is also made to interim reports, results presented here are original.

[9] The author was actively involved with the experimental design (Vermeulen & Geldenhuys 2004) based on lessons learnt from the CPWild project implemented in the southern Cape. The author was responsible for the implementation of the project and all remeasurements and data analysis reported on in this dissertation. Although reference is also made to interim reports, results presented here are original.

In South Africa the bark of *O. bullata* is widely used as a traditional medicine for headache, urinary and nervous disorders, and for treating diarrhoea (Van Wyk *et al*. 1997, Grace *et al*. 2003). The bark of *C. dentata* is commonly used for stomach ailments, diarrhoea, as a blood purifier, aphrodisiac (Hutchings *et al*. 1996, Van Wyk *et al*. 1997, Grace *et al*. 2003), and as a skin lightener (La Cock & Briers 1992). Decoctions of the bark of *R. melanophloeos* are used as expectorants and emetics (Watt & Breyer-Brandwijk 1962), and also for muscular pain, stomach disorders and to strengthen the heart (Hutchings *et al*. 1996, Van Wyk *et al*. 1997). The bark of *I. mitis* is used for treating fever, diarrhoea (Grace *et al*. 2003) and colic in children (Watt & Breyer-Brandwijk 1962, Coates Palgrave 2002), as well as rashes and facial sores (Hutchings *et al*. 1996). *Rhus chirindensis* is used to strengthen the body, stimulate circulation and relieve rheumatism, to treat mental illnesses (Hutchings *et al*. 1996) and for heart complaints (Pooley 1993). *Prunus africana* is exploited on a large scale in tropical Africa and exported to Europe, America and Japan (Van Wyk & Gericke 2000, Stewart 2003, Diederichs 2006) to treat benign prostatic hypertrophy (Hutchings *et al*. 1996, Van Wyk *et al*. 1997). With the exception of *R. chirindensis*, all of the species are highly in demand in the commercial bark-harvesting industry, and there are concerns about overutilisation (Cunningham 1993, Mander 1997, 1998, Du Toit 2000, Botha *et al*. 2001, Geldenhuys 2002, Grace *et al*. 2003, Williams 2004, Cocks *et al*. 2004, Mander *et al*. 2006).

4.2 STUDY OBJECTIVES

In this chapter, Specific objective 3 is addressed, namely "to assess, through experimental research, the response of different species to bark stripping of relevance to the sustainable harvesting and management of medicinal bark species". The results presented form part of the broader study to scrutinise and describe the process towards obtaining ecological and socio-economic sustainability with the harvesting of different NTFPs from the Southern Cape forests and to set harvest prescriptions for sustainable use (Chapter 1).

Associated research questions:

- How do different tree species respond to the removal of their bark in vertical strips, in terms of bark regrowth?
- How do the different tree species vary in terms of their susceptibility to fungal and insect attacks following bark removal?
- What would the impact be of tree size on the rate of recovery or dieback?
- What is the effect of season of bark removal on the recovery potential?

4.3 STUDY AREA

The study was conducted in natural, closed-canopy Afrotemperate forest in the southern Cape, consisting of mountain, coastal platform and scarp forests (Mucina & Rutherford 2006). The area receives orographic rain throughout the year, but with peaks during autumn and early summer, and has a moist, warm temperate climate. The State-owned forests are managed in accordance with a participatory, multiple-use management system, with conservation, resource use (timber and non-timber) and ecotourism as important land-use types. A more detailed description of these forests and their management is provided in Chapter 1.

Three sites (Groenkop, Woodville and Witelsbos) were selected for the study (CPWild and FRP-DFID projects) in the western and eastern parts of the distribution range of the Southern Cape forests, all within platform forest (Figure 4.1). The drier Groenkop Forest (33°56.5'S, 22°33'E) near George is located about 260 m a.m.s.l. with a rainfall of 850 mm per annum (Geldenhuys 1998b). The Woodville Forest lies further east at approximately 33°55'S, 22°40'E, consisting of mainly medium-moist High-Forest underlain by spotted shales and mica schists (Von dem Bussche 1970). The moister Witelsbos Forest (33°59.5'S, 24°06'E) near Storms River is located at 200 m a.m.s.l. with approximately 1200 mm of rain per annum (Geldenhuys 1998c).

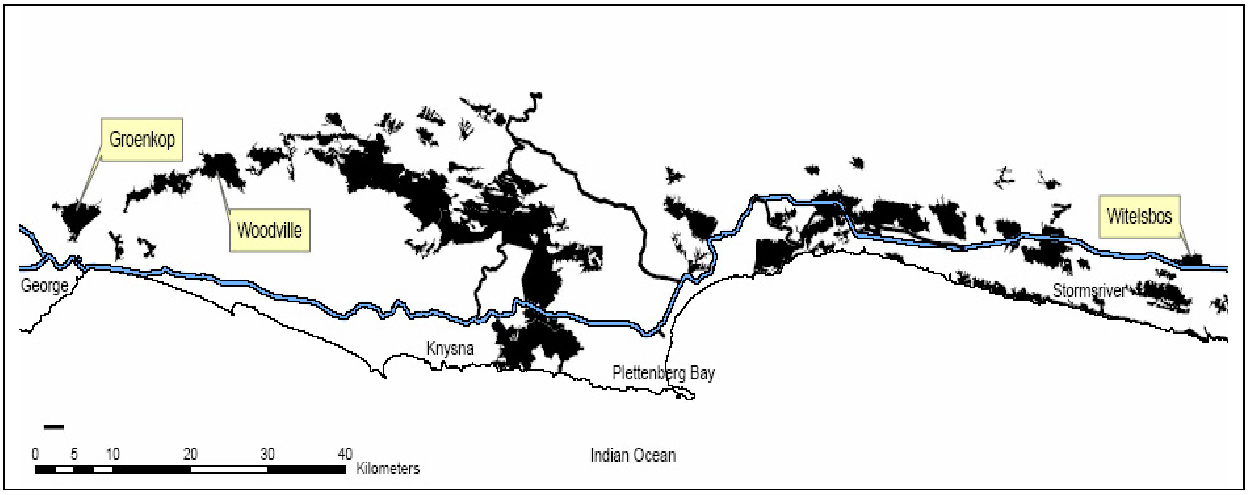


Figure 4.1. Distribution of natural forests in the southern Cape and location of study sites (Groenkop, Woodville and Witelsbos) for experimental bark stripping.

Species were allocated as follows to the different study sites:

- *Rapanea melanophloeos*[10], *C. dentata*, *I. mitis* and *R. chirindensis* were treated in Groenkop Forest. Studies on the first three species were conducted in medium-moist High-Forest (a research site), found on quartzitic and mica schists of the Kaaimans formation (Geldenhuys 1998b). *Rhus chirindensis* was treated in dry High-Forest (Saasveld site) on spotted shales and mica schists (Von Breitenbach 1968b).
- *Ocotea bullata*[11] and *C. dentata* were treated at the Witelsbos Forest in wet High-Forest found on quartzitic sandstone of the Peninsula Formation (Toerien 1979).
- At Woodville, a hedge of *P. africana* trees, planted in the early 1980s (Geldenhuys pers. com.) along a road on the edge of the forest, was used for the study.

At both the Groenkop and Witelsbos sites, long-term studies on recruitment, growth and mortality are also conducted (Geldenhuys 1998b,c) as part of an ongoing forest dynamics monitoring programme.

[10] Treated as part of the CPWild and FRP-DFID projects
[11] Also treated at Groenkop as part of the FRP-DFID project

4.4 METHODS

The experimental layout and assessment protocols for the CPWild project are described in detail by Geldenhuys & Rau (2001) and Geldenhuys *et al*. (2002). The research methodology was revised by Vermeulen & Geldenhuys (2004) for the FRP-DFID project and is described in Vermeulen & Geldenhuys (2005).

4.4.1 Tree selection

For the CPWild project trees were categorized in three tree size classes, taking into consideration the diameter class distribution of the species, as follows:

- *Ocotea bullata* and *Rapanea melanophloeos*: 10 – 19 cm DBH (Small), 20 – 39 cm DBH (Medium), ≥ 40 cm DBH (Large)
- *Curtisia* dentata: 10 – 19 cm DBH (Small), 20 – 29 cm DBH (Medium), ≥30 cm DBH (Large)

For the CPWild project a total of 361 trees were treated, 182 at Groenkop (90 *C. dentata*, 92 *R. melanophloeos*) and 179 at Witelsbos (90 *C. dentata*, 89 *O. bullata*), with 182 in winter and 178 in summer. They were largely distributed equally between the combinations of diameter class, strip width and season (Table 4.1). Due to the limited number of *O. bullata* and *R. melanophloeos* trees present at the Groenkop and Witelsbos study sites respectively, only *C. dentata* was treated at both sites.

For the FRP-DFID project, 20 trees each of *I. mitis*, *R. chirindensis* and *P. africana* (as well as *O. bullata* and *R. melanophloeos* not reported on here, as they are dealt with under the CPWild project) with a minimum DBH of 20 cm were selected, to represent the range of sizes of that species in the site.

Table 4.1. Actual number of trees treated (CPWild project) by site, species, tree size, strip width and season

Site	Species	Tree size	Dry season				Rainy season				Total
			Strip width (cm)				Strip width (cm)				
			5	10	15/20	Total	5	10	15/20	Total	
Groenkop	*Curtisia dentata*	Small[1]	6	5	5	16	4	4	3	11	
		Medium[2]	5	5	5	15	5	6	7	18	
		Large[4]	5	5	4	14	6	5	5	16	
		Totals				45				45	90
	Rapanea melanophloeos	Small[1]	8	5	6	19	4	5	3	12	
		Medium[3]	3	4	5	12	6	6	6	18	
		Large[5]	6	6	5	17	5	4	5	14	
		Totals				48				44	92
Witelsbos	*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	90
	Ocotea bullata	Small[1]	4	4	5	13	5	5	5	15	
		Medium[3]	6	6	5	17	4	5	5	14	
		Large[5]	5	5	5	15	5	5	5	15	
		Totals				45				44	89

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

Trees were selected as paired samples (trees of approximately similar size in close proximity to each other), and numbered numerically. In the case of multi-stemmed trees, a maximum of one stem was selected per tree for treatment. Also, only relatively healthy trees that met the following crown health categories of percentage foliage (after Lübbe & Geldenhuys 1990) were selected for treatment:

- 81% – 100% healthy crown (crown densely covered with foliage with no apparent dieback);
- 61% – 80% (tips of terminal shoots without leaves while the rest of the tree appears healthy).

Trees with major structural damage (e.g. large branches broken off) or serious stem rot did not qualify for selection.

4.4.2 Treatment procedures

For the initial project (*C. dentata*, *O. bullata* and *R. melanophloeos*), two bark removal methods were used namely total and partial bark removal (Geldenhuys *et al*. 2002, Vermeulen & Geldenhuys 2004). For total bark removal, an axe was used to cut two vertical lines through the bark onto the wood and the bark 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. Both methods were applied to each selected tree, allocated randomly to the eastern and western sides of the tree. Strip widths of 5, 10 and 15 or 20 cm (15 cm for trees < 20 cm DBH) were used; and allocated proportionally to the number and diameter classes of trees selected for each species (Table 4.1). Strips were 1 m in length and removed in a vertical direction, upward from a starting point at about 50 cm above ground level. A minimum of five trees per species was initially selected for each combination (i.e. diameter class, strip width and season of treatment). Commercial tree sealer was used on the lower part of each wound (total and partial removal) to test its effect on wound recovery or the process of decay (Plate 4.1a).

For *I. mitis*, *R. chirindensis* and *P. africana*, only total bark removal treatment was applied, and strip width confined to 15 cm (Plate 4.1b). To ensure that the remaining bark did not lift away from the wood, as experienced with the CPWild Project (Vermeulen & Geldenhuys 2004), the edge was cut by inserting a sharp axe at an angle so that the thin blade lift only the bark on the wound side of the edge. The experimental strip was removed on the southern or southeastern side of the stem. For both projects, one tree of a pair was treated during winter (a dry period in the southern Cape but with relatively low temperatures) and the other during summer (good rains but higher temperatures).

During project establishment, a horizontal line was drawn with lumber crayon in the middle of the strip for both the sections with and without tree sealer (total bark removal only), for the CPWild project. On this line (‘A’ in Figure 4.2a), the distance between the boundaries of the phellogen edge growth (where it exists) or the inner edge of the wound, on the wood, was measured. This distance was re-measured during assessments to determine the rate of wound closure through phellogen edge growth. This methodology was revised for the FRP-DFID project (Vermeulen & Geldenhuys 2004):

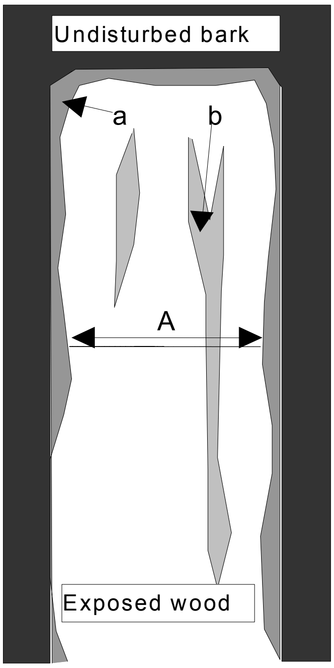
- Three horizontal lines were marked with lumber crayon on the cleared strip: upper third (top), middle third (middle) and lower third (bottom) (Figure 4.2b).

Plate 4.1. (a) *Curtisia dentata* with a 5 cm strip of bark removed and the bottom part treated with tree sealer; (b) *Ilex mitis* being treated to assess tree response to bark stripping; (c) monitoring of rate of wound closure through edge development; (d) bark regrowth (sheet growth), *I. mitis*; (e) agony shoot development, *Rapanea melanophloeos*; (f) bark lift, *C. dentata*; (g) unsustainable bark harvesting in the southern Cape.

- Two measurements were recorded for each line: distance between the two inner edges of the wound (mm); and distance between the two upper edges (outer bark) of the wound (mm).
- The midpoints of the lines were marked with pencil during the first assessment.
- The distance from the midpoints to the wound edge (or phellogen edge growth if it was present) was measured during follow-up assessments.

Additional data recorded during study establishment include the thickness and mass of removed bark and, for *I. mitis*, *R. chirindensis* and *P. africana*, the ease with which the bark was removed, and the moisture content of the bark during removal. This is reported on by Geldenhuys *et al.* (2002) and Geldenhuys & Rau (2004).

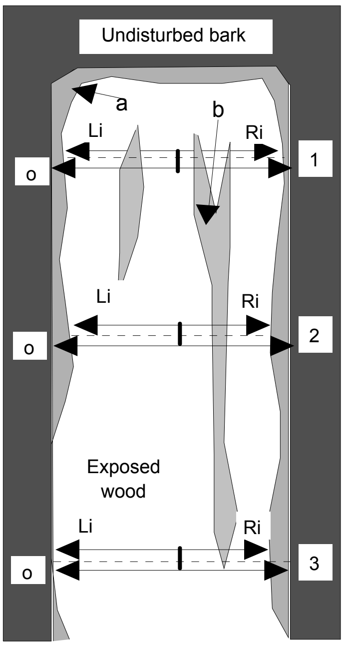
a



a – phellogen edge growth
b – phellogen sheet growth

A – width of exposed wood

b



'a' is edge growth, i.e. tissue showing wound recovery from underneath the bark. With bark lift on the edge, this tissue starts to develop underneath the lifted bark.

'b' is sheet growth, i.e. live tissue developing on the wood of the wound surface.

'1, 2, 3' represents three horizontal lines (shown as dotted lines) across the wound, marked with lumber crayon at the time of bark removal, to indicate the points for bark growth measurements. The midpoint of each line is indicated with a short vertical pencil line.

'i' represents the distance between the midpoint of the line and boundaries of the edge growth (where it exists), or the inner edge of the wound (on the wood), to the left (L) and the right (R) of the midpoint.

'o' represents the distance between the outer edges of the wound (edge of the bark surface).

Figure 4.2. Schematic view of measurements taken during project establishment and of response after bark removal for (a) the CPWild project (after Geldenhuys *et al*. 2002) and (b) the FRP-DFID project (after Geldenhuys & Vermeulen 2004).

4.4.3 Assessment protocols

The assessment protocols are described in detail by Geldenhuys *et al*. (2002) and Vermeulen & Geldenhuys (2004, 2005). Assessments were done six monthly, with the first done six months after treatment, over a period of 36 and 12 months for species treated during the CPWild and FRP-DFID projects respectively. For the former, a separate evaluation was made of the four treatments applied to each tree i.e. total versus partial bark removal, and application of tree seal or not. Data and information recorded during each assessment included crown condition, the extent of bark lift from the wood, recovery through phellogen edge growth (not for partial bark removal treatment), recovery through phellogen sheet growth, insect damage, fungal growth and the presence of agony shoots. General observations that could be potentially linked to the treatment were also recorded.

Tree condition
A visual assessment of crown condition was made, and trees were allocated to one of six crown health categories of percentage foliage (after Lübbe & Geldenhuys 1990), as described in Table 4.2.

Bark lift
This was only recorded for species treated during the FRP-DFID project (*I. mitis*, *R. chirindensis* and *P. africana*). A micro-calliper was used to measure the vertical lift from the wood surface to the inner part of the lifted bark both on the left and right edge of the wound, at the top, middle and bottom of the strip (Figure 4.2b). The percentage of the wound edge that shows bark lift (defined as 1 mm or more lift of the bark away from the wood) was also recorded, separately for the upper and lower part of the wound, according to bark lift classes described in Table 4.2.

Edge development and rate of growth
This was recorded as a percentage of the edge of the wound showing phellogen growth i.e. tissue showing wound recovery from underneath the bark ('a' in Figure 4.2b), according to edge development classes described in Table 4.2. For *I. mitis*, *R. chirindensis* and *P. africana*, two assessments of edge development were done. The percentage of the wound edge that shows (i) visible phellogen edge growth; and (ii) total phellogen edge growth, including those visible underneath the lifting bark, was recorded according to the same categories used for bark lift. This was done separately for the upper and lower half of the wound.

For *C. dentata*, *O. bullata* and *R. melanophloeos*, the distance between the boundaries of the phellogen edge growth (where it exists) or the inner edge of the wound, on the wood, was measured on the horizontal line marked during project establishment ('A' in Figure 4.2a). For *I. mitis*, *R. chirindensis* and *P. africana*, the distances were measured from the marked midpoint to the left (Li) and to the right (Ri) to the boundary of the edge growth tissue (where it exists and is visible outside the bark edge of the wound), or the inner edge of the wound (on the wood, if there was no visible edge growth) (Figure 4.2b). Successive measurements indicate the rate of wound closure through phellogen edge growth (Plate 4.1c).

Sheet development
This was recorded as a percentage of the wound surface (exposed wood) showing phellogen sheet growth i.e. live tissue development on the wound surface ('b' in Figure 4.2a, 4.2b), recorded separately for the upper and lower half of the strip (Plate 4.1d). For partial bark

removal, it refers to the amount of living bark below the outer hardened surface of the remaining inner bark. The same percentage classes were used as for edge development (Table 4.2).

Insect damage and fungal growth

The number of pinholes on the wound surface, irrespective of size, was recorded to assess damage by insects according to pinholes classes described in Table 4.2. The presence of surface fungal growth (white, green, grey discolouration) was recorded as percentage cover on the exposed wound surface, using the same percentage classes as for edge and sheet development (Table 4.2). The assessments were done separately for the top and bottom part of the wound. For the FRP-DFID project, the experimental layout also made provision for more destructive research on selected trees to determine the extent of fungal spread into the xylem and other cells, reported on by Roux *et al*. (2005).

Table 4.2. Description of classes used to define tree response to bark stripping in terms of different variables

Variable	Class description
Crown condition	0 = Tree dead; 1 = 1% – 20% healthy crown (few leaves present near bole of tree); 2 = 21% – 40% healthy crown; 3 = 41% – 60% healthy crown; 4 = 61% – 80% healthy crown; and 5 = > 80% healthy crown (crown densely covered with foliage, no apparent dieback)
Bark lift	0 = none; 1 = 1% – 10%; 2 = 11% – 20%; …… 8 = 71% – 80%; 9 = 81% – 90%, 10 = 91% - 100%
Edge development	0 = no edge recovery; 1 = 1% – 10% edge recovery; 2 = 11% – 20% edge recovery; 3 = 21% – 30%; 4 = 31% – 40%; 5 = 41% – 50%; 6 = 51% – 60%; 7 = 61% – 70%; 8 = 71% – 80%; and 9 = > 80% edge recovery
Sheet development	As for edge development
Pinholes	1 = 1 – 2 pinholes present; 2 = 3 – 5 pinholes present; 3 = 6 – 10 pinholes; 4 = 11 – 20 pinholes; and 5 = more than 20 pinholes present
Fungal growth	As for edge development

Agony shoot development and other observations

The presence and number of vegetative shoots developing on the stem around the wound (agony shoots) were recorded, as were observations (especially on or around the wound area) that may be relevant to the interpretation of the results, or anything that could be a reaction to the treatment (Plate 4.1e). This included the presence of exudates, cracks in the exposed wood, and woodpecker activity on the bark adjacent to the wound.

4.4.4 Data analysis

A preliminary analysis of data for the different treatments, strip width and DBH classes for *C. dentata*, *O. bullata* and *R. melanophloeos* (CPWild project) was conducted by Vermeulen & Geldenhuys (2004), with little differences found in tree response between different strip widths. For the current study, analysis of the CPWild project data was restricted to total bark removal treatment without tree sealer, and was conducted for strip widths pooled. For *I.*

mitis, *R. chirindensis* and *P. africana* (FRP-DFID project), assessment data for the top and bottom parts of the wound, and measurement data for top, mid and bottom were first analysed separately, after which data were pooled, as no significant differences were found. Analysis was done separately for the CPWild and DFID projects.

A multi-level ANOVA was conducted to test the hypothesis that bark regrowth and susceptibility to fungal and insect damage are affected by tree size and harvest season, and varies between species, using the Statistica 7 computer program (StatSoft Inc., Tulsa Oklahoma, USA). Differences were further separated applying the Bonferroni test. Where data did not represent a normal distribution, the non-parametric Mann-Whitney U test was conducted to confirm results. P-values from the three Mann-Whitney tests were Bonferroni adjusted to correct for multiple testing. A Repeated measures ANOVA was conducted to assess edge and sheet development over time, separated further by applying the Bonferroni test. The non-parametric Friedman test was conducted where data did not represent a normal distribution, to confirm results.

4.5 RESULTS

Results of the assessments for total bark removal 36 months after treatment for *O. bullata*, *R. melanophloeos* and *C. dentata*, and 12 months after treatment for *I. mitis*, *P. africana* and *R. chirindensis* are presented in Appendix 2. They show a differential response of tree species in terms of bark lift, phellogen edge growth, sheet growth and the development of agony shoots, as well as susceptibility to fungal and insect attack.

4.5.1 Tree condition

For *O. bullata* and *C. dentata* no clear deterioration in crown condition was evident over the 36-month monitoring period. The biggest change in crown condition class was recorded for *R. melanophloeos* i.e. 0.3 for both the dry and rainy season treatments (Appendix 2). For this species, 5.4% (five trees) of the treated trees died through crown dieback or wind damage (bole snapped or wind-falls), compared to 1.1% (one tree) for *O. bullata* and *C. dentata* (Groenkop) and 2.2% (two trees) for *C. dentata* at Witelsbos. Eight of the nine trees (88.9%) were smaller than 25 cm DBH. This is consistent with the significant effect of tree diameter on change in crown condition ($P < 0.01$), largely as a result of die-back recorded for *R. melanophloeos* (Figure 4.3). No difference was found between change in crown condition and season of treatment. For all species, trees with a 5 cm strip width treatment generally showed the least decline in crown condition.

Due to the short monitoring period of 12 months, no results are available on crown condition changes for *I. mitis*, *P. africana* and *R. chirindensis*.

4.5.2 Bark lift

In terms of the percentage of wound edge with lift, the class average varies from 0.4 (median 0.3) (i.e. less than 10% of the edge) for *R. chirindensis* dry season treatment to 6.7 (median 7.5) (more than 60% of the edge) for the *I. mitis* rainy season treatment (Appendix 2). For *P. africana*, there was a significant class difference six months after bark removal ($P < 0.001$), with the higher lift recorded for dry season treatment; but 12 months after treatment this was neutralised by aggressive edge development. Bark lift (as reflected in the distance of lift from the wood) is largely consistent with the findings based on percentage edge lift. The largest lift was recorded for *I. mitis* (4.4 mm) followed by *R. chirindensis* (1.6 mm), all for rainy season treatment (Appendix 2). Extensive bark lift was observed for *R. melanophloeos* and, to a lesser degree, *C. dentata*, but this was not quantified with the initial CPWild project (Plate 4.1f).

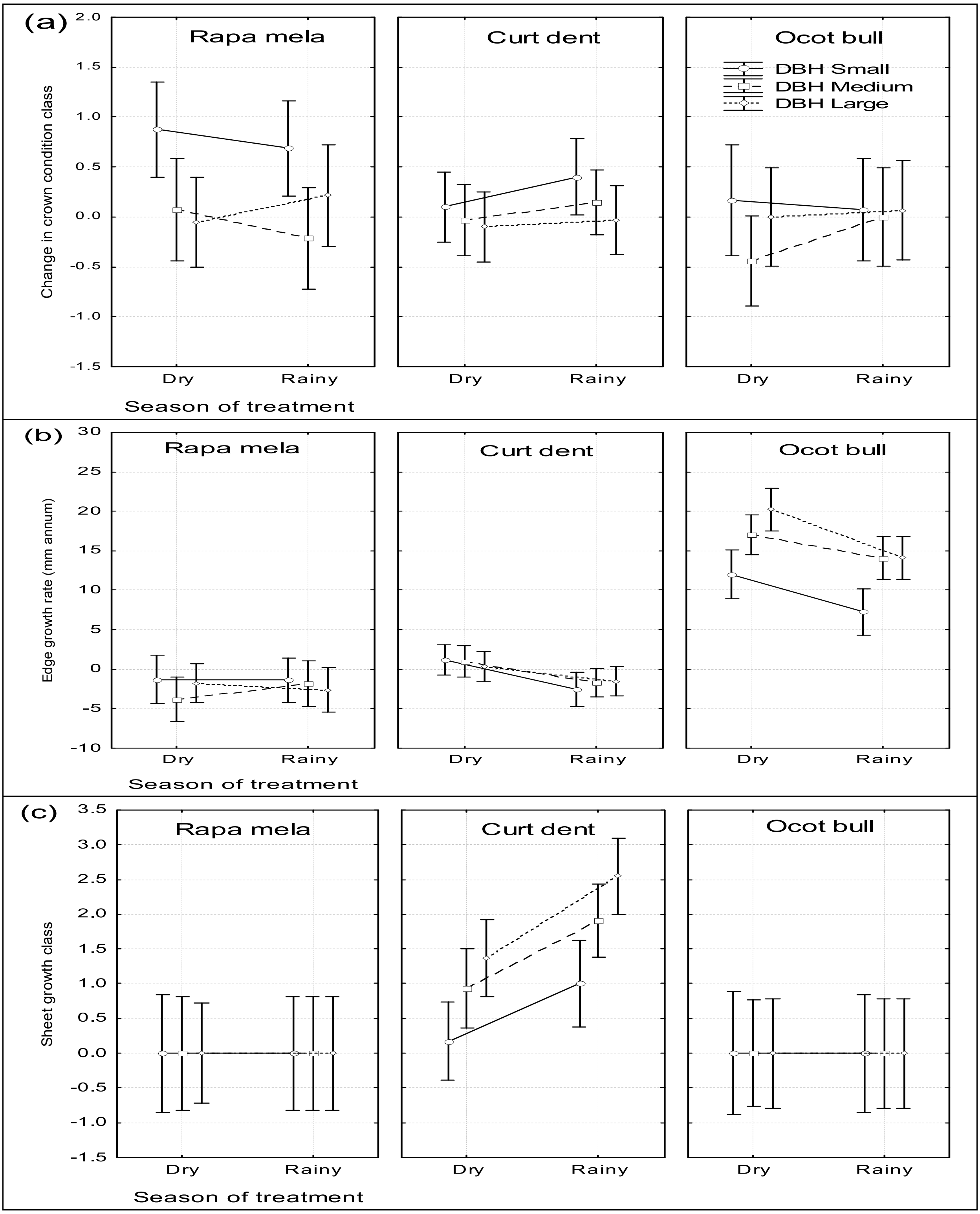
Although the Anova results indicate that season of treatment had a significant effect on bark lift ($P < 0.05$), this was not supported by the Bonferroni test in terms of specific species. Tree diameter also did not have a significant effect on bark lift.

4.5.3 Edge development and rate of wound closure

Prunus africana and *O. bullata* showed the strongest edge development with class averages for visual edge growth of more than eight for both dry and rainy season treatments, i.e. growth covers more than 70% of the edge 12 and 36 months after treatment respectively (Appendix 2). A much smaller percentage edge development of between 30 and 60% (depending on site and season) was recorded for *R. chirindensis* and *C. dentata*, 12 and 36 months after treatment respectively. However, only *O. bullata* showed a positive rate of wound closure for both dry and rainy season treatments, i.e. 16.2 and 12.1 mm/annum (combined growth from both sides). For *C. dentata* (Witelsbos), *P. africana* and *R. chirindensis*, only the dry season treatment showed a positive rate of wound closure, i.e. 2.0, 9.7 and 3.3 mm/annum for the three species respectively (Appendix 2). For *C. dentata*, edge development was significantly better, both in terms of percentage of edge with growth ($P < 0.01$) and rate of wound closure ($P < 0.001$) for dry season treatment, 36 months after bark removal. Also for *O. bullata* ($P < 0.05$) and *P. africana* ($P < 0.01$), the dry season resulted in significant faster edge growth ($P < 0.01$) (Figure 4.4).

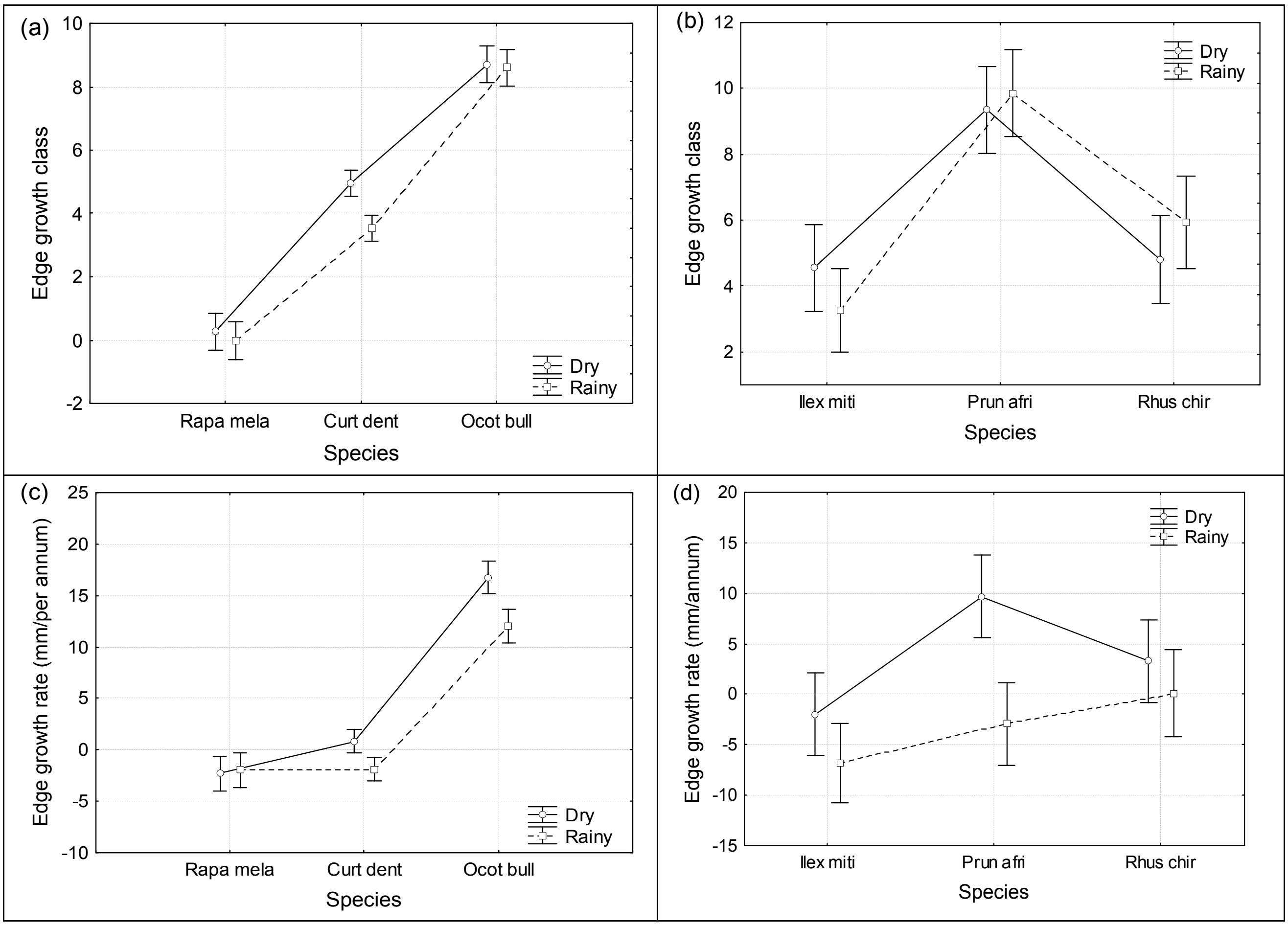
For *R. melanophloeos*, phellogen edge growth was insignificant with a class average of 0.3 (median 0) (less than 10% cover) for dry season treatment, and no growth recorded for rainy season treatment 36 months after the initiation of the experiment. For *I. mitis*, less than 30% of the edge was covered by growth 12 months after treatment. These two species, as well as *C. dentata* at the drier Groenkop site, also showed a negative rate of wound closure for both the dry and rainy season treatments (Appendix 2). This was especially prevalent in *R. melanophloeos*, with the wound widening an average of 5.8 and 4.9 mm over the period six to 36 months after treatment, for the dry and rainy season treatments respectively.

There was no significant difference between visible and total edge growth 12 months after treatment for any of the species. Significantly better edge growth was recorded for *O. bullata* for trees for the large DBH size class compared to smaller trees, for both the dry and rainy season treatments ($P < 0.05$) (Figure 4.3). For *C. dentata* there was a significant increase in edge development for both study sites and season of treatment, over time ($P < 0.001$). The same applies to *O. bullata* but only for the rainy season treatment, attributed to an initial slow rate of edge development (Figure 4.5).



Rapa mela = *Rapanea melanophloeos*; Curt dent = *Curtisia dentata*; Ocot bull = *Ocotea bullata*

Figure 4.3. Change in crown condition (a), edge growth (b) and sheet development (c) for different tree diameter classes. Data points represent means and vertical bars 0.95 confidence intervals.



Rapa mela = *Rapanea melanophloeos*; Curt dent = *Curtisia dentata*; Ocot bull = *Ocotea bullata*; Ilex miti = *Ilex mitis*; Prun afri = *Prunus africana*; Rhus chir = *Rhus chirindensis*

Figure 4.4. Seasonal difference in terms of mean edge growth class (a & b) and rate of edge development (c & d) for different species. Data points represent means and vertical bars 0.95 confidence intervals.

4.5.4 Sheet growth

The best recovery through sheet growth occurred with *I. mitis* and *P. africana* with class averages of 4.6 and 0.7 (median 5 and 0.5) (dry season treatment) and 6.9 and 6.2 (median 6) (rainy season treatment) for the two species respectively. For *C. dentata*, surface cover varied from just under 10 to 30%, depending on study site and season of treatment (Appendix 2). For *R. chirindensis* less than 10% of the wound surface was covered from sheet development 12 months after bark removal. Although some sheet growth was also recorded for *O. bullata* and *R. melanophloeos* six months after treatment, it died back with none present after 36 months. Also for *C. dentata*, there was is a gradual decline in sheet growth cover over time for both study sites.

For *C. dentata* ($P < 0.05$) and *P. africana* ($P < 0.01$), sheet development was significantly better following rainy season treatment (Figure 4.6). In terms of site differences, the drier Groenkop site showed significantly better sheet development for *C. dentata* than the wetter Witelsbos site, for both dry ($P < 0.01$) and rainy season ($P < 0.001$) treatments (Appendix 2).

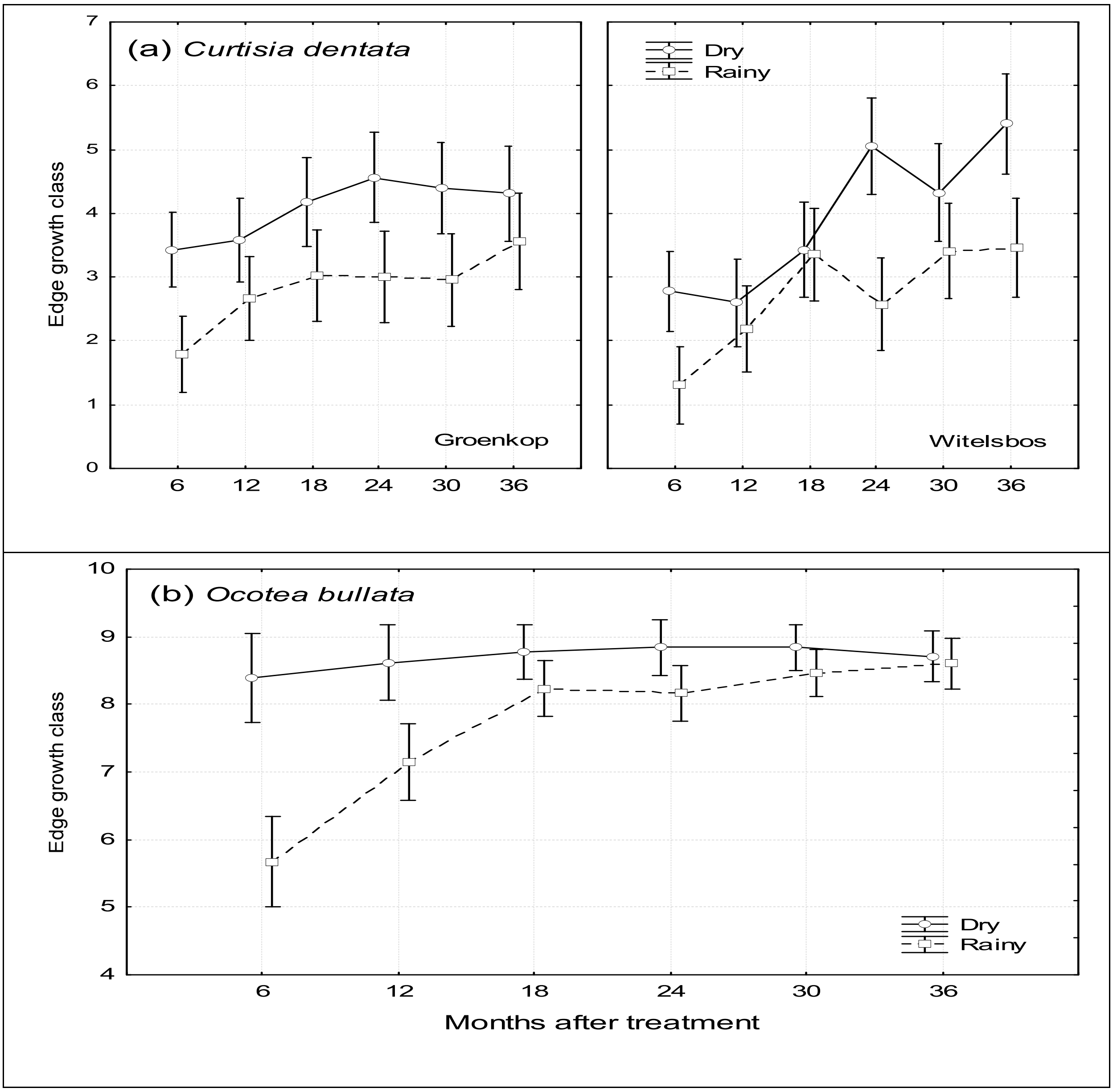
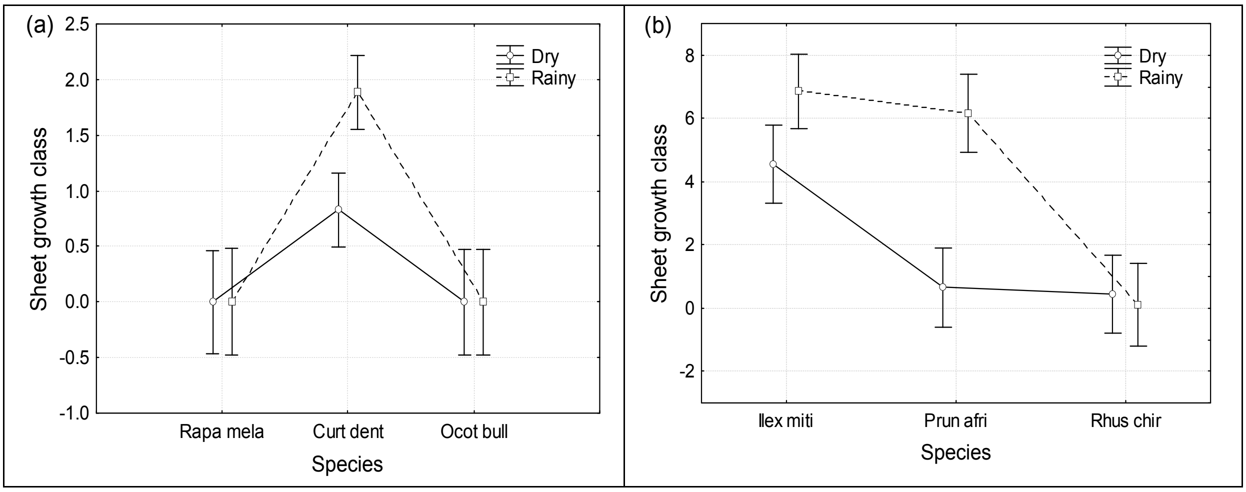


Figure 4.5. Edge development for *Curtisia dentata* at two study sites (a) and *Ocotea bullata* (b) over time after treatment. Data points represent means and vertical bars 0.95 confidence intervals.

Significantly better sheet development was also recorded for larger trees ($P < 0.01$) (Figure 4.3).

4.5.5 Insect damage

Rapanea melanophloeos and *R. chirindensis* were most susceptible to insect attack with pinholes recorded on the exposed wood of more than 90% (36 months after treatment) and 70% (only 12 months after treatment) of the treated trees for the two species respectively, for both dry and rainy season treatments) (Appendix 2). For *O. bullata*, 77.3% (dry season



Rapa mela = *Rapanea melanophloeos*; Curt dent = *Curtisia dentata*; Ocot bull = *Ocotea bullata*; Ilex miti = *Ilex mitis*; Prun afri = *Prunus africana*; Rhus chir = *Rhus chirindensis*

Figure 4.6. Sheet development for selected species for different seasons of treatment. Data points represent means and vertical bars 0.95 confidence intervals.

treatment) and 53.5% (rainy season treatments) of treated trees had pinholes compared to less than 50% for *C. dentata*. Insect damage to the other species was minimal.

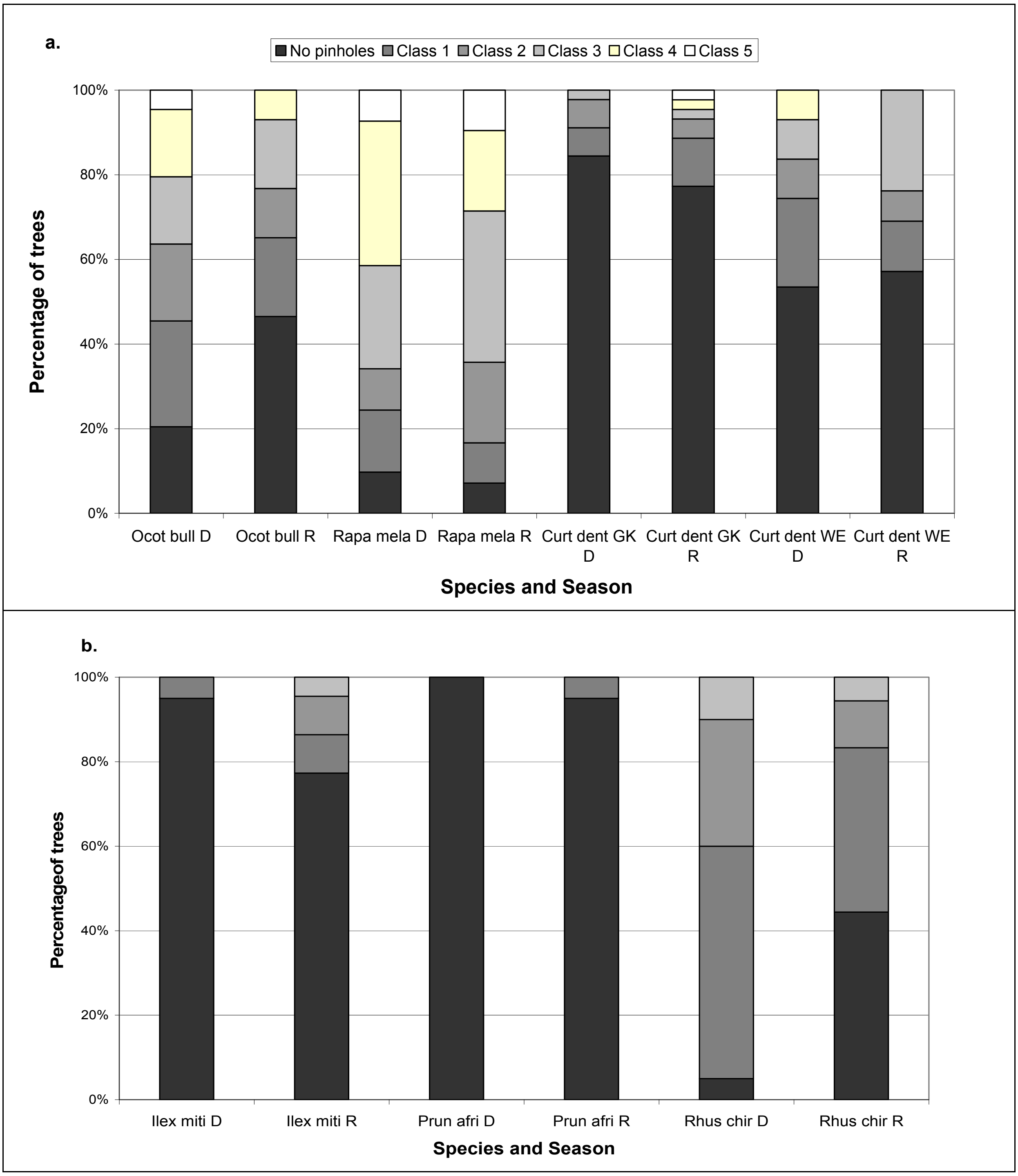
This trend is supported by the pinhole class average (for trees with pinholes) of 3.2 and 3.0 (median 4 and 3) (i.e. six or more pinholes per wound) for *R. melanophloeos* followed by *R. chirindensis* and *O. bullata* (Appendix 2). The vulnerability of *R. melanophloeos* to insect attack is also supported by the fact that it is the only species for which all five pinhole classes were recorded, while three pinhole classes were recorded for *R. chirindensis* only 12 months after treatment (Figure 4.7). For all species monitored over the 36-month period, there was a gradual increase in the level of insect damage (as measured by the pinhole class average for all treated trees) following treatment (Figure 4.8).

Measured by pinhole class average and number of trees affected, no significant difference or clear trends in terms of season of treatment were recorded (Appendix 2). For *C. dentata*, a lower percentage of trees were attacked at the Groenkop site compared to the wetter Witelsbos site, but with no significant difference in terms of pinhole class average between the two sites. Also, tree size did not have an effect on the level of insect damage.

4.5.6 Fungal growth

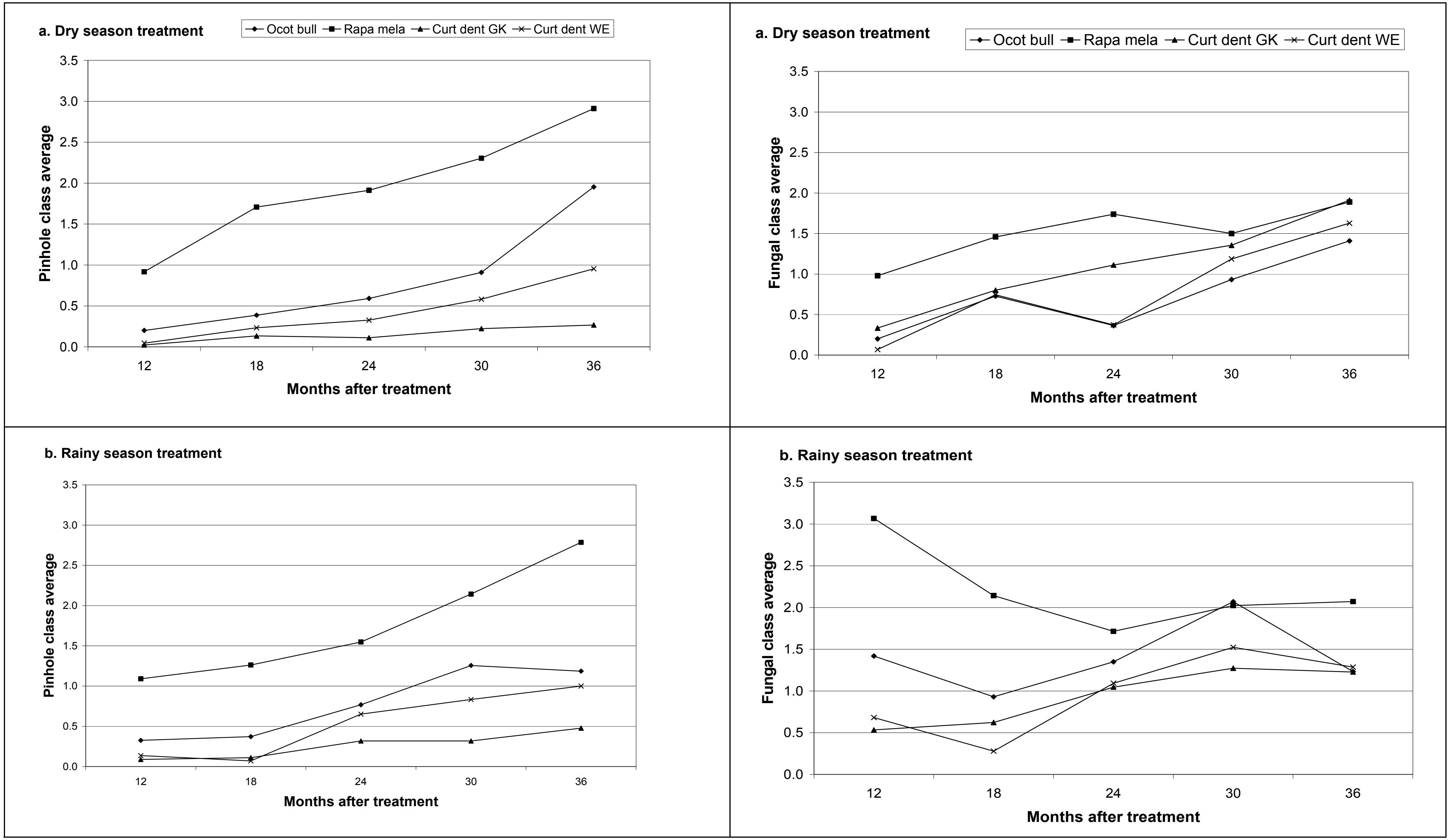
As with insect damage, *R. melanophloeos* and *R. chirindensis* seem to be most susceptible to fungal growth. A class average of 2.1 (median 2) (more than 20% of the wound surface covered) was recorded for *R. melanophloeos* 36 months after bark removal, and 3.9 (median 3.5) (almost 40%) 12 months after treatment for *R. chirindensis*, both for rainy season treatments (Appendix 2).

For the remaining species, less than 20% of the wound surface was covered at the time of the last assessment. Fungal growth showed a gradual increase for dry season treatment over the 36-month monitoring period, but this trend was not consistent with rainy season treatment (Figure 4.8). As with insect damage, the effect of season of treatment on fungal growth



Rapa mela = *Rapanea melanophloeos*; Curt dent = *Curtisia dentata*; Ocot bull = *Ocotea bullata*; Ilex miti = *Ilex mitis*; Prun afri = *Prunus africana*; Rhus chir = *Rhus chirindensis*
D = dry season, R = rainy season; GK = Groenkop study site, WE = Witelsbos study site

Figure 4.7. Representation of pinhole classes for (a) *Ocotea bullata*, *Rapanea melanophloeos* and *Curtisia dentata* (36 months after treatment) and (b) *Ilex mitis*, *Prunus africana* and *Rhus chirindensis* (12 months after treatment) for different seasons of treatment.



Rapa mela = *Rapanea melanophloeos*; Curt dent = *Curtisia dentata*; Ocot bull = *Ocotea bullata*; GK = Groenkop; WE = Witelsbos

Figure 4.8. Insect damage (left) and fungal growth (right) recorded for selected tree species for dry (a) and rainy (b) season treatments over a 36 month period following bark removal.

varied between species, but with no clear trends. Fungal development was not effected by tree diameter.

4.5.7 Agony shoot development

Rhus chirindensis, *I. mitis* and *C. dentata* showed the highest incidence of agony shoot development. For the former two species, 44 and 27% respectively of trees treated during the rainy season had agony shoots 12 months after treatment, with between 15.9 and 32.6% for *C. dentata* between the two study sites 36 months after treatment, followed by 9.3% for *R. melanophloeos* (Appendix 2). However, for *R. melanophloeos*, the number of trees with agony shoots gradually declined as a result of agony shoot dieback, while *C. dentata* showed a steady increase in agony shoot development from date of treatment. In terms of the number of agony shoots per tree (of those that developed agony shoots), the highest average was recorded for *R. chirindensis* with 5.8 and 5.3 shoots per tree 12 months after dry and rainy season treatment respectively. However, season of treatment, and tree size, did not have a significant effect on agony shoot development.

4.5.8 Other observations

For *P. africana*, three trees (15%) had a black, jelly excretion around the wound edge during the second assessment. In the case of *R. chirindensis* a white, sticky excretion was recorded on the wound surface of almost 50% percent of the trees. The relevance or impact of this needs to be assessed with continued monitoring. For *R. melanophloeos*, insect damage and woodpecker pecking marks were observed on the bark around the wound of many trees, increasing with time.

4.6 DISCUSSION

Wounds to tree bark are potentially detrimental as they expose tissue to invasion by insects and decay-causing organisms (Shigo 1993, Bai *et al.* 2005, Chungu *et al*. 2007). Also, ringbarking (or excessive bark removal) would prevent the transport of the products of photosynthesis to the roots through the phloem in the inner bark (Fahn 1985) leading to root and eventually tree death (Lübbe *et al*. 1991, Cunningham 2001).

The differential response of species to bark stripping recorded with this study is consistent with the findings of similar studies conducted on various other forest and woodland species in Africa (Du Toit 2000, Delvaux *et al*. 2007, Geldenhuys *et al*. 2007) and beyond (Bai *et al.* 2005). It is also reported on by Shigo (1993) who studied a large number of damaged trees of different species, Hall (2005) who conducted a literature review on bark harvesting, and Cunningham (2001). This differential response could largely be attributed to the variation in the anatomical composition and tissue structure of tree stems and bark, and its development (Fahn 1985, Shigo 1993, Romberger *et al*. 1993), further influenced by tree physiology, ecology and habitat of the specific species (Bidwell 1979, Kozlowski *et al*. 1991). This needs to be considered with resource-harvesting practices involving damage to tree bark.

4.6.1 Bark regrowth following wounding

Wound closure starts with the formation of callus or wound tissue, consisting of masses of soft parenchyma tissue (Fahn 1985) which gradually overgrows the wound surface (Bai *et al.* 2005). The wound tissue is mostly formed by cells of the cambium (Fahn 1985, Bai *et al.* 2005) but also through the division of parenchyma cells of the phloem (Fahn 1985). Wound closure through edge growth, as recorded for species such as *O. bullata* and *P. africana*, could thus be the result of phellogen development after wounding and callus formation by the intact cambium. Also, wound closure is best when the cambium "slides" over the wound surface (Shigo 1993); when it turns inward to form a callus roll, as was observed with some individuals of *O. bullata* and *C. dentata*, the wound may never close (Shigo 1993).

Where cambium has been stripped, callus may also be formed from immature xylem below (Fahn 1985). Also, if the vascular cambium is killed, but not the extended radial parenchyma cells, these cells may divide to form new wood and bark, recorded as sheet growth on the wound surface (Shigo 1993). Recorded sheet growth for *I. mitis*, *P. africana* and *C. dentata* could thus be attributed to cell division of immature xylem or radial parenchyma cells. This, however, will have to be confirmed through more detailed studies of the wood anatomy of the target species and cell reaction to damage.

The way that the phellogen cells divide also differs between species (Romberger *et al*. 1993), further contributing to the differential responses to bark stripping and bark regrowth through, especially, edge development. The presence and/or distribution of lenticels could also determine bark regrowth for a species as, according to Romberger *et al*. (1993), lenticular phellogens produce derivatives at a higher rate than non-lenticular phellogens. The distribution of lenticels varies with taxa, growth rate, development stage of the individual, as well as environmental variables such as moisture (Romberger *et al*. 1993). Also, through a process of compartmentalisation (Schweingruber 1993, Shigo 1993), whereby defensive chemicals are deposited around the wound (Hall 2005), decay-causing fungi could be restricted to the wood present at the time of wounding (Shigo 1993). The extent to which decay organisms invade the tree is species specific and varies with tree vigour and environmental conditions (Kozlowski *et al*. 1991, Chungu *et al*. 2007), which is consistent with the variation in susceptibility to fungal and insect attack recorded for the different species during this study.

4.6.2 Species-specific response to damage and implications for bark harvesting

Ocotea bullata

Of all the species studied, the best bark regrowth, through phellogen edge development was recorded for *O. bullata*. The smooth bark characteristics of the species, especially with younger trees (Von Breitenbach 1974), could reflect the ability of phellogen to divide anticlinally and periclinally (Shigo 1993), which is consistent with good wound closure through edge growth recorded for the species. In addition, damage through insect and fungal attack seems to be limited, with only a small percentage of trees developing agony shoots as a sign of stress. The lack of wound closure through sheet growth is consistent with findings by Du Toit (2000) of little sheet development.

In the southern Cape, *O. bullata* is most abundant in the mountainous wet forest types (very wet Scrub-Forest and wet High-Forest), although the tallest in moist High-Forest (Von Breitenbach 1974, Geldenhuys 1993). Recovery and survival of the species following fire damage is possible through adventitious buds, which are protected by relatively thick bark (Lübbe 1989, Stewart 1995), and coppicing ability (Botha 1986, Lübbe 1989, Lübbe & Geldenhuys 1990). The abundance of the species in mountain forests that are regularly exposed to fire is therefore partly attributed to its resilience to damage incurred during forest fires (Stewart 1995, Watson & Cameron 2001) and ability to regenerate (Geldenhuys 1993). Also, Davis (1959) cited in Lübbe (1989) reported that *O. bullata* trees survive fires if only parts of the cambium on the stem are damaged through callus tissue development. This resilience is consistent with the ability of the species to recover through phellogen edge growth after bark stripping.

The response of the species to bark stripping allows for various options for sustainable bark harvesting through strip harvesting, despite the fact that little recovery through sheet growth occurs. Its ability to develop strong coppice shoots, and the fact that the chemical compounds with healing effects are also present in the leaves (Zschocke & Van Staden 2000, Zschocke *et al*. 2000, Geldenhuys 2004b, Drewes *et al.* 2006), present further management options for harvesting of the species for medicinal use (see Chapter 5).

Curtisia dentata

Indications are that *C. dentata* can survive for a long period after wind-induced structural damage, as it develops strong leader shoots to form a new crown after such damage (Vermeulen pers. obs., SANParks Unpublished data). Also, the mortality rate-calibrated harvest selection criteria developed for the species (as part of the timber yield regulation system) require advanced crown dieback before it could be considered for harvesting, compared to some other canopy species (Seydack *et al*. 1995). This indicates an ability to persist despite an advanced stage of deterioration, supported by Geldenhuys (1982) who found that some trees still appear healthy 30 months after complete ringbarking.

Despite this resilience, the response of *C. dentata* to bark stripping allows little scope for sustainable bark harvesting through strip harvesting. Less than 60% of the wound edge showed phellogen edge development 36 months after treatment, while it also does not result in wound closure due to the erratic growth and bark lift as the bark dries out around the wound (Vermeulen & Geldenhuys 2005). Also, although phellogen sheet growth was recorded, less than 30% of the wound surface was covered 36 months after treatment, with little or no increase over the 36-month monitoring period. In addition, the regrowth bark (through sheet development) is less than half the thickness of the bark initially removed (Vermeulen Unpublished data[12]), which would not allow for a second harvest.

In terms of sheet development, these results are consistent with findings by Du Toit (2000), but contrary to the thick edge development recorded by Du Toit (2000) in Newlands Forest in the Cape Peninsula, Western Cape. This variation or inconsistency between sites is also reflected in the significantly better sheet development recorded for *C. dentata* at Witelsbos and the smaller number of trees suffering insect damage, compared to the Groenkop study site. With the inconsistent and poor bark regrowth recorded, options other than strip harvesting will have to be explored to ensure a sustainable supply of medicinal bark (See Chapter 5).

Rapanea melanophloeos

Rapanea melanophloeos is fast growing (Von Breitenbach 1974), light demanding and disturbance responding (Geldenhuys 1993), and considered to be an early regrowth species (Geldenhuys 1994c). Its response to bark stripping does not allow for sustainable strip harvesting. There is little phellogen sheet or edge growth, while wound widening occurs as a result of bark lift, evident from the woodpecker pecking marks on the bark around the wound (Vermeulen & Geldenhuys 2005). In addition, of all the species studied, it is the most susceptible to fungal and insect attack, while the high incidence of agony shoot development is consistent with trees experiencing stress (Seydack *et al*. 1995). These findings are consistent with the low survival rate after severe bark stripping reported by Du Toit (2000). The impact of bark stripping and lack of recovery are also reflected in its susceptibility to fire damage (Sutherland 1992, Geldenhuys *et al*. 1994, Watson & Cameron 2001), although this has been contradicted by Homann (1996). However, contrary to findings in the southern Cape, bark regrowth through edge development was recorded for *R. melanophloeos* in the Amatola forests in the Eastern Cape (Viljoen pers. comm. 2006) and KwaZulu-Natal (Vermeulen pers. obs.), as well as in natural forest in Malawi (Syampungani 2005, Geldenhuys *et al*. 2007). This indicates a differential response to bark stripping of the same species over a larger geographical area.

In terms of resource use, the pioneer-like characteristics of *R. melanophloeos* (Phillips 1931), the fact that it is an early regrowth species (Geldenhuys 1994c) and the presence of some of the active compounds in the leaves (Van Wyk *et al*. 1997) do open up various management options for sustainable harvesting for medicinal use. Alternative resources (see Chapter 5) could be developed through growing the species on the forest edge (Geldenhuys 1994c) or other cultivation options (Diederichs 2006) that would reduce pressure on the natural stock.

Ilex mitis

In the southern Cape, *I. mitis* occurs as a small to large tree in the wet and moist forest types (Von Breitenbach 1968a, 1974, Geldenhuys 1993), which could be considered as a fair resource base for bark harvesting (see Chapter 5). However, it recovers poorly through edge development with only about 40% of the wound edge covered 12 months after bark stripping. In addition, together with *R. melanophloeos*, bark lift is most prominent with *I. mitis* both in terms of percentage of the wound edge and distance of lift from the wood. The lift appears to be partly a result of the inner part of the bark on the wound edge crumbling away, exposing a gap between the remaining bark and the wood. This, together with erratic edge development, resulted in a negative rate of wound closure.

In contrast, of all the species treated, *I. mitis* showed the best recovery through sheet development. This is consistent with the good sheet development recorded for it in the Newlands Forest in the Western Cape (Du Toit 2000, 2001). However, although the wound could be fully covered by growth, the regrowth was much thinner than the bark originally removed and was not harvestable (Vermeulen Unpublished data[12]), with little sign of thickening 12 months after treatment. As a result of the good sheet development that covers the wound, the species is less vulnerable to insect and fungal attacked. The large average number of agony shoots per tree recorded for *I. mitis* could be an indication that it experiences

[12] Data were collected as from the 4th remeasurement but were not analysed as part of this study.

stress after bark stripping. Harvest season seems to be less relevant, as for none of the tree response variables was there a significant difference in terms of season of bark removal.

Based on these results, strip harvesting does not seem to be a viable management option for *I. mitis*, as new sheet growth is too thin to allow for a second harvest; other harvest options need to be explored (see Chapter 5). This is contrary to the interpretation by Du Toit (2000) that the good phellogen development and wound surface cover recorded for *I. mitis* in the Cape Peninsula would allow for sustainable strip harvesting.

Prunus africana

With about 90% of the wound edge covered 12 months after bark removal for both seasons of treatment, *P. africana* could be regarded as recovering well through phellogen edge development. However, season of treatment seems to be of great significance in terms of effective bark regrowth and wound closure for the species. While there was a positive rate of wound closure (best after *O. bullata*, of the species studied) following treatment in the dry season, wound widening was recorded following rainy season treatment. This indicates that the percentage of the wound edge with phellogen growth is not always a true reflection of a species' ability to recover through edge development, as was also partly found with *C. dentata*. The importance of season of treatment for *P. africana* is also reflected in the significantly better sheet growth recorded for the rainy season treatment. Although there was bark lift six months after bark removal, it was insignificant 12 months after treatment as a result of aggressive edge development. Bark lift in *P. africana* thus does not negatively affect phellogen edge development as in *I. mitis*, *C. dentata* and *R. melanophloeos*.

The good bark regrowth recorded is consistent with experimental bark harvesting results from KwaZulu-Natal and Malawi (Syampungani 2005, Geldenhuys *et al*. 2007). Regrowth in the southern Cape, however, seems to be less vigorous when compared to recovery in Cameroon in west Africa, where the species is regarded as having a "remarkable ability to withstand bark removal" (Cunningham & Mbenkum 1993). This allowed for the development of sound harvest prescriptions for the species although overexploitation remains a concern (Cunningham & Mbenkum 1993, Stewart 2003, Dawson & Were 2001).

Of all the species treated, *P. africana* was the least affected by insect damage and also seems to be fairly resistant to fungal attack. It is the only species that did not develop agony shoots after bark stripping, although agony shoot development has been recorded for the species in KwaZulu-Natal and Malawi (Geldenhuys *et al*. 2007). This, together with the good bark regrowth recorded for it, indicate that strip harvesting could be a viable option in terms of sustainable bark harvesting. It should be kept in mind that the trees selected for experimental harvesting in the southern Cape are from a planted stand, although the results compare well with those of trees treated in their natural habitat in KwaZulu-Natal and Malawi (Geldenhuys *et al*. 2007). Also, the species has a disjunct distribution in the southern Cape, occurring as a few isolated large trees inside the forest (Geldenhuys 1992), and thus has a limited resource base in the region (Geldenhuys 1981).

Rhus chirindensis

Although phellogen edge development was recorded for *R. chirindensis*, it is erratic and the rate of growth is minimal. Bark regrowth is further negatively affected by bark lift, especially following rainy season treatment, and wound closure through sheet development is insignificantly small. Together with *R. melanophloeos*, it is the most susceptible to insect damage of the species studied.

In the southern Cape it is found occasionally as a small or medium tall tree in dry scrub and high forest (Von Breitenbach 1968a, 1974, Geldenhuys 1993), and could be regarded as having a limited to fair resource base for bark harvesting. Based on the species' response to bark stripping, it is unlikely that bark could be harvested on a sustainable basis through a strip harvesting system. Other options to meet the demand for medicinal bark will have to be explored (see Chapter 5).

4.6.3 Seasonal variation in tree response to bark stripping

Influenced by climatic conditions, vascular cambium shows great variation in the period and intensity of activity (Fahn 1985) which impacts on wound recovery and tree response to damage inflicted to tree bark during different seasons (Neely 1970, Biggs 1986, Kozlowski *et al*. 1991, Schmitt & Liese 1992). In regions with definite seasonal climates (four seasons), cambium activity ceases towards the end of summer with the onset of unfavourable conditions and become active again in spring (Fahn 1985). Periderm formation and subsequent phellogen development that could result in wound closure are also influenced by environmental factors such as light intensity, photoperiodicity, temperature, soil moisture and humidity (Borger 1973, Fahn 1985, Biggs 1986). The temperature at which periderm development is at its maximum and the minimum light intensity required for development are species-specific (Borger 1973), which is consistent with the differential response recorded between species in terms of season of harvest. Furthermore, it appears that a high relative humidity is necessary for wound periderm development and that a very low relative humidity could prevent wound periderm formation (Borger 1973). Dickison (2000) also stresses that the way and the rate that new secondary tissue differentiate, are influenced by which tissue is exposed by wounding, and the ambient conditions during wound closure.

Consistent with the above, Neely (1970) recorded better bark regrowth for selected species following damage during spring and summer, compared to winter and autumn. This was attributed to higher radial growth during summer. Kozlowski *et al*. (1991) also reported that wounds made just prior to the start of the growing season heal rapidly compared to wounds made after the growing season. In terms of species, Dyer (1989) reported that growth rings are clearly visible for *O. bullata* and *C. dentata*, but not for *R. melanophloeos*. Seasonality in cambium activity thus seems to be more pronounced in *O. bullata* and *C. dentata* (the species that showed phellogen development through edge growth) than in *R. melanophloeos* (no phellogen growth after bark stripping) in the southern Cape. However, also for *P. africana*, growth rings are not clearly visible (Dyer, 2005) despite the relatively good edge growth recorded for it. In addition, wound healing is positively correlated with the vigour of individual trees (Neely 1970, Kozlowski *et al*. 1991) which is, as was found for most canopy species in the southern Cape forests, influenced by inter- and intraspecific competition (Van Daalen 1993a), crown position and crown form (Van Daalen 1993b), as well as tree senility (or maturity) condition (Seydack *et al*. 1995, Seydack 2000b; also see Van Daalen 1991, Wyckoff & Clark 2002). This all adds to the complexities with interpreting of results of the effect of harvest season on tree response to bark stripping.

Seasonal variation in bark regrowth through edge development

Of the species that showed best bark regrowth through edge development (i.e. *O. bullata*, *P. africana* and *C. dentata*), growth was significantly poorer for trees treated during the rainy season (summer). Following the pattern of rainfall peaks in early and late summer with drier, colder periods during winter (see Chapter 1), summer would represent the period of highest cambium activity in the southern Cape. The poorer bark regrowth recorded for the rainy season treatment is thus contrary to the expected better growth during this period of higher cambium activity. However, Vasillauskas (2001) reported that, for the northern hemisphere, damage in the non-growing season could be less than at other times, partly because the bark adheres more tightly to the sapwood, while damage could be more extensive when detached at times of elevated cambium activity (Malan & Van Wyk 1993). This is supported by the higher bark lift recorded for *R. chirindensis* following rainy season treatment. Also, energy reserves of trees are at their lowest at the end of the dormant season, just after new growth has started (Shigo 1993). During this period defence mechanisms are at their lowest, and trees are most vulnerable following injuries (Shigo 1993). In the southern Cape, renewed cambium activity occurs towards the end of spring (Geldenhuys 1982), and bark stripping during this period could thus be regarded as less favourable. This could explain the poor bark regrowth for species such as *O. bullata* and *C. dentata* treated during December, just after renewed cambium activity.

Furthermore, physiologically, trees are more vulnerable during the period that sugars are converted to insoluble energy reserves, which coincides with the period that leaves are falling (Shigo 1993). In the southern Cape, tree species flush during early summer, and nutrients are transported from the old to the new leaves before the peak of leaf fall is reached in mid-summer (December-January), which also coincides with plant moisture deficit (Geldenhuys & Theron 1994). This could further explain the poor edge development recorded for trees treated during December and January, despite the fact that stripping occurred during the season of active cambium growth (summer). Patterns of seasonal response to bark stripping could also be upset by other factors. For example, Kozlowski *et al*. (1991) reported that cambium activity is sensitive to abiotic (drought, temperature extremes, etc.) and biotic (plant competition, insect attack, browsing, etc.) environmental stresses, and is often interrupted by drought, resuming after rains. Also, in the southern Cape, trees could be in an active vegetative phase during winter months as a result of warm berg wind conditions and intermittent rains (Geldenhuys 1982, Kotze & Geldenhuys 1992). This, for example, upset the results of seasonal patterns following experimental culling of canopy trees in the southern Cape (Geldenhuys 1982), which could also explain the unexpected good edge growth recorded for *O. bullata*, *P. africana* and *C. dentata* following dry season treatment.

Seasonal variation in bark regrowth through sheet development

Climatic conditions and the extent to which the wound surface remains moist after bark stripping could determine whether recovery would be through sheet or edge development (Hall 2005). When the wound surface is moist, uniform wound callus could develop across it while, under less favourable circumstances (dry wound surface), callus growth would be from the wound periphery (Dickison 2000). This is supported by Fahn (1985), stating that cambium may be re-formed from immature xylem below the wound surface *if* protected from drying after the wound is formed.

Of the species that showed best recovery through sheet development, namely *I. mitis*, *P. africana* and *C. dentata*, the better growth recorded following rainy season treatment could be attributed to the moist conditions and higher temperatures during the season of treatment (Durrheim & Vermeulen 2006; see Chapter 1). This is supported by the findings of Geldenhuys & Rau (2004) that bark removed during the rainy season treatment was generally moister than that removed during the dry season. On the other hand, trees treated during the dry winter months with dry berg winds rely more on edge development for wound closure, although this could be hampered by the lack of cambium activity. For *P. africana*, this is not only consistent with the significantly better sheet development for the rainy season treatment, but also with the significantly poorer edge growth recorded for this treatment.

Seasonal variation in susceptibility to fungal and insect attack

The warmer, moist conditions during summer are most favourable for fungal growth (as has been recorded for *Phytophthora cinnamomi* on *O. bullata*) (Kotze & Geldenhuys 1992). Furthermore, during the growth period protective and defensive boundaries in the bark may be broken, caused by natural processes of bark expansion, resulting in the rapid spread of pathogens in the bark (Shigo 1993). This is consistent with the higher fungal growth recorded for *C. dentata* (Groenkop site) and *R. chirindensis* following warm, rainy season treatment. The potential advantage of quicker bark regrowth, when strip harvesting is conducted during the period of more active growth, could thus be counteracted by the high vulnerability to fungal attack during the wet summer months. Insect damage seems to be less affected by season, as for none of the species was there a significant difference between rainy and dry season treatment.

Direct comparisons between successive assessments and between rainy and dry season treatment should, however, be treated with caution. As fungal growth varies seasonally, it could be expected that surface fungal growth present during an assessment would be affected by the time of year that the assessment is conducted (winter or summer), resulting in variation between successive assessments. Also, as the rainy and dry season treatments were conducted six months apart and assessments were conducted every six months, the first assessment (for example) for the dry season treatment was conducted during the rainy season and *vice versa* for the rainy season treatment. Direct comparisons between rainy and dry season treatments, especially in terms of months after treatment, are therefore difficult. The effect of season of treatment on fungal development is speculative and will not be explored further. Also, what is presented here only represents surface fungal growth; internal damage to the exposed wood could be more severe (Roux *et al*. 2005). Season of assessment could also affect the presence or absence of agony shoots, and should be considered with interpretation of results.

Optimum season for harvesting

The variety of factors that influence the response of trees and tree species to season of bark stripping, and the variable response from different trees species, do not allow for easy interpretation of experimental results that could influence harvest prescriptions. Considering these complexities, only broad guidelines across species in terms of season of harvesting could thus be provided. To benefit from seasonal cambium growth, bark harvesting should be conducted in early summer, after leaf flush (not during) but before leaf fall increases. Although better edge development was recorded for the winter treatment (July and August), October and November seem to be most favourable for bark harvesting in the southern Cape.

Late summer (March and April) could also be favourable, as energy reserves are at their highest point as the tree goes into dormancy (Shigo 1993).

Although temperature, photoperiod and rainfall patterns generally control the length of the growing season (Kozlowski *et al*. 1991), the proportion of the season actually used differs widely among species, and growth is usually discontinuous (Fahn 1982). Because phenology differs between species (Koen 1992, Koen & Geldenhuys 1992, Geldenhuys & Theron 1994), the energy flow patterns of individual species (Shigo 1993) should ideally be known to make more informed decisions on season of bark harvesting.

4.6.4 Strip width, strip length and tree diameter

Although the occurrence of edge or sheet growth is not affected by strip width as such, strip width could affect the rate of wound closure (Neely 1970), impact on the extent of fungal and insect attack and affect sapflow and tree vigor (Shigo 1993). Unlike with large wounds where pathogens spread rapidly, the growth of organisms does stop with smaller wounds that close rapidly (Shigo 1993). For *R. melanophloeos*, O. *bullata* and *C. dentata*, the least decline in crown condition over the 36-month study period was recorded for trees with a narrow strip width of 5 cm, although also influenced by tree diameter. Strip width is therefore an important consideration in the development of best practices for sustainable bark harvesting and has to be accommodated in any harvest system for a particular species (see Chapter 5).

As reported by Kozlowski *et al*. (1991), cambium activity is not only a variable in time but also in space. In terms of wound closure, the increment of radial growth at the wound site itself (Neely 1970) is therefore significant. In suppressed trees, wounds in the upper stem where the rate of cambial growth is most rapid, would heal much faster than those on the lower stem, and *vice versa* for vigorous open-crown trees (Kozlowski *et al*. 1991). This holds potential implications for optimum strip length and height of bark removal along the clear bole, to be considered when developing harvest prescriptions. Also, no significant difference in tree response to bark stripping between the top and bottom part of the 1 m long strip was found with this study, indicating that the strip length could probably be extended; this would add to the harvestable bark volume without jeopardising sustainability.

As crown dieback and mortality are part of a natural ecological process, it is difficult to conclusively link crown dieback to bark stripping, and variation across tree diameter. However, it can be expected that the smaller trees with a wide strip width would be most severely affected, compared to larger trees with a narrow strip width. Also, significantly better sheet and edge development was recorded for bigger trees, while a higher incidence of tree die-back was recorded for smaller trees following bark stripping. A minimum tree diameter should thus be set for bark harvesting.

4.7 CONCLUDING REMARKS

In achieving the study objective, it has been demonstrated how the different species respond to bark stripping in terms of bark regrowth and susceptibility to fungal and insect attack. The research questions on the response of the target species to bark stripping were adequately answered to inform prescriptions for sustainable bark harvesting (see Chapter 5). The study showed that through experimental bark stripping, species-specific results of tree response to bark removal can be obtained in a relatively short period to assess harvest options and to allow for the development of harvest prescriptions that could be refined further with continued monitoring. In terms of the species studied, the results are disappointing, with only *O. bullata* and *P. africana* showing adequate bark regrowth for sustainable strip harvesting. For *C. dentata*, *I. mitis*, *R. chirindensis* and *R. melanophloeos*, full-tree harvesting, which would in effect require the development of a timber yield regulation system for the species, seems to be a more viable option. For species such as *O. bullata* and *R. chirindensis*, bark and leaf harvesting through coppice management could also be explored.

The study results largely support the general hypothesis that response to bark stripping is influenced by season of bark stripping, as well as tree diameter. For some variables and species, the results showed significant differences between rainy and dry season treatments, but this would only be of relevance if the species has potential for strip harvesting. Despite significantly better wound closure through edge growth for the dry season treatment for both *O. bullata* and *P. africana*, the optimum time of year to conduct bark harvesting remains difficult to clearly define, considering the wide range of environmental and other factors affecting tree response to bark removal. Although it varied between species, smaller trees showed a higher incidence of crown die-back, while more aggressive bark regrowth was recorded for bigger trees.

Although bark regrowth allows for successive strip harvesting, Shigo (1993) emphasises that trees do not heal or restore injured and infected wood, but that wounds merely close as the tree produces new wood in a new spatial position. The tree walls off injured or infected wood, but the wound will remain for the life of the tree. Long-term implications of strip harvesting are thus unknown. The results, however, provide enough information to implement conservative approaches to sustainable bark harvesting, whether through cycles of strip harvesting, full-tree harvesting, or the creation of alternative resources. This, and how bark harvesting could be integrated with the current management system for the southern Cape forests, is explored further in Chapter 5.

4.8 ACKNOWLEDGEMENTS

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CHAPTER 5: MANAGEMENT OPTIONS AND POTENTIAL FOR MEDICINAL BARK HARVESTING FROM SELECTED FOREST SPECIES IN THE SOUTHERN CAPE

5.1 INTRODUCTION

Since 1711 when European settlers reached the large tracts of natural forest in the southern Cape (Von Breitenbach 1968a, 1974), forest management has largely focused on timber exploitation (Seydack & Vermeulen 2004). A formal policy of multiple-use conservation management was only implemented in 1966 (Grewar 1982). Harvesting of non-timber forest products (NTFPs) was initiated in 1982 with the forest being opened up for conservative commercial harvesting of *Rumohra adiantiformis* (seven-weeks fern) for the flower market (Geldenhuys 1994b). A policy of participatory forest management (PFM) was adopted and implemented to ensure local participation in decision-making and the sharing of economic, social and environmental benefits from the forests (Horn 2002, Durrheim & Vermeulen 2006, DWAF 2004; see Chapter 1).

In South Africa a large percentage of especially rural communities still use traditional medicines (Lawes *et al.* 2004a). Medicinal tree bark from a wide range of forest tree species (Grace *et al*. 2003) constitutes nearly one-third of plant material used in South African traditional medicine (Grace *et al*. 2002). Following the promulgation of the National Forests Act (Act No. 84 of 1998) (NFA) and the restoration of access rights to forest resources, there has been a growing demand in the southern Cape for access to natural forests for the harvesting of medicinal plants, including tree bark,. This is exacerbated by a fast-changing population demography in the region (Reuther & Gebhardt 2005, Anon. 2007) and more people, who traditionally use medicinal plants, moving into the area.

Sound systems exist worldwide – including in the southern Cape (Seydack *et al*. 1990, 1995) – for the sustainable harvesting of timber (Khasa *et al*. 1995, Brand 1997, Parren 2000). However, despite the demand for and importance of medicinal bark, the development of bark harvest systems has been neglected. A multiple-use forest management system is in place in the southern Cape providing access to forest resources other than timber, but there is still no management strategy for sustainable bark harvesting.

5.2 STUDY OBJECTIVES

The study was motivated by the management objective of ensuring optimum, sustainable harvesting of NTFPs from natural forests in the southern Cape, including medicinal bark, with due consideration of other management objectives and land-uses. Following experimental bark harvesting on certain target species (*Ocotea bullata*, *Curtisia dentata*, *Rapanea melanophloeos*, *Ilex mitis*, *Rhus chirindensis* and *Prunus africana*) (see Chapter 4), this chapter deals with Specific objective 4, namely "to develop a conceptual framework and decision tree based on experimental research; to identify the most appropriate harvest options for the sustainable supply of medicinal bark for target species; and to guide the formulation of harvest prescriptions"; and Specific objective 5, namely "to assess and demonstrate how sustainable medicinal bark harvesting could be integrated with the existing forest management system in the southern Cape, with due consideration of other management objectives and land-uses". The demand for medicinal bark, especially in terms of species from natural forest in the southern Cape, is assessed and discussed.

Associated research questions:

- How could the response of different species to bark stripping, in terms of bark regrowth and susceptibility to fungal and insect attack, be consolidated to inform the choice of a harvest system for sustainable bark exploitation?
- How could the response of different species to bark stripping inform harvest prescriptions for specific species?
- Which tree bark species are used and most in demand in the Southern Cape?
- What alternatives exist where the supply of medicinal bark is restricted by the resource base and/or tree response to bark stripping?
- How could sustainable bark harvesting be incorporated with the current, largely timber-based, forest management system in the southern Cape? Should bark harvesting follow the established timber management system, or should a different approach be followed incorporating the peculiarities of bark response of different species?

5.3 HISTORICAL BACKGROUND TO MEDICINAL BARK HARVESTING IN THE SOUTHERN CAPE

The demand for medicinal bark is growing in the Western Cape, as in other provinces in South Africa (Mander 1998, Williams 2004, Cocks *et al*. 2004, Botha *et al*. 2001), with some target species already under threat in forests in the Cape Peninsula (Du Toit 2000). The demand for medicinal bark in the southern Cape and bark removal damage have always been regarded as negligible (Mostert & Lübbe 1991), yet isolated incidences of illegal bark stripping have been recorded as far back as the 1980s (Reynell & Durrheim 1989, Ferguson 1995). This has escalated, especially along the more accessible roads (Lübbe 1989, Lübbe *et al*. 1991, Ferguson 1995, Van der Merwe pers. comm. 2006, Wessels pers. comm. 2007) and in forests around the town of Knysna (Berry 1993a,b, Vermeulen pers. obs.), demonstrating the urgency to address user needs (see Plate 4.1g). The demand for medicinal bark from certain target species (e.g. *O. bullata*, *C. dentata*, *R. melanophloeos*) has been confirmed through structured interviews with traditional healers practicing in the southern Cape (Vermeulen, Unpublished data[13]).

The first formal request to make medicinal bark from timber species available to traditional healers in the Western Cape was received in 1991 (DWAF Unpublished records), but concerns were raised that allowing these healers access to forest resources could trigger illegal, uncontrolled harvesting in the region. With the lack of a formal policy on addressing wider stakeholder needs, it was recommended that collectors rather obtain the bark from timber buyers once the timber has been sold on auction. Lübbe *et al*. (1991) revealed that herb traders in KwaZulu-Natal consider this bark marketable, especially in terms of species which are not freely available. However, Geldenhuys & Lübbe (1990) and Lübbe *et al*. (1991) indicated that, compared to the demand, only a limited supply of bark would be available from auctioned logs, and that other options should also be explored. The harvesting of medicinal bark as a by-product of commercial timber harvesting in the southern Cape was

[13] Interviews were conducted with 15 traditional healers as part of this study to gain better insight in stakeholder needs and user trends, but are not reported on here in any detail.

also advocated by Lawes *et al*. (2000). Research on the response of selected tree species to bark stripping to inform harvest prescriptions was initiated in the southern Cape in 2001 and is reported on in Chapter 4.

5.4 CONCEPTUAL MODEL AND DECISION TREE FOR THE DEVELOPMENT OF A BARK HARVEST SYSTEM

Various management options could be explored for medicinal bark, which entails using existing natural forest resources, as well as resource expansion by developing alternatives (Diederichs *et al*. 2003, Geldenhuys 2004a,b, Geldenhuys & Mitchell 2006, Geldenhuys & Delvaux 2007, Vermeulen 2007b). The scope of management options would largely depend on the response of the target species to bark stripping.

Managers, however, need to take an objective decision on the most appropriate harvest options for a particular species to ensure that bark harvesting is sustainable and viable in the long term, and to optimize socio-economic benefits from resources used. A conceptual framework for the development and choice of a bark harvest system is provided in Figure 5.1. The first step is to identify high-demand species, evaluate their resource base and assess the ecological characteristics of the target species. Thereafter the process entails (a) experimental harvesting or assessment through field observations to determine species response to bark stripping; (b) the grouping of species based on response to bark stripping; and (c) the choice of a harvest system for species that show a similar response to bark stripping. This culminates in the formulation of species-specific harvest prescriptions. A further challenge is the integration of bark harvesting with multiple-use forest management systems where it already exists, while alternatives such as coppice management and leaf harvesting can also be explored.

5.4.1 Identification of high-demand species

The development of a management system and harvest prescriptions should be done in close cooperation with users and other relevant stakeholders. Indigenous knowledge and traditional practices should, as far as possible, be incorporated into harvest systems and accommodated in harvest prescriptions. Thus, before the onset of ecological studies, the target product needs to be clearly defined in consultation with users. Various methods have been developed for engaging with communities and identifying user needs. These include structured and semi-structured interviews (questionnaires), as well as rural appraisal (RA) and rapid rural appraisal (RRA) techniques (Molnar 1989, Cunningham 2001). Especially with medicinal plants, harvesters or healers could also accompany researchers on reconnaissance field visits, which could include e.g. formal transect walks to ensure positive species identification (Cunningham 2001, Martin 2004, DWAF 2005c). Surveys at medicinal plant markets also proved to be effective in identifying the most valued and high-demand species (Mander 1998, Williams 2004, Cocks *et al*. 2004, Botha *et al*. 2001).

5.4.2 Experimental bark harvesting

The response of different forest species to bark stripping is the single most important aspect

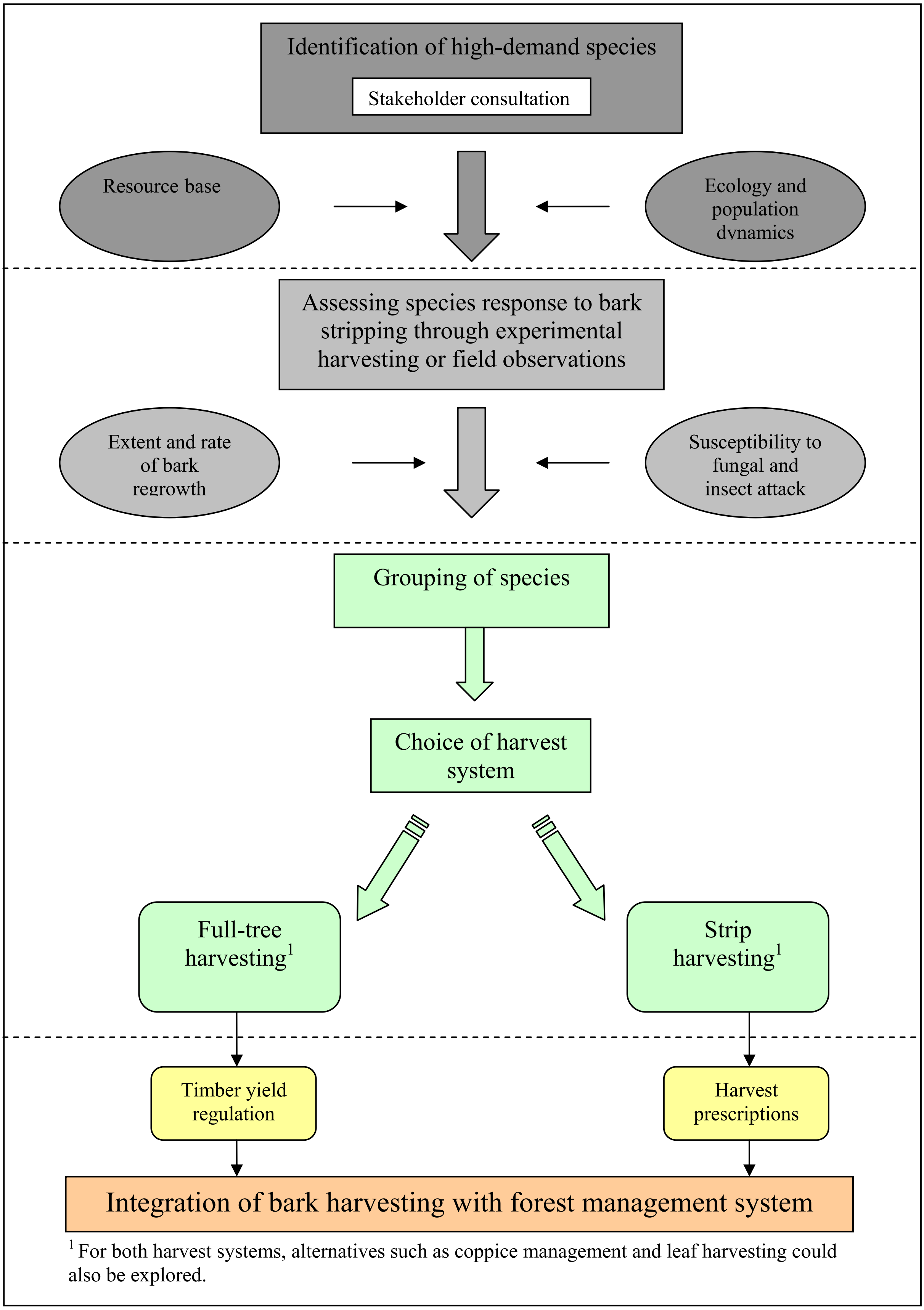


Figure 5.1. Conceptual framework for the development and choice of a harvest system for medicinal bark in natural forests.

determining the scope for sustainable medicinal bark harvesting and harvest options that could be explored with a particular species. Assessing species-specific tree response to stripping can best be achieved through controlled, experimental harvesting and long-term monitoring as reported by Syampungani (2005), Delvaux *et al*. (2007), Geldenhuys *et al*. (2007), and dealt with in detail in Chapter 4. Key aspects are the extent and rate of bark regrowth and susceptibility to fungal and insect attack following bark removal.

5.4.3 Grouping of species

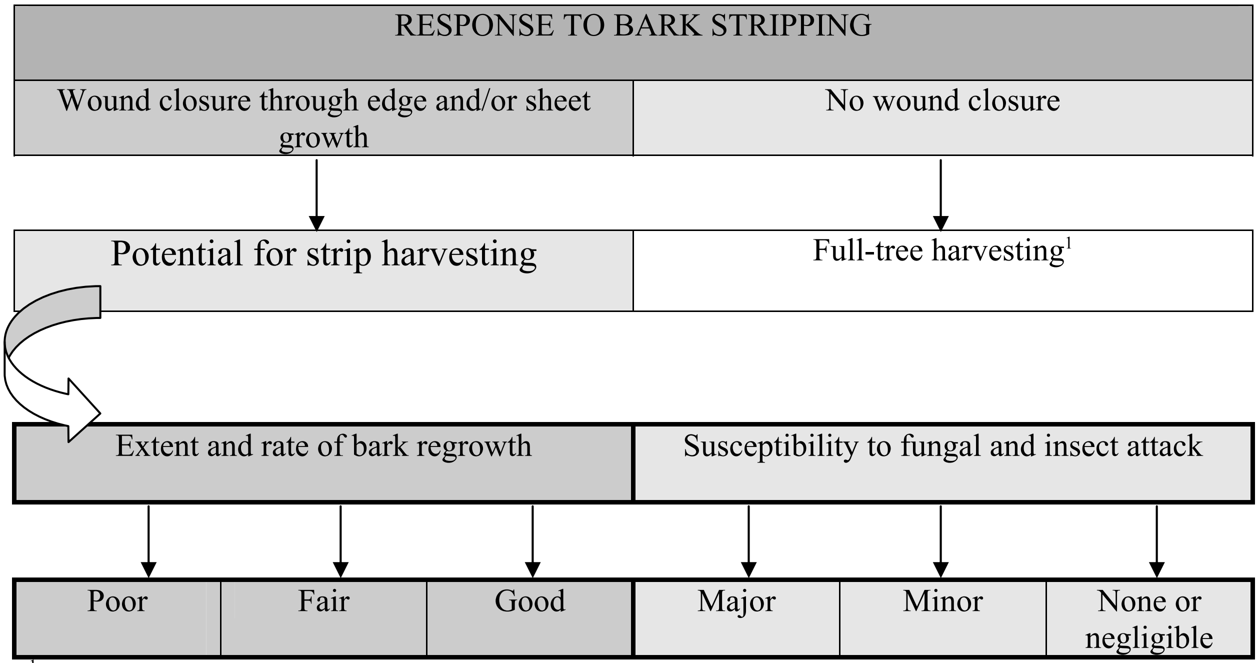
Based on experimental harvesting results (Chapter 4) a decision tree was developed to aid forest managers in selecting the most appropriate harvest system for a particular species (also see Vermeulen 2007b). Applying the decision tree and grouping the species need not be based on experimental harvesting results only, but, in anticipation of research results or where experimental harvesting has not yet been conducted, could also be informed by field observations in harvest areas, following an adaptive management approach (Geldenhuys 2004b).

The first step entails grouping the species based on their response to bark stripping, incorporating the ability and rate of bark regrowth through phellogen edge and/or sheet growth, and susceptibility to fungal and insect attack (Figure 5.2). Species that show bark regrowth and thus have potential for strip harvesting, could be further categorised based on the extent and rate of bark regrowth (i.e. species with poor, fair and good rate of wound closure). Harvest options and prescriptions are also affected by the extent of damage to the exposed wood through insect and/or fungal attack after bark stripping. A species could thus be further defined by allocating it to one of three insect/fungal damage susceptibility classes (i.e. major, minor and none/negligible) (Figure 5.2). The different groups could be defined more clearly as results of experimental harvesting and broader field observations become available.

5.4.4 Choice of harvest system

Depending on whether or not wound closure through bark regrowth occurs, a species would either be allocated to strip or full-tree harvesting (Figures 5.1 and 5.2). Not all species, though, that show bark regrowth have the potential to supply a sustainable flow of bark through strip harvesting. Rate of wound closure and extent of damage through insect or fungal attack would be the final determinants of whether strip harvesting is a viable option. To identify species with true potential for strip harvesting, a combined assessment of rate of wound closure and susceptibility to fungal and/or insect attack is required (Table 5.1). Based on this combined assessment, a species would either be a clear candidate or have marginal scope for strip harvesting. Those species with fair or good wound closure and that suffer minor or no insect/fungal damage, are most likely to sustain strip harvesting. For example, a species with a fair rate of wound closure would not qualify for strip harvesting if it suffers major damage through insect attack; it would have marginal scope if insect damage is minor; but it would be a clear candidate if insect damage is negligible (Table 5.1).

Regarding species with marginal scope, other factors such as bark lift from the remaining wood and the presence of agony shoots, cracks and excretions on or around the wound surface



[1] Could also be considered for species with bark regrowth when large volumes of bark are required

Figure 5.2. Grouping of species based on response to bark stripping to aid in selecting the most appropriate management system (see Table 5.1) for sustainable bark harvesting.

would be the final determinants of whether bark supply could be sustained through strip harvesting (see Chapter 4). For species that show no bark regrowth, full-tree harvesting or other harvest options need to be explored.

Strip harvesting

Strip harvesting entails the removal of vertical strips of bark from the target species, and is most appropriate where relatively small volumes of bark are required. Key aspects of a management system for strip harvesting include:

- strip width and length;
- harvest rotation;
- minimum diameter of harvest trees;
- percentage of the trees in the population to be exposed to bark stripping; and
- the number and rotation of strips on selected trees.

A decision on harvest prescriptions should be taken after assessing all the variables. There is, however, no fixed rule for the development of such prescriptions. The combined assessment of wound closure and susceptibility to fungal and/or insect attack could guide the formulation of prescriptions for those species that do qualify for strip harvesting (Table 5.2).

Strip width, harvest rotation and number of strips

The faster the rate of wound closure through sheet and/or edge growth, the shorter the harvest rotation or wider the strip width that could be used. When formulating harvest prescriptions, though, there is a trade-off between rotation and strip width – the shorter the rotation, the smaller the strip width, and *vice versa*. This is especially the case where wound closure takes

Table 5.1. Decision matrix to determine the scope for strip harvesting of medicinal bark, based on species response to bark stripping

		SUSCEPTIBILITY TO INSECT AND FUNGAL ATTACK		
		Major	**Minor**	**None or negligible**
BARK REGROWTH	**None**	Full-tree harvesting	Full-tree harvesting	Full-tree harvesting
	Poor	Full-tree harvesting	Full-tree harvesting	Marginal scope for strip harvesting[1]
	Fair	Full-tree harvesting	Marginal scope for strip harvesting[1]	Strip harvesting
	Good	Marginal scope for strip harvesting[1]	Strip harvesting	Strip harvesting

[1]Consider factors such as bark lift, drying out of bark around the wound edge, thickness of bark regrowth, presence of agony shoots, cracks and excretions on or around the wound surface for a final decision

Table 5.2. Decision matrix to guide the formulation of prescriptions for strip harvesting, based on species response to bark stripping

		SUSCEPTIBILITY TO INSECT AND FUNGAL ATTACK		
		Major	**Minor**	**None or negligible**
BARK REGROWTH	**Poor**			5 cm strip 33% of population
	Fair		5 cm strip 33% of population	5–10 cm strip 50% of population
	Good	5 cm strip 33% of population	5–10 cm strip 50% of population	10 cm strip 66% of population

OTHER CONSIDERATIONS:

- Harvest rotation should allow for wound closure
- Strip width for sheet growth could be proportional to tree diameter
- One or more strips depending on tree diameter
- Strip length up to 2 m
- Minimum DBH of 20 cm for canopy species
- Harvest season that would improve bark regrowth

place exclusively through edge growth. In addition, harvest rotation would also be affected by the extent and rate of fungal and/or insect attack. For example, even though the rate of wound closure might be fast, harvesting could still be restricted to a short rotation or small strip width to limit the impact of fungal or insect attack.

Based on experimental research (Chapter 4; Vermeulen & Geldenhuys 2004), a strip width of 5 to 10 cm seems to be the most likely for species that recover through sheet or edge growth (Table 5.2). Where wound closure takes place through sheet growth, strip width could also be proportional to tree diameter. Strip length is more flexible and could be up to 2 m, depending on taper and bark thickness. Depending on the rate of wound closure and the selected strip width, the harvest rotation is likely to be two years or more. Harvesting could either be rotated between trees within a forest stand, or by dividing the stand into smaller harvest units to be worked according to a fixed schedule.

Various options exist in terms of the number of strips that could be harvested per tree and how they should be rotated around the stem between successive harvests. In the case of large trees and species that recover well after bark stripping, two strips per harvest (e.g. east and west) could be considered. At the next rotation (once full wound closure has taken place), the two strips could be harvested south and north on the stem, etc. In most cases, though, only one strip per harvest is recommended until supporting evidence is available through long-term monitoring that more than one strip at a time could be sustained.

Diameter of harvest trees, and harvest percentage

As smaller trees are more affected by bark stripping, a minimum diameter for harvest trees should be set. Based on the results from experimental harvesting (Chapter 4; Vermeulen & Geldenhuys 2004), it is recommended that the minimum diameter at breast height (DBH) be set at 20 cm. This could be lowered where supporting evidence is available for a species that can sustain the harvesting of smaller trees, or for subcanopy species.

As the long-term effect of strip harvesting on the survival and longevity of trees is still not known, it is advisable to also restrict harvesting to only a certain percentage of the healthy population of the target species. It is recommended that no more than two-thirds of the healthy trees of a population be exposed to strip harvesting, and not more than one-third for species that have a low wound closure rate or are susceptible to fungal or insect attack. Table 5.2 could be used to guide decision making on this.

Harvest season

Experimental results show that response to bark stripping (in terms of e.g. edge growth, sheet growth, susceptibility to fungal and insect attack) could be affected by season and climatic conditions during harvesting, and this varies between species (Chapter 4; Geldenhuys *et al*. 2002, Vermeulen & Geldenhuys, 2004). Where possible, this should be considered with the formulation of harvest prescriptions by concentrating harvesting in the seasons, and conducting it during climatic conditions that would yield the most positive response to bark stripping.

Harvest method

An instrument with a thin blade should be used to remove the vertical strip of bark. Measures should be taken to prevent the remaining bark lifting from the wood as this would negatively affect wound recovery, especially regarding edge development. The harvesting tool should be inserted at an angle to ensure that the bark is only lifted at the wound side of the edge during the harvest operation. Removing narrow strips of bark and working gradually outwards until the specified strip width is reached would help prevent bark lift (Geldenhuys & Mitchell, 2006).

Neely (1970) reported that the top and especially the bottom of wounds are slow to heal compared to the sides. This has also been observed for *O. bullata*, and especially for *C. dentata* and *R. chirindensis*, following experimental harvesting in the southern Cape (Vermeulen pers. obs.). In addition, for some species (e.g. *R. melanophloeos* and *C. dentata*) water also tends to accumulate on the bottom (horizontal) edge of the wound (Geldenhuys *et al.* 2002, Vermeulen pers. obs.) which could contribute to fungal growth or hamper bark regrowth. An ellipse wound shape or a V-shape at the bottom would thus enhance wound closure through edge development. Chungu *et al*. (2007) found that covering the wound with mud (a traditional practice) and harvesting at night could reduce fungal and insect infestation.

Full-tree harvesting

Full-tree harvesting applies to species that show little or no wound closure through edge or sheet growth after wounding, so bark supply through strip harvesting could not be sustained (Figure 5.2). Full-tree harvesting would entail felling mature trees and harvesting all utilisable bark (including bark on the branches), or stripping as much bark as possible off the standing tree if it cannot be felled. In essence, this would involve the development of a timber yield regulation system for the tree populations of target species. It would require a growing-stock survey and gathering information on rate of turnover (regeneration, increment, mortality, etc.) through long-term monitoring to calculate sustainable harvest levels. For a single-tree selection system, it is advisable that criteria for the selection of harvest trees (based on tree condition) also be developed (see Seydack *et al* 1995). Ideally, a use or market for the timber (furniture, construction poles, etc.) should be found to ensure optimal use of the available resource.

Full-tree harvesting need not be confined to species that do not recover after bark stripping. Especially for commercial use where there is a demand for large volumes of medicinal bark, full-tree harvesting would be a more viable option than strip harvesting.

5.5 APPLYING THE CONCEPTUAL MODEL TO SOUTHERN CAPE SPECIES

The conceptual model (Figure 5.1) and the decision tree (Figure 5.2, Tables 5.1 and 5.2) were used to inform harvest options and best practices for sustainable bark harvesting in the southern Cape.

5.5.1 Important bark species and resource base in the southern Cape

A total of 21 tree species have been identified from which bark is harvested for medicinal use from natural forest in the southern Cape (Table 5.3). This is based on observations of bark stripping (Reynell & Durrheim 1989, Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991, Mostert & Lübbe 1991, Ferguson 1995), resource surveys (Berry 1993a,b) and structured interviews with traditional healers (Vermeulen Unpublished data[13]). With the exception of Limpopo Province, most of these species are also traded or used medicinally in other provinces (Table 5.4), with *O. bullata, C. dentata* and *R. melanophloeos* highly in demand (Mander 1998, Grace *et al*. 2003, Williams 2003). However, *Apodytes dimidiata*, *Celtis africana* and *Olinia ventosa* have not been listed for other provinces – although the use of *A. dimidiata* for medicinal purposes has been recorded by Hutchings (1989) – and the medicinal use of their bark in the southern Cape will have to be confirmed.

The distribution of the different species in the region per forest type, with a rating of bark availability (based on tree abundance and dimensions reached in the different forest types), is given in Table 5.5. Based on distribution, each species was subsequently rated in terms of its

Table 5.3. Tree species observed or recorded to be harvested medicinally for their bark in the southern Cape forests

Species	**Source**
Apodytes dimidiata	Reynell & Durrheim 1989, Berry 1993a,b
Calodendrum capense	Berry 1993a,b
Celtis africana	Berry 1993a,b
Cunonia capensis	Berry 1993a,b
*Curtisia dentata**	Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991, Mostert & Lübbe 1991, Berry 1993a,b, Ferguson 1995
Ekebergia capensis	Geldenhuys & Lübbe 1990
Elaeodendron croceum	Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991
Ficus sur	Berry 1993a,b
*Ilex mitis**	Berry 1993a,b, Vermeulen pers. obs.
Maytenus acuminata	Berry 1993a,b
Nuxia floribunda	Berry 1993a,b
*Ocotea bullata**	Lübbe 1989, Reynell & Durrheim 1989, Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991, Berry 1993a,b, Ferguson 1995, Vermeulen pers. obs.
Olea capensis subsp. *macrocarpa*	Reynell & Durrheim 1989
Olinia ventosa	Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991, Berry 1993a,b
Pittosporum viridiflorum	Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991
Pterocelastrus tricuspidatus	Berry 1993a,b, Vermeulen pers. obs.
*Rapanea melanophloeos**	Lübbe 1989, Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991, Ferguson 1995, Vermeulen pers. obs.
*Rhus chirindensis**	Reynell & Durrheim 1989
Scolopia mundii	Berry 1993a,b
Strychnos decussata	Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991
Vepris lanceolata	Berry 1993a,b

*Species on which experimental bark harvesting has been conducted

resource base for bark harvesting. Some are largely restricted to the drier forest types comprising relatively small areas in the southern Cape, limiting their harvest potential. These include *Calodendrum capense*, *Celtis africana*, *Ekebergia capensis*, *Maytenus acuminata*, *Pittosporum viridiflorum*, *Scolopia mundii* and *Vepris lanceolata*. In addition, the harvest potential of *P. africana* and *Strychnos decussata* is extremely limited as they only occur as disjunct populations in the southern Cape, with *Ficus sur* also having a limited distribution, reaching its western distribution limit in the region (Geldenhuys 1992). *Apodytes dimidiata*, *Elaeodendron croceum*, *I. mitis*, *Nuxia floribunda*, *O. ventosa* and *R. chirindensis* occur as fairly large trees in the moister plateau forest types, and the resource base for bark harvesting could be considered as fair. The species with the best resource base for bark harvesting are well represented on the plateau and in wetter mountain forest, and reach large dimensions in medium-moist, moist and wet High-Forests. These include *Cunonia capensis*, *O. bullata*, *Olea capensis* subsp. *macrocarpa*, *C. dentata*, *Pterocelastrus tricuspidatus* and *R. melanophloeos* (Table 5.5).

Table 5.4. Southern Cape bark species (from Table 5.3) traded in or harvested medicinally in provinces other than the Western Cape, based on (unless otherwise indicated as superscripts) recent surveys by Botha *et al*. (2001) (Limpopo and Mpumalanga), Williams (2003) (Gauteng), Grace *et al*. (2003), Mander (1998) and Geldenhuys (2004b) (KwaZulu-Natal), and Cocks *et al*. (2004) (Eastern Cape)

Species	Limpopo	Mpumalanga	Gauteng	KwaZulu-Natal	Eastern Cape
Apodytes dimidiata				x[3]	
Calodendrum capense		x	x	x	x[6]
Celtis africana				x	
Cunonia capensis			x	x[4]	
Curtisia dentata			x	x	x
Ekebergia capensis		x	x	x	x
Elaeodendron croceum			x	x	x
Ficus sur			x	x	
Ilex mitis			x	x	x
Maytenus acuminata			x	x	
Nuxia floribunda			x	x	
Ocotea bullata		x	x	x	x
Olea capensis subsp. *macrocarpa*[1]				x	x[6]
Olinia ventosa			x[2]		
Pittosporum viridiflorum			x	x	
Pterocelastrus tricuspidatus			x	x	
Rapanea melanophloeos		x	x	x	x
Rhus chirindensis			x	x[3,5]	x[6]
Scolopia mundii			x	x	
Strychnos decussata			x	x	x
Vepris lanceolata			x	x[4]	

[1] Subspecies not confirmed for KwaZulu-Natal and the Eastern Cape
[2] *Olinia radiata* reported to be traded at medicinal plant markets in Gauteng (Williams 2003)
[3] Geldenhuys (2004b)
[4] Hutchings (1989)
[5] Cunningham (1993)
[6] La Cock & Briers (1992)

5.5.2 Species grouping and choice of harvest system

Of the species with a fair or good resource base for bark harvesting in the southern Cape, only *C. dentata*, *I. mitis*, *O. bullata*, *R. melanophloeos* and *R. chirindensis* were subjected to experimental strip harvesting to gain insight into their response to bark harvesting (see Chapter 4). These, however, are also the species in large demand in either the southern Cape or other regions (Cunningham 1993, Mander 1998, Du Toit 2000, Botha 2001, Williams

2003, Cocks *et al*. 2004; Table 5.4). The development of harvest prescriptions and management options in the southern Cape will thus be restricted to these species, together with *P. africana* that is highly in demand in southern Africa and other parts of Africa (Cunningham & Mbenkum 1993, Dawson & Were 2001).

The responses of the selected tree species to bark stripping (see Chapter 4) are summarised in Table 5.6. Applying the decision matrix, *R. melanophloeos* and *R. chirindensis* do not qualify for strip harvesting, and full-tree harvesting has to be explored as an option (Table 5.7). Strip harvesting cannot be regarded as a viable management option for *C. dentata* and *I. mitis*. They fall in the sphere of "marginal scope for strip harvesting"; sheet regrowth is thin and would not allow for a second harvest (except on a very long rotation); and bark lift also hampers edge development (see Chapter 4). Based on the decision matrix, only *O. bullata* and *P. africana* qualify for strip harvesting to support a sustainable supply of medicinal bark to resource users.

5.6 INTEGRATION OF BARK HARVESTING WITH THE FOREST MANAGEMENT SYSTEM

The management policy for the southern Cape forests (Durrheim & Vermeulen 2006) makes provision for biodiversity conservation and the multiple use of forest resources, both consumptive (timber and non-timber) and non-consumptive (outdoor recreation and ecotourism) (see Chapter 1). Considering the importance of commercial timber harvesting in the southern Cape (Heyl 1999) and the extent of timber harvesting operations (Durrheim 2000, Stehle 2000, Kok 2002) compared to medicinal bark harvesting, the various harvest and management options for medicinal bark should be integrated with the current timber harvesting-based forest management system to ensure the optimum, sustained use of available bark resources.

The current management system for the southern Cape forests (Seydack *et al*. 1982, Durrheim & Vermeulen 1996, 2006; see Chapter 1) makes provision for five management classes, *viz*. Timber Harvesting, Protection, Nature Reserves, Outdoor Recreation and Research, with forest types as the ecological basis for management (Table 5.8). In terms of resource use, the following is of relevance:

- In Timber Harvesting compartments the primary management objective is the optimum, sustainable harvesting of furniture timber.
- The management of Protection compartments is aimed at soil and water conservation, but consumptive resource use, especially of NTFPs, is allowed where and if harvesting can be conducted with a minimum of disturbance.
- No consumptive resource use is allowed in Nature Reserves as the management objective for these areas is to maintain natural, ecological processes in an undisturbed state (Durrheim & Vermeulen 1996).
- As with seven-weeks fern (*Rumohra adiantiformis*) harvesting (Stehle 1987), bark harvesting in Outdoor Recreation compartments or close to such facilities, would degrade the forest-based ecotourism experience available to other stakeholders in the region (see Vermeulen 2004a).
- Bark harvesting in Research compartments could interfere with existing research and monitoring projects and limit the scope and potential for future research in such areas, as was experienced with timber harvesting in forest dynamics study sites at Witelsbos (Geldenhuys 1998c).

Table 5.5. Resource base for medicinal bark in the southern Cape forest, based on abundance and tree dimensions of target species in different forest types [after Von Breitenbach (1974) and Geldenhuys (1993)]

Species	Forest type[2] and resource availability							Comments
		Escarp		Plateau		Mountain		
	Overall rating[1]	vd-SF	d-HF	mm-HF	m-HF	w-HF	vw-SF	
Apodytes dimidiata	2	*	*	**	*			
Calodendrum capense	1	*	*					
Celtis africana	1	*	*					
Cunonia capensis	3				*	***	*	Often pure stands in wet High-Forest
Curtisia dentata	3	*	**	***	**	*		
Ekebergia capensis	1	*	*	*				
Elaeodendron croceum	2	*	**	*	*			
Ficus sur	1							Restricted distribution
Ilex mitis	2			*	**	**	*	Abundant along streams
Maytenus acuminata	1	*	*	*	*			
Nuxia floribunda	2	*	*	**	**	**		
Ocotea bullata	3		*	**	***	***	*	Most valuable commercial timber species
Olea capensis subsp. *macrocarpa*	3		**	***	***			Most common species in mm-HF and m-HF
Olinia ventosa	2	*	**	**				
Pittosporum viridiflorum	1	*	*					
Pterocelastrus tricuspidatus	3	*	**	**	*	*	*	
Rapanea melanophloeos	3		*	**	**	*	*	Fast-growing pioneer
Rhus chirindensis	2	*	**					
Scolopia mundii	1	*	*					
Strychnos decussata	1							Restricted distribution
Vepris lanceolata	1	*	*					
Prunus africana	1							Restricted distribution

[1]Resource base for bark harvesting, arbitrarily allocated based on abundance and dimensions in different forest types (1=Limited; 2=Fair; 3=Good)
[2] vd-SF: very dry Scrub-Forest; d-HF: dry High-Forest; mm-HF: medium-moist High-Forest; m-HF: moist High-Forest; w-HF: wet High-Forest; vw-SF: very wet Scrub-Forest

Table 5.6. Summary of species response to bark stripping, based on experimental bark harvesting (Chapter 4)

	Rate of wound closure			Insect and fungal damage			
Species	Phellogen edge growth	Phellogen sheet growth	Overall	Insect attack	Fungal damage	Overall	Comments
Curtisia dentata	Fair	Fair	Fair	Minor	Minor	Minor	Sheet growth initially too thin for second harvest; Wound widening as a result of bark lift; Erratic edge growth
Ilex mitis	Slow	Good	Fair	Minor	Minor	Minor	Sheet growth initially too thin for second harvest; Bark lift
Ocotea bullata	Good	None	Good	Minor	Minor	Minor	Very good edge development
Rapanea melanophloeos	None	None	None	Major	Major	Major	Agony shoot development; Bark dries out around wound and is damaged by woodpeckers
Rhus chirindensis	Poor	Poor	Poor	Major^{-}	Minor	Minor	Gum excretions on wound surface
Prunus africana	Good	Good	Good	Minor	Minor	Minor	

Table 5.7. Harvest options for selected tree species based on response to bark stripping

		INSECT AND FUNGAL ATTACK		
		1 Major	**2 Minor**	**3 None or negligible**
WOUND CLOSURE	**None**	Full-tree harvesting *Rapanea melanophloeos*	Full-tree harvesting	Full-tree harvesting
	1 Poor	Full-tree harvesting	Full-tree harvesting *Rhus chirindensis*	Marginal scope for strip harvesting
	2 Fair	Full-tree harvesting	Marginal scope for strip harvesting *Curtisia dentata* *Ilex mitis*	Strip harvesting
	3 Good	Marginal scope for strip harvesting	Strip harvesting *Ocotea bullata* *Prunus africana*	Strip harvesting

Table 5.8. Revised management classification proposed for the southern Cape forest under management of the South African National Parks (area in ha) (adapted from Durrheim & Vermeulen 2006)

Management class and Forest type	Resource use zone		Protection	Nature reserve	Recreation	Research	Total	Percentage of total forest area
	Timber Harvesting	NTFP Harvesting[1]						
vd-SF[i]		[2]	294.6	1380.6	40.7		1715.9	4.8
d-HF[ii]		1987.6	3975.1	2991.3	13.0	14.2	8981.2	25.1
mm-HF[iii]	6891.5	[3]	4839.9	2766.8	37.0	205.5	14740.7	41.2
m-HF[iv]	2384.6	[3]	806.1	909.4	36.3	176.0	4312.4	12.1
w-HF[v]		1214.5	2429.0	1606.6		24.9	5275.0	14.7
vw-SF[vi]		[2]	486.2	233.2		20.8	740.2	2.1
Total	9276.1	3202.1	12830.9	9764.9	127.0	441.4	35765.4	100
Percentage of Total	25.9	9.0	35.9	27.3	0.4	1.2	100	

[1] Proposed new management class; [2] Harvesting of NTFPs could be set as a secondary management objective in selected Protection compartments of these forest types; [3] Harvesting of NTFPs as a secondary management objective in Timber Harvesting compartments, catering for medium-moist and moist High-Forest
[i] Very dry Scrub-Forest; [ii] Dry High-Forest; [iii] Medium-moist High-Forest; [iv] Moist High-Forest; [v] Wet High-Forest; [vi] Very wet Scrub-Forest

Of the five management classes, bark harvesting would thus only be compatible with the management objectives set for Timber Harvesting and Protection compartments. Considering the wide range of NTFPs that could be harvested from natural forest (Lawes *et al*. 2004a), it is proposed that the management system be revised to make provision for a NTFP Harvesting management class. Compartments selected for this management class would be current Protection compartments of the dry and wet High-Forest types bordering the moist and medium-moist High-Forest Timber Harvesting compartments (Table 5.8).

The harvesting of NTFPs could be set as a secondary management objective in medium-moist and moist High-Forest in Timber Harvesting compartments. In this way the High-Forest types could be consolidated into a resource-use zone that would provide for the harvesting of timber as well as NTFPs. To ensure that the management objectives with the Protection management class are not compromised, it is proposed that only a maximum of a third (arbitrarily chosen) of the current area of dry and wet High-Forest be re-allocated to the NTFP Harvesting management class (Table 5.8). Regarding dry and wet Scrub-Forest, consolidation into the resource-use zone would be difficult due to the spatial distribution of compartments of these forest types. To provide opportunity for harvesting those forest products largely confined to Scrub-Forest, the harvesting of NTFPs could be set as a secondary management objective in selected compartments of the Protection management class. As with timber harvesting, areas zoned for the harvesting of NTFPs should be easily accessible for harvesting operations and resource monitoring.

Resource availability for the different bark target species per forest type, based on tree abundance and dimension, is presented in Table 5.5. The various bark harvest options for the seven target species, as per management class and forest type, are presented in Table 5.9. Considering conservation management objectives and the small area of dry and wet Scrub-Forest types in the management area (Table 5.8), together with its limited harvest potential (Table 5.5), bark harvesting should be restricted to the High-Forest types. However, in terms of species with a limited resource base in High-Forest (see Table 5.5), harvesting from dry or wet Scrub-Forest could be considered as a secondary management objective (see Table 5.8).

Seeing that bark species are already removed from the growing stock through timber exploitation, strip harvesting is not regarded to be an acceptable harvest option in Timber Harvesting compartments. The present timber yield regulation system is based on natural mortality patterns of canopy species (Seydack *et al*. 1995), with an extensive forest dynamics monitoring programme to assess the long-term impact of timber harvesting on the resource (Vermeulen 2000, Durrheim 2002). Strip harvesting would be an additional disturbance agent, and could interfere with existing forest dynamics monitoring programmes. In addition, strip harvesting could affect timber quality in the long term and would violate the objective of optimum use of timber resources in these areas. Strip harvesting should thus largely be restricted to areas allocated to the proposed NTFP Harvesting management class, but could include “ineffective areas” in Timber Harvesting compartments, i.e. areas too wet or steep for timber extraction (Table 5.9).

5.7 STRIP HARVESTING

Based on the decision matrix of the species studied (Table 5.7), only *P. africana* and *O. bullata* could be considered for strip harvesting.

5.7.1 Harvesting of *Prunus africana*

As a result of overexploitation in other parts of its distribution range (Cunningham & Mbenkum 1993, Dawson & Were 2001, Msekandiana & Mlangeni 2002, Stewart 2003), *P. africana* is a CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) listed species and trade in its products is strictly controlled (UNEP-WCMC 2006). Prescriptions for strip harvesting have been formulated (e.g. minimum exploitable diameter 40 cm DBH; bark removal from opposing quarters of the trunk; < 50% of the circumferential portion of the stem) (Cunningham & Mbenkum 1993, Ndam & Marcelin 2004, Hall *et al*. 2000 cited in Hall 2005) while programmes for cultivation of the species have also been initiated (Cunningham & Mbenkum 1993, Dawson & Were 2001, Ndam & Marcelin 2004).

In South Africa, *P. africana* reaches its westernmost distribution limit in the southern Cape as a disjunct and declining population in the sheltered Bloukrans River gorge. Here it survives on the warmer north-eastern slopes near streams and on the more fertile shale band, with fewer than 50 individuals (1978) and with a high rate of mortality (Geldenhuys 1981, 1986, 1992). The potential for sustainable harvesting of the species in this Protection management

Table 5.9. Options for bark harvesting for five target species from natural forest in the southern Cape, per forest type and management class

Harvest option	Forest type				Management class
	d-HF[i]	mm-HF[ii]	m-HF[iii]	w-HF[iv]	
Strip harvesting		*O. bullata*	*O. bullata*		Timber harvesting[1]
		O. bullata	*O. bullata*	*O. bullata*	NTFP harvesting
Full-tree harvesting		*C. dentata* *R. melanophloeos* *I. mitis*	*C. dentata* *R. melanophloeos* *I. mitis*		Timber harvesting
	R. chirindensis	*O. bullata* *C. dentata* *R. melanophloeos* *I. mitis*	*O. bullata* *C. dentata* *R. melanophloeos* *I. mitis*	*O. bullata* *I. mitis*	NTFP harvesting
As by-product of		*O. bullata* *C. dentata* *R. melanophloeos* *I. mitis*	*O. bullata* *C. dentata* *R. melanophloeos* *I. mitis*		Timber harvesting
Coppice management	*R. chirindensis*	*O. bullata* *C. dentata*[2]	*O. bullata* *C. dentata*[2]		Timber harvesting
	R. chirindensis	*O. bullata* *C. dentata*[2]	*O. bullata* *C. dentata*[2]	*O. bullata*	NTFP harvesting

[1] From ineffective areas (too steep or wet areas excluded from timber extraction) only; [2] When confirmed that the active compound is also present in the leaves or thin bark
[i] Dry High-Forest; [ii] Medium-moist High-Forest; [iii] Moist High-Forest; [iv] Wet High-Forest;

class for medicinal bark is negligible, both in terms of strip and full-tree harvesting. Should a high demand for it develop in the southern Cape, alternative resources will have to be developed through planting, although precautionary measures would be required to prevent it from becoming an invader outside its natural range. Near the hedge of planted *P. africana* trees adjacent to Woodville forest (see Chapter 4), seedlings already establish inside the forest (Vermeulen pers. obs.).

5.7.2 Harvesting of *Ocotea bullata*

Ocotea bullata occurs in a range of forest types (Table 5.5) but is particularly abundant in very wet Scrub-Forest and wet High-Forest, and reaches its largest dimensions in moist High-Forest (Geldenhuys 1993). It is a highly valued timber species harvested from medium-moist and moist High Forest (Seydack & Vermeulen 2004). Strip harvesting is thus a management option from wet High-Forest in the proposed NTFP Harvesting compartments, covering a potential harvest area of 1214.5 ha (see Table 5.8), as well as from ineffective areas of medium-moist and moist High-Forest in Timber Harvesting compartments (Table 5.9).

Harvest prescriptions

For *O. bullata*, wound closure after bark stripping takes place at a rate of between 12 and 16 mm/annum (see Chapter 4). The species is also fairly resistant to insect and fungal attack. Considering the results of experimental bark stripping and applying the decision tree (Tables 5.2 and 5.7), the following conservative prescriptions for strip harvesting are recommended for the species:

Strip width: 5 cm
Strip length: 1.5 m
Wound shape: preferably ellipse or V-shaped at bottom
Minimum tree diameter: 30 cm DBH
Harvest rotation: 2-3 years, but only after wound closure has occurred
Number of strips: 1-2, depending on tree diameter
Rotation of strips: rotate along four wind directions
Harvest season: preferably in winter (dry season)
Harvest percentage: 50% of healthy trees

Ocotea bullata is considered to be a pioneer-like species that grows quickly in partial shade (Van Daalen 1993a, Geldenhuys 2004c). Although it has weak competition abilities (Van Daalen 1993a), it also tolerates deep shade (Geldenhuys 2004c). The minimum tree diameter has therefore been set at 30 cm DBH at which size it forms part of the canopy layer; this is also the minimum diameter for commercial timber harvesting. A maximum of two strips per harvest are recommended, as wound closure only takes place through edge development. With no sheet growth that could quickly cover the wound, a relatively short rotation and narrow strip width has been set for the species to minimise exposure of the wood to fungal and insect attack. As wounds do not heal but are merely covered by callus growth (Shigo 1993), the long-term effect of bark stripping on tree health is not clear. The harvest percentage has thus been set conservatively at 50% of the growing stock. Considering that the bottom of wounds is slow to heal and that the accumulation of water could add to fungal growth, an elliptical wound shape or a V-shape at the bottom would enhance wound closure.

Harvest system and selection procedures

The selection of compartments from the proposed NTFP Harvesting management class for strip harvesting would largely be based on accessibility, the *O. bullata* growing stock and the demand for bark from local stakeholders. The more accessible wet High-Forest compartments with an *O. bullata* growing stock of up to 35 stems/ha ≥ 30 cm DBH (Vermeulen 1995a), compared to fewer than 10 stems/ha for moist High-Forest (Seydack *et al*. 1995), could be selected first.

The procedure for selecting trees for bark harvesting would be labour intensive as it requires a census (similar to full-count monitoring in Timber Harvesting compartments – see Seydack 1991, Vermeulen 2000, Durrheim 2004) of all *O. bullata* trees ≥ 30 cm DBH, with every second tree (50% of growing stock) selected for strip harvesting. On a three-year harvest rotation, one-third of the total area selected for strip harvesting could be exposed to bark harvesting annually.

Harvest method

As suggested by Geldenhuys & Mitchell (2006), an axe with a thin blade, or a similar tool, should be used, and inserted at an angle to ensure that the bark is only lifted at the wound side of the edge. Bark should be removed in long, narrow strips, working gradually outwards until the specified strip width is reached.

5.8 FULL-TREE HARVESTING

Full-tree harvesting would be the only viable option for *R. melanophloeos*, *R. chirindensis*, *C. dentata* and *I. mitis* (of the six target species) (Table 5.7). However, it could also be considered for *O. bullata* (Table 5.9), especially in the case of commercial bark harvesting when large volumes of bark are required. The timber yield regulation system already in place in the southern Cape (Seydack *et al*. 1995) could be applied with the selection of trees to ensure sustainability. Considering resource availability, dry High-Forest should be targeted for *R. chirindensis*, medium-moist and moist High-Forest for *R. melanophloeos* and *C. dentata*, and moist and wet High-Forest for *I. mitis* (Table 5.5). Depending on the species and forest type, full-tree harvesting could be implemented in compartments of the Timber and NTFP Harvesting management classes (Table 5.9).

5.8.1 Timber Harvesting compartments

With only medium-moist and moist High-Forest allocated to the Timber Harvesting management class, this would apply to *R. melanophloeos*, *C. dentata* and *I. mitis*. These are harvested for the furniture market, but, due to market demands (in terms of timber quantity and quality), not to their full potential (Seydack & Vermeulen 2004). This creates scope for marking additional trees specifically for full-tree bark harvesting, according to the selection criteria and yield regulation system that is in place for timber harvesting (Seydack *et al*. 1995). With the high demand for *O. bullata* timber, the species is already harvested to its full potential, and there is no scope for additional full-tree harvesting from Timber Harvesting compartments, other than using bark from branchwood (see Par 5.9).

Of the three species, formal selection criteria, calibrated to the rate of turnover of the species, have only been formulated for *C. dentata* (*viz*. ≥ 35% crown dieback; ≥ 50% crown loss *and* ≥ 20% dieback of remaining crown *or* severe stem rot) (Seydack *et al*. 1995). The system, however, makes provision for the selection of species for which formal criteria are lacking, focusing on dead and dying trees, and the development of criteria through an adaptive management approach. The selection of trees could be done during marking operations for timber harvesting, which entails systematically sweeping through the selected forest area (Durrheim & Vermeulen 1996, Durrheim 2000) and searching for trees that meet the selection criteria. Additional management input for the selection of trees for bark harvesting in Timber Harvesting compartments would thus be limited.

5.8.2 NTFP Harvesting compartments

Full-tree harvesting of *R. chirindensis* (and *O. bullata* where the demand cannot be met through strip harvesting) would largely be confined to NTFP Harvesting compartments. For

R. chirindensis, accessible compartments of the dry High-Forest type could be selected for bark harvesting, while wet High-Forest compartments should be targeted for *O. bullata*. The same harvesting rotation of 10 years that applies to timber harvesting (Seydack *et al*. 1995) could apply and the same marking/selection procedure could be followed. Unlike the selection of bark trees in Timber Harvesting compartments, this would require substantial management input as additional areas will have to be searched for harvestable trees. Formal selection criteria for *R. chirindensis* are still lacking, but could be developed with time, focusing initially on dead and dying trees. For *O. bullata*, the harvest criteria formulated for timber harvesting (*viz*. ≥ 35% crown dieback; main shoot or fork broken off or dead and ≥ 10% of remaining crown dead) (Seydack *et al*. 1995) could be used for the selection of trees to ensure sustainability.

5.9 BARK AS A BY-PRODUCT OF TIMBER HARVESTING

In the southern Cape where commercial timber harvesting is an important management objective (Durrheim & Vermeulen 2006, Seydack & Vermeulen 2004), the harvesting of medicinal bark as a by-product of timber harvesting holds good potential for certain species (Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991, Mostert & Lübbe 1991, Vermeulen & Van der Merwe 2004). During harvesting operations only the utilisable timber is extracted for the furniture timber market. Owing to quality specifications for most furniture timber, branchwood and logs of small dimensions are not harvested, and bark for medicinal use could be stripped from the remaining wood. Of the target species, potential for this exists especially for *C. dentata*, *R. melanophloeos*, *I. mitis* and *O. bullata* which are fairly well represented in medium moist and moist High-Forest. Following the completion of timber harvesting operations, selected compartments could be made accessible for medicinal bark harvesting under controlled conditions.

In addition, bark could be harvested from the auctioned logs through negotiation with the successful bidder, as suggested by Lübbe *et al*. (1991). The harvesting of bark before logs are auctioned is not feasible as the removal of bark could render timber more susceptible to fungal and insect attack, and cause it to dry out. Also, because logs are graded before selling at auction, a good appearance is important to obtain the maximum price.

5.10 ALTERNATIVE APPROACHES TO BARK HARVESTING

In addition to strip and full-tree harvesting, and the harvesting of bark as a by-product of commercial timber harvesting, various other management options could be explored should the demand for bark justify the additional management input. This would particularly be of relevance where the potential for commercial bark harvesting needs to be expanded or if supply cannot meet local demand for bark.

5.10.1 The establishment of forest stands for bark harvesting

The harvest potential of selected species could be expanded by establishing stands of the target species on suitable sites (Geldenhuys & Lübbe 1990, Lübbe *et al*. 1991, Mostert & Lübbe 1991), especially where seedlings or saplings of the target species are already well established. Depending on species, these stands could then be exposed to strip or full-tree harvesting. Establishing pure stands of indigenous species, however, could be expensive and an intensive management operation (Laughton 1937, Geldenhuys 1975, Van Daalen 1988b, Lübbe & Geldenhuys 1991), and most of the target species are also slow-growing (Van Daalen 1991, Geldenhuys 1994c, Seydack 1995). The establishment of forest stands should thus only be considered where it forms part of an integrated plan to meet the demand for medicinal bark of a particular species in the long term.

A cheaper and more viable option in the shorter term is enrichment plantings on the forest edge, especially where the target species are already well represented, where it borders disturbed areas (such as roads and commercial plantations), and where it is protected from fire (Van Daalen 1988b). This would not only provide a resource for bark harvesting, but would also contribute towards consolidating the forest area and serve as a buffer to outside disturbances. The objective would be to establish mixed stands of the high-demand species and encourage expansion of the forest from which bark and leaves could eventually be harvested on a sustainable basis. In the southern Cape, this could be a management option for particularly the early regrowth species *R. melanophloeos* (Geldenhuys 1994c) that is well represented on the fynbos/forest ecotone and, to a lesser degree, *O. bullata*. Forest development and expansion of the resource base of the target species could be encouraged by planting of seedlings collected in the neighbouring forest, by the manipulative management (thinning, etc.) of the forest stand, and protection from fire. In the case of *R. melanophloeos*, full trees could be harvested upon reaching a harvestable size (15-20 cm DBH), while coppice growth for leaf harvesting could be encouraged for *O. bullata*.

5.10.2 Cultivation for leaf harvesting

From the testing of biological activity (Van Wyk *et al*. 1997, Duncan *et al*. 1999, Drewes *et al*. 2006) and considering the different uses of medicinal tree species (Hutchings *et al*. 1996, Grace *et al*. 2003), indications are that for most species the active compounds with healing properties are present in different plant parts. Should the harvesting of leaves be acceptable to users, this would allow further scope for the development of alternative resources. For such species, stands could be established and managed in the same manner as tea plantations, keeping the crowns and main stem cropped (Geldenhuys 2004a). This would be much less destructive than bark harvesting and stands would be in production at a much earlier age. However, indications are that cultivated plants could be poorer in total chemical components (Drewes *et al*. 2006, George *et al*. 2001). For example, for *R. melanophloeos*, the chemical compound rapanone was isolated in large quantities from wild plants, but could not be detected in cultivated ones (Mashimbye 1993 cited in George *et al*. 2001). There seems to be general acceptance, though, of propagated medicinal plants by most traditional healers and their clients (Spring & Diederichs 2006, Vermeulen Unpublished data[13]).

Active components have been isolated from the leaves of *O. bullata* (Zschocke *et al*. 2000, Drewes *et al*. 2006) and *R. chirindensis* (Duncan *et al*. 1999). Propagation for leaf harvesting would be a particularly viable option for species that could be grown from cuttings (see Dry 1991 for *O. bullata*) or are adapted to browsing, or generate from coppice growth. Should the demand justify it, and the harvesting of leaves is acceptable to the primary users, the propagation of *O. bullata* and *R. chirindensis* could be explored further.

5.10.3 Bark and leaf production through coppice management

The ability of *O. bullata* to develop strong coppice shoots when cut or damaged (Lübbe 1989, Geldenhuys 2004b), and the fact that the chemical compounds with healing effects are also present in the leaves (Zschocke & Van Staden 2000, Zschocke *et al*. 2000, Drewes *et al.* 2006), present further management options for harvesting of the species for medicinal use. Should traditional healers and other stakeholders buy into the concept of using leaves or thin bark, *O. bullata* leaves as well as bark could be produced through coppice management (rotational harvesting of multi-stemmed trees) (Geldenhuys 2004a, Mander *et al*. 2006), similar to the approach used in commercial forestry with the production of *Eucalyptus* timber (Schönau *et al*. 1994). Coppice shoots are heavily browsed by bushbuck (*Tragelaphus scriptus*) and many eventually die due to continuous browsing (Lübbe 1989). As suggested by Lübbe (1989), Geldenhuys (2004b) and Geldenhuys & Mitchell (2006), coppice shoots could be protected by stacking branches around developing shoots to prevent browsers from getting to them until the growing tips are beyond their reach.

To a lesser extent the same coppice management approach could be followed with *C. dentata* (Geldenhuys 2004b) and *R. chirindensis*, as these also produce coppice following cutting or damage, while the latter also carries the active compounds in its leaves (Duncan *et al*. 1999). Geldenhuys (1993) reported that *R. melanophloeos* on the forest margin develops multiple stems when damaged by fire at a young stage, which also opens up options in terms of coppice management for the species.

5.11 BARK YIELD POTENTIAL

With the expected escalating demand for medicinal bark from natural forest in the southern Cape, the potential bark yield under different management options should ideally be quantified. This should include the yield through strip harvesting under different harvest regimes as well as through full-tree harvesting. The potential bark yield is important in assessing:

- whether the demand for bark (domestic or commercial) in a forest area could be met;
- the economic viability for commercial harvesting; and
- the need for alternative resources.

Potential yield would depend on the growing stock of the target species, rate of turnover (increment, ingrowth, mortality, rate of wound closure), bark thickness, etc. Bark thickness and volume generally increase with stem age and diameter (Borger 1973, Williams *et al*. 2007), as has been demonstrated by Geldenhuys *et al*. (2002) and Geldenhuys & Rau (2004) for the six southern Cape target species. Models to estimate the potential yield of medicinal bark for different harvest options have been developed for selected species, including *O. bullata* and *C. dentata* (Lamy 2006). As the quantification of bark yield for the different target species would require a resource inventory and the detailed mapping of areas earmarked for bark harvesting under the different harvest options, it will not be explored further as part of this study.

Regarding the harvesting of bark from auctioned logs, Lübbe *et al*. (1991) calculated (based on the volume of timber sold) that about 15.2 to 23.1 m^3 of *O. bullata* bark would become available from auctioned logs, compared to 0.6 to 1.1 m^3 for *C. dentata* and 0.5 to 0.9 m^3 for *R. melanophloeos*. This, however, is a substantial underestimate of the bark yield potential from timber-harvesting areas considering the source from branchwood and non-utilisable trees.

5.12 CONCLUDING REMARKS

The overall objective of this chapter was to explore options for the sustainable supply of medicinal bark from natural forests in the southern Cape, based on experimental harvesting conducted on certain target species (Chapter 4), and to integrate medicinal bark harvesting with the current forest management system as described in Chapter 1. In terms of the research questions posed, the conceptual model and decision tree presented here demonstrate that tree response to bark stripping could be used effectively in the choice of a management system for bark harvesting, and inform harvest prescriptions. It was shown that systems for medicinal bark harvesting, as well as the alternative options to meet the demand, can be successfully integrated with the existing multiple-use forest management system in place in the southern Cape. Although largely based on timber exploitation considerations, the current forest management system proved to be flexible enough to accommodate harvest systems for medicinal bark.

For many species that are in big demand for medicinal bark, the relevant information on tree response to wounding is not available, and an adaptive management approach would therefore be required. This would entail the formulation of conservative, interim harvest prescriptions to control use, which could be refined as monitoring results of tree response to bark stripping become available. Also, although harvest prescriptions could be based on sound, scientific research and local knowledge of the resources, the long-term impact of strip harvesting on tree growth and the resource is not known. The recommended practices should therefore be implemented with a monitoring system to assess the response of species over a longer period.

CHAPTER 6: THE DISTRIBUTION, POPULATION STRUCTURE AND COMMUNITY ASSOCIATION OF *Bulbine latifolia* (L.F.) SCHULT. & SCHULT.F. HARVESTED FOR MEDICINAL USE FROM NATURAL FOREST IN THE SOUTHERN CAPE

6.1 INTRODUCTION

A large percentage of the South African population still rely on traditional medicinal plants for healthcare (Cunningham 1993, Mander 1998) with the most valued medicines coming from natural forests (Lawes *et al.* 2000). Plant species with medicinal properties and their uses are well documented (Watt & Breyer-Brandwijk 1962, Bryant 1970, Hutchings 1989, Van Wyk *et al*. 1997, Mander 1998, Diederichs 2001, Matsiliza & Barker 2001, Arnold *et al*. 2002, Grace *et al*. 2003, Pakia & Cooke 2003b), and phytochemical research on medicinal plants is gaining momentum (George *et al*. 2001, Van Wyk 2002, Drewes *et al*. 2006, Wynberg 2006). However, harvest strategies and management systems to ensure sustainable use of these plants from the wild are largely still lacking, and overutilisation is of increasing concern (Cunningham 1993, 1997, Balick & Cox 1997, Ngulube 1999, Ouédraogo 2001, Walter 2001, Grace *et al*. 2002, Lawes *et al*. 2004b).

With the recognition of traditional healthcare practices [Traditional Health Practitioners Act (Act No. 35 of 2004)] (Richter 2003) and the restoration of access rights to forest resources, there is a growing demand for access to medicinal plants from natural forest in the southern Cape. The promulgation of the new National Forests Act (Act No. 84 of 1998) (NFA) has created legal mechanisms whereby local communities and other stakeholders can access forest products for domestic and commercial harvesting. In addition to medicinal bark (see Chapters 4 and 5), the increased demand for *Bulbine latifolia*, especially from the Rastafarian community, has resulted in illegal and uncontrolled harvesting of the species in the region (Vermeulen 2005). The corm has various medicinal uses, which result in whole plant, destructive harvesting. In the spirit of the participatory forest management (PFM) policy adopted for the management of natural forest in the southern Cape (DWAF Undated, 2005a; Chapter 1), an interim arrangement was made with the Rastafarian community granting them limited, controlled access (Plate 6.1a), while applied research is conducted, aimed at developing harvest prescriptions for sustainable use (Vermeulen 2005).

Management strategies for the development of harvest systems for sustainable use of NTFPs are given by Van Daalen (1988a), Peters (1996), Geldenhuys (2000b), Grundy (2000) and Cunningham (2001). A better understanding of the distribution and community association of the target species, its population dynamics, demography, reproduction and phenology is needed to provide the scientific basis for the formulation of harvest prescriptions and to assess resource-use potential (Geldenhuys & Van der Merwe 1988, Pfab & Witkowski 2000, Venter 2000, Raimondo & Donaldson 2003, Martínez-Romero *et al*. 2004).

6.2 STUDY OBJECTIVES

In this chapter, Specific objective 6 is addressed, namely "to gain a better understanding, through applied research, of the habitat and distribution, community association and population dynamics of *B. latifolia* and their relevance to the sustainable harvesting of the species in the southern Cape". The results are discussed within the context of developing a sustainable harvest system for the species.

Plate 6.1 (a) The corm of *Bulbine latifolia* harvested for medicinal use; (b) measurement of corm length; (c) *B. latifolia* growing in the fynbos/forest ecotone; (d), (e) and (f) long-term monitoring of plant growth and regeneration; (g) coppice growth after harvesting.

Associated research questions:

- How is *B.latifolia* distributed through the Harkerville State Forest and how does this affect harvest potential?
- What is its community association and with which other plant species used medicinally or for other purposes, is it associated?
- What does its population structure look like and how could it impact on the development of harvest prescriptions for the species?

6.3 STUDY AREA

The study was conducted at Harkerville State Forest, consisting of 3 933 ha of natural forest and 466 ha of fynbos. The forest, classified as Southern Afrotemperate Forest (Mucina & Rutherford 2006) mainly comprises of dry High-Forest (46.9%), very dry Scrub-Forest (10.7%) and medium moist High-Forest (33.9%). It lies on the seaward margin of the southern Cape coastal platform (Figure 6.1) and is managed as part of the bigger Southern Cape forest complex, in accordance with a multiple-use management system, with conservation, resource use and ecotourism important land-use types (Durrheim & Vermeulen 2006; see Chapter 1). Forty-one percent (1 555 ha) of the Harkerville Forest has been allocated to the Nature Reserve management class (see Chapter 1) and, together with 289 ha of coastal fynbos, forms the Sinclair Nature Reserve where extractive utilisation is prohibited (Vermeulen 1993, Herd 2006).

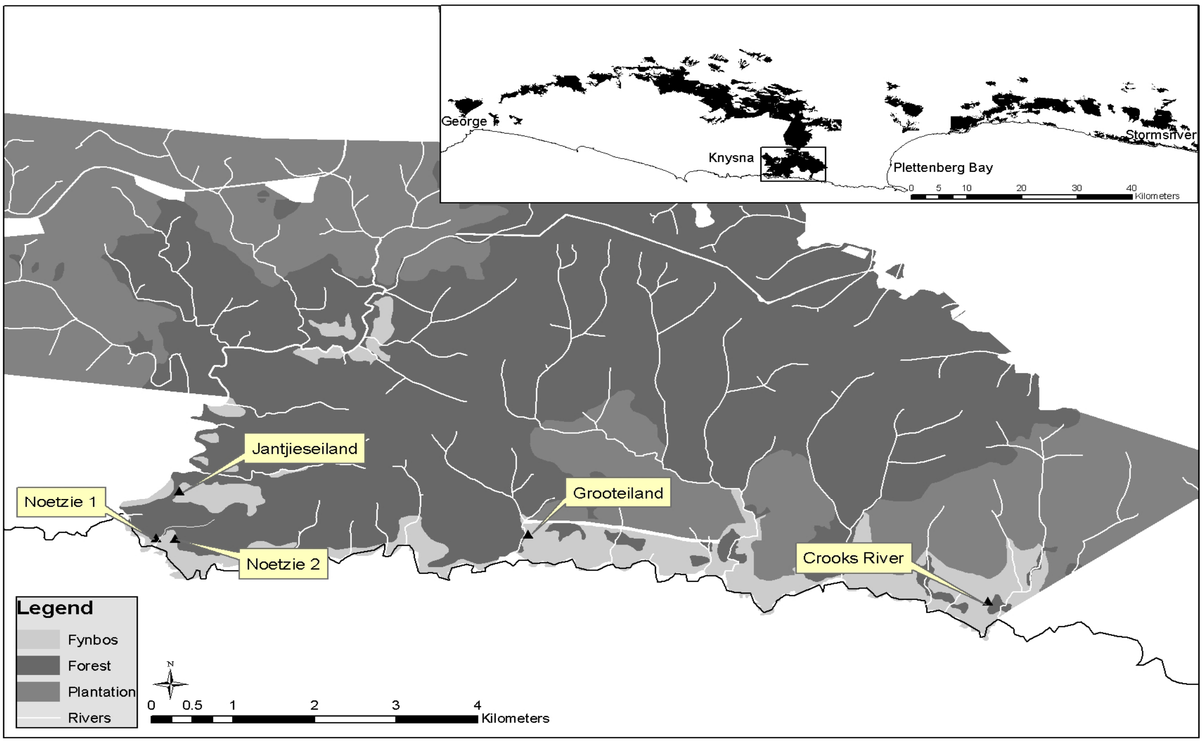


Figure 6.1. Location of Harkerville State Forest (insert) and *Bulbine latifolia* study sites in the southern Cape.

The very dry Scrub-Forest varies from a low, closed canopy scrub of 3 to 6 metres in height to forest of approximately 6 to 12 metres tall. It is often found on steep western and northern slopes, but also on the southern slopes of the coastal scarp (Von Breitenbach 1974, Herd 2006). Common tree species are *Cassine peragua*, *Allophylus decipiens*, *Psydrax obovata*, *Elaeodendron croceum*, *Euclea schimperi* var. *schimperi*; the shrubs *Buddleja salviifolia*, *Carissa bispinosa* and *Euclea racemosa* are also well represented (Von Breitenbach 1974). It is sparse in ground flora species, but *Cheilanthes hirta* and *Gerbera cordata* are often found in the more open areas.

The dry High-Forest forest is relatively dense with an irregular canopy 10 to 18 m high, and occurs on well-drained or shallow soils, on all aspects of moderate slope (Von Breitenbach 1974, Herd 2006). Characteristic tree species are *Elaeodendron croceum, Rapanea melanophloeos, Maytenus acuminata, Canthium inerme, Sideroxylon inerme* and *Pterocelastrus tricuspidatus.* It is fairly rich in ground flora and includes *Dietes iridioides*, *Aristea ensifolia* and *Asplenium rutifolium*.

The medium-moist High-Forest is found on a variety of, and generally poorly-drained, soils. The main canopy is 16 to 22 m high with *Trichocladus crinitus* often forming a dense shrub layer. The upper canopy is composed of, among others, *Olea capensis* subsp. *macrcocarpa, Podocarpus latifolius*, *Apodytes dimidiata, Curtisia dentata* and *Psydrax obovata.* The lower canopy consists of species such as *Gonioma kamassi, Canthium mundianum* and *Diospyros whyteana.* Ground flora is abundant.

The fynbos in the study area has been classified as South Outeniqua Sandstone Fynbos (Mucina & Rutherford 2006). Important taxa include species such as *Leucadendron eucalyptifolium*, *Erica densifolia*, *Peneaea cneorum*, *Berzelia intermedia* and *Restio triticeus*.

The parent rock throughout most of the State Forest is Peninsula Sandstone of the Table Mountain Group, with the Peninsula Formation, Enon deposits and fixed dunes of recent origin the dominant geological formations (Toerien 1979). Shallow, duplex soils dominate the southern, coastal part of the State Forest, with podzolised sands further inland (Vermeulen 1995b, Herd 2006). Annual average rainfall is 977 mm (recorded at the Harkerville forestry station, 242 metres a.m.s.l.), evenly distributed throughout the year, but with slight peaks in spring and autumn (Herd 2006). Mean daily maximum temperature (recorded at George airport, 220 metres a.m.s.l.) varies between 18.7ºC (August) and 24.7ºC (February) with the mean daily minimum between 7.9ºC (July and August) and 15.5ºC (February). Extreme maximum temperatures of more than 40ºC are experienced in January with minimum extremes of 2ºC occurring in August (Herd 2006). Light frost and hail occur infrequently, but lightning is fairly common (Herd 2006).

Five accessible *B. latifolia* populations occurring in very dry Scrub-Forest were selected for the study (Figure 6.1), namely Jantjieseiland (western aspect), Grooteiland (northern aspect), Crooks River (eastern aspect), Noetzie 1 (western and eastern aspects) and Noetzie 2 (western aspect). As the Noetzie sites have been disturbed by illegal and uncontrolled harvesting of *B. latifolia* in the past, the population dynamics study was confined to the former three study sites.

6.4 THE SPECIES

Bulbine latifolia (L.f.) Schult. & Schult.f. (= *Anthericum latifolium* L.f., *B. brunsvigiaefolia* Baker, *B. ensifolia* Baker, *B. natalensis* Baker, *B. transvaalensis* Baker) (Family: Asphodelaceae) is a succulent, perennial, geophytic herb (Germishuizen & Meyer 2003). Vernacular names include broad-leafed bulbine (English), geelkopieva (Afrikaans), and ibhucu, inacelwane and ibucu (Zulu/Xhosa) (Diederichs 2001). In the southern Cape, it is commonly known by the Afrikaans name "rooiwortel", referring to the red-orange corm.

The species forms part of the broad-leafed *Bulbine* complex (Ramdhani 2002) and is considered to be highly polymorphic with a wide distribution in southern Africa (Kativu 1996 cited in Ramdhani 2002). There are great discrepancies with the classification of this group, and *B. latifolia* is treated differently by different authors. For example, the species from the southern Cape is not treated by Ramdhani (2002) as *B. latifolia*, but as an affiliate of *B. natalensis* – which is regarded by Arnold & De Wet (1993) and Germishuizen & Meyer (2003) as a synonym of *B. latifolia* – and is recorded as *Bulbine* sp. 1 *affinis natalensis*. For the current study the classification and nomenclature of Germishuizen & Meyer (2003) are followed.

The leaves of *B. latifolia* are oblong-lanceolate and range from 122 to 300 mm in length and 30 to 90 mm in width (Ramdhani 2002). The inflorescence is a simple, densely flowered raceme up to 570 mm in length, with yellow petals (Ramdhani 2002). In South Africa the species is found in the Western Cape and Eastern Cape as well as KwaZulu-Natal and Gauteng at altitudes between 35 and 1 405 m (Germishuizen & Meyer 2003). It grows 250 to 910 mm in height (Germishuizen & Meyer 2003) and has a yellow-orange or red-orange corm of 27-95 x 18-70 mm (Ramdhani 2002). In the southern Cape, it grows from sea level and is associated with dry Scrub-Forest (Geldenhuys 1993a, Baard 2002), often on steep dry western and northern slopes (Baard 2002).

The medicinal properties of the species have been recorded by various authors. The leaf sap of *Bulbine* species is used for treating wounds, burns, rashes, itches, ringworm, cracked lips and herpes (Hutchings 1989, Van Wyk *et al*. 1997). The corm is used to quell diarrhoea and vomiting (Hutchings 1989, Van Wyk *et al*. 1997), to strengthen muscles (Hutchings *et al*. 1996), and to treat venereal diseases (Hutchings 1989), rheumatism, blood disorders (Watt & Breyer-Brandwijk 1962, Van Wyk *et al*. 1997), convulsions, diabetes and urinary complaints (Van Wyk *et al*. 1997). It is also used for psychological ailments (Hutchings 1989) and to prevent antisocial behaviour (Hutchings *et al*. 1996), while young Zulu men use it to harm rival lovers of their unfaithful girlfriends (Bryant 1970). In addition, the corm yields an excellent carmine dye (Watt & Breyer-Brandwijk 1962, Van Wyk & Gericke 2000). In the southern Cape it is regarded as having aphrodisiac properties and is widely used as a preventative "health drink" in addition to treating specific illnesses (Dixon, pers comm. 2006).

Bulbine latifolia (incorrectly recorded as *B. alooides* – Ramdhani 2002) rates among the top ten most sought-after medicinal plant species in the Eastern Cape (Cocks & Dold 2000). It is also listed among the plant species most frequently demanded by consumers in KwaZulu-Natal and large quantities are sold by herb traders (Cunningham 1990 cited in Cunningham 1993, Mander 1998). *Bulbine latifolia* is not among the *Bulbine* spp. recorded by Williams (2003) at the Faraday Street Traditional Medicine Market in Johannesburg, Gauteng (where more than 300 "ethnospecies" are traded). This could probably be attributed to difficulties with species identification and confusion around the taxonomy of the broad-leafed *Bulbine* spp. (Ramdhani 2002), rather than to there being no trade in the species. Also, *B. natalensis*, listed as a synonym of *B. latifolia* by Germishuizen & Meyer (2003), has been recorded at the market (Williams 2003). Although the demand for the species in the southern Cape has not been quantified, regular incidences of illegal harvesting along the southern Cape coast (Havenga pers. comm. 2008), also for financial gain, are proof of the increasing pressure on the resource.

Concerns were raised by Dold & Cocks (2002) and Ramdhani (2002) about the overutilisation of *B. latifolia* and other *Bulbine* species from the wild. A number of *Bulbine* spp. have been listed as red data species in South Africa (SANBI 2007), but this does not include *B. latifolia.*

6.5 METHODS

Potential sites for detailed studies were identified through reconnaissance visits with forest guards familiar with the distribution of *B. latifolia* in the area through law enforcement patrols. Additional populations were identified and mapped by Baard (2002) using GIS techniques, based on known habitat characteristics such as slope, aspect and vegetation type.

6.5.1 Floristic studies

Five-metre wide, gradient-directed belt transects (Kent & Coker 1992, Sutherland 1996), divided into contiguous 5x5 m subplots, were located perpendicular to the forest edge, spanning the fynbos/forest ecotone. The grandsect approach (Gillison & Brewer 1985) has been used successfully for the floristic sampling and description of fynbos/forest ecotones in the Western Cape and Southern Cape (Masson & Moll 1987, Masson 1990, Manders 1991, Sutherland 1992, Homann 1996). Transects were 30 metres long and were located 20 to 30 m apart. Number of transects varied between two and three, depending on the extent of the population sampled.

Cover abundance values were recorded for all species in a sub-plot based on the Braun-Blanquet scale (Barbour *et al*. 1987) as adapted by Westhoff & Van der Maarel (1973) (Table 6.1). For each plot, total percentage of plant cover, slope, soil depth and percentage stone/rock cover were recorded. Structural data recorded for plots in ecotone and forest vegetation include the number of stems 1 to 4.9 and ≥ 5 cm DBH (diameter at breast height), per species. The sociability value, an estimate of the dispersion of a member of a species, of *B. latifolia* was recorded for each plot, according to an adapted Braun-Blanquet sociability scale (Barbour *et al.* 1987) (Table 6.2).

Relevé data were captured into a database managed by TURBOVEG software, developed for storing, editing and selecting phytosociological relevés (Hennekens & Schaminée 2001). A Two-Way Indicator Species Analysis (TWINSPAN) (Hill 1979), was applied to the floristic dataset to derive a first approximation of vegetation groups. TWINSPAN is a polythetic divisive method of classification, arranging multivariate data in an ordered two-way table by classification of the individuals and attributes (cluster analysis). The results were further refined by applying Braun-Blanquet procedures in the MEGATAB table editing program (Hennekens 1996). MEGATAB, which is part of the TURBOVEG package, was designed to

Table 6.1. Cover abundance classes used for floristic studies to assess the community association of *Bulbine latifolia* (after Westhoff & Van der Maarel 1973)

0	Present outside plot
r	< 1% cover; 1 to 2 individuals
+	< 1% cover; 3 to 9 individuals
1	< 1% cover; more than 10 individuals; 1% – 5% cover; 1 to 9 individuals
2m	1% – 5% cover; more than 10 individuals
2a	6% – 12% cover
2b	13% – 24% cover
3	25% – 49% cover
4	50% – 74% cover
5	75% – 100% cover

Table 6.2. Sociability scale used to estimate the dispersion of *Bulbine latifolia* during floristic studies at Harkerville State Forest (adapted from Barbour *et al*. 1987)

Value	Meaning
5	Growing in large, almost pure stands
4	Growing in small colonies or carpets
3	Forming small patches or cushions
2	Forming small but dense clumps, consisting of a few individuals
1	Growing single

handle basic shuffling procedures with phytosociological tables, aiding construction of relevé and synoptic tables.

6.5.2 Population dynamics studies

As with the floristic studies, 5-metre wide, gradient-directed belt transects (Kent & Coker 1992, Sutherland 1996), divided in 5x5 m subplots, were located perpendicular to the forest edge, spanning the fynbos/forest ecotone. Two to four transects were located 20 to 30 m apart (depending on size of population and plant distribution) through natural and undisturbed (not subjected to harvesting) *B. latifolia* populations. Transects extended into the forest for as far as *B. latifolia* plants were located. For each plot, the corm length (Plate 6.1b) and diameter (measured at both ends) of plants with a corm diameter ≥ 10 mm, were recorded (Figure 6.2). The same environmental data determined for the floristic study, were recorded.

An analysis of variance (Two-way ANOVA) was used to test the hypothesis that there is a difference in plant characteristics (corm diameter and length) between plants in the forest and the fynbos/forest ecotone (defined as a distance of 10 metres from the fynbos edge into the forest), and between study sites, using the Statistica 7 computer program (StatSoft Inc., Tulsa Oklahoma, USA). Significantly different "treatment" means (sites, ecotone/forest) were separated applying a post hoc Bonferroni test. Descriptive analysis was carried out, using Excel 2003, to further scrutinise the data and to present results on the size class distribution of the species. Regression analysis was conducted to assess the relationship between corm diameter and length.

Principal Component Analysis (PCA), an indirect gradient analysis ordination technique (Ter Braak & Prentice 1988, Ter Braak 1995) was conducted using Canoco 4.5 Software (Ter Braak & Smilauer 2002) to explore the relationship between vegetation type (ecotone and forest plots), *B. latifolia* characteristics (number of plants, corm diameter, corm length) and environmental variables (soil depth, stoniness, slope, exposure). Data were square-root transformed. In addition, direct gradient analysis methods (Barbour *et al*. 1987, Kent & Coker 1992, Gaugh 1995) were used to further assess the distribution gradient for *B. latifolia*. With this ordination method plots are located along some obvious environmental gradient determined at the beginning of the sampling (the fynbos/forest ecotone), and not along mathematically determined axis as with indirect gradient analysis.

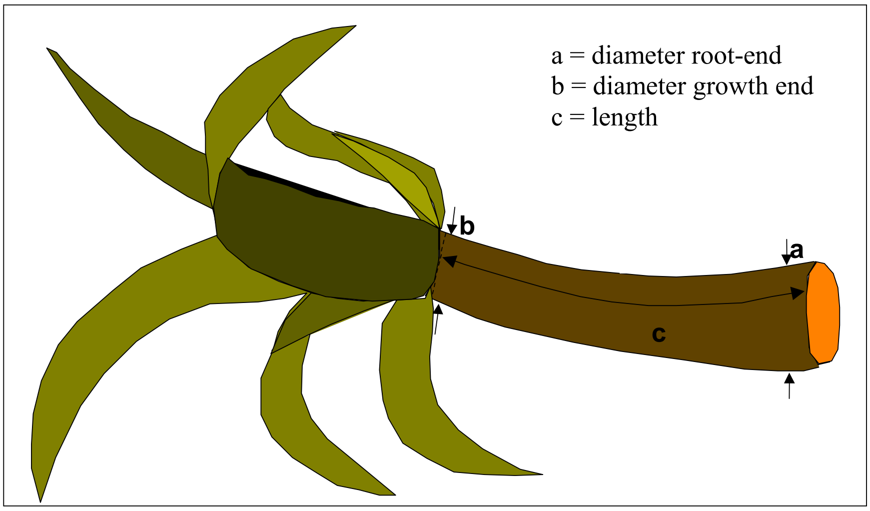


Figure 6.2. Schematic diagram showing measurements taken of the corm of *Bulbine latifolia*.

6.6 RESULTS

Bulbine latifolia is largely confined to the coastal area of Harkerville State Forest. It occurs as isolated populations and is often found on the ridges and upper slopes of river gorges, where it is associated with dry Scrub-Forest. Most of the populations are found within the boundaries of Sinclair Nature Reserve.

6.6.1 Floristic study

Floristic composition of plant communities with which *B. latifolia* is associated, is presented in Table 6.3. Two forest, ecotone and fynbos communities each can be distinguished. The *Grewia occidentalis–Asplenium rutifolium* dry Scrub-Forest community (1.1) is largely found on the drier, northern and western slopes. Diagnostic species are *Grewia occidentalis* and *Putterlickia pyracantha* (Species group 1). The *Agapanthus praecox* subsp. *minimus–Asplenium rutifolium* dry Scrub-Forest community (1.2) is more confined to the moister southern and eastern slopes, with *Agapanthus praecox* subsp. *minimus* and *Cussonia thyrsiflora* diagnostic species (Species group 2). The two communities are further defined by

Table 6.3. Phytosociological table of vegetation with which *Bulbine latifolia* is associated at Harkerville State Forest in the southern Cape. Species present in only two or less relevés are not shown

```
Relevé number              1155 1 1222  5|556335224434355| 43 2455| 311324|1122|4441142333
                           56569064012584|290341785690208|34846937|7193753|7834|178122905612
Aspect (degrees)           22223332333332|111  1112222 11|32231123|3 32212|2233|222332111133
                           99993359444539|544885009988854|58850592|3849808|9955|866448000055
                           77227777777772|277772777777727|77777222|7777777|7700|777777772277
Slope (degrees)            22444442422444|333443444422433|44344383|4442344|1122|222222221122
                           99335507377003|533555220055503|03505003|0537553|9900|500555223322
Total vegetation cover (%) 11111  1  1 1 |1   11 1      1|        |       |1   |       1
                           00000990880909|098800908989990|678882 3|4658566|0975|896455907968
                           00000550050000|000500000050050|55500555|0500000|0050|055000000555
Cover tree layer (%)                     |1              |        |       |    |
                           77876678257389|086587993634858| 3577   |       |    |
                           00050500500050|005000000050500|05000000|0000000|0000|000000000000
Cover shrub layer (%)      67862167737623|111361545566552|16733   |1457434|9854|785454556747
                           00000500000000|050055005055500|55000007|0000055|0005|505005005500
Cover herb layer (%)                     |               |        |       |    |       1
                               11122 1132|6226121111 1121|611412 3|34 1 2 |143 |      6057 8
                           46335050552500|550050020255250|00005550|0075704|2008|835554000540
Soil depth (cm)            44225454344823|322242342222211|21173  1|2134211|3323|11123 244735
                           00210852315053|046535550406555|55555500|0455535|4650|031508273555
Stone cover (%)               1    2    1|   111  111 31 | 51 1996|353 775|    |212676    1
                           67825115011125|555550312028086|70530000|0001000|3511|555000101001
Height tree layer (m)      67447876656554|545444344433433|03345000|0000000|0000|000000000000
Height shrub layer (%)     11111111211111|111111111111111|11111000|1311111|1111|111111111111
                           58558338059255|355553555555570|25657004|5088040|7878|433555656635
                           00000000000000 000000000000000 00000000 0000000 0000 000000000000
Height herb layer (cm)     22212233434343|333431443333333|33333222|3332222|3434|222112567824
                           05050000000000|050055005505550|00500050|0000000|0050|555005000000
Vegetation type            SSSSSSSEESSSEE|SSSSSSSSSSSSEEE|EEEEEEEE|EEEEEEE|FFFF|NFFFFNFFFFFF
(Forest, Ecotone, Fynbos)
Number of species          32111122222121|112222222112222|11212111|1221222|1111|111111112111
                           09557729038808|891362234992956|39170026|2058101|3274|111340830335
Community                        1.1           1.2           2.1     2.2    3.1     3.2    .
------------------------------------------------------------------------------------------------

Species Group 1
Grewia occidentalis        11r1r.a.1ra1r1|...............|........|.......|....|............
Putterlickia pyracantha    a1ara1a11.aa1a|.a.....r.......|........|..r....|....|............
Euclea schimperi schimperi aa....r1.rr...|......r........|........|.......|....|............
Scutia myrtina             r1..r.r...1...|...............|........|.......|....|............
Chlorophytum comosum       ....1+.1...m..|...............|r..1....|.......|....|............
Gymnosporia buxifolia      1r....m+....r.|...............|........|.......|....|............
Sarcostemma viminale       .......++rr...|...............|........|..1....|....|............
Senecio deltoideus         r1....r.......|.......r.......|........|.......|....|............
Elaeodendron croceum       1a....r..1b...|...............|........|.......|....|............
Mystroxylon aethiopicum    1......r.....1|...............|........|...r...|....|............
Tarchonanthus camphoratus  1b..........b.|.............1.|........|.......|....|............
Ochna arborea arborea      .r.....ra1a...|...............|........|..r....|....|............
Ornithogalum longibractea. 11.......11...|...............|........|.......|....|............
Allophylus decipiens       r1.......1....|...............|........|.......|....|............
Dovyalis rhamnoides        r1.....r......|...............|........|.......|....|............
Species Group 2
Agapanthus praecox minimus ..............|.a13aaaa....3b1|........|.....r.|....|............
Cussonia thyrsiflora       ..............|1rr.11.1.1...1r|........|.......|....|............
Pelargonium cordifolium    ..............|...+.....r..r.r|........|.......|....|............
Crassula orbicularis       ..............|1..1aa.......m.|........|.......|....|............
Asparagus asparagoides     ..............|...++.........r|........|.......|....|............
Species Group 3
Olea capensis capensis     ab...a.b......|...aa13b....1a.|........|.......|....|............
Euclea racemosa            11........1...|a.a..3ra.....a3|.a......|.......|....|............
Oxalis purpurea            ++............|m++..+.........|........|.......|....|............
Lachnostylis hirta         .....r1....4..|....a.ab.......|........|.......|....|............
Cassine peragua            a..1...r......|.....1.........|........|.......|....|............
Ficus burtt-davyi          ..aa..........|..1............|........|.......|....|............
Species Group 4
Ehrharta erecta erecta     +1+1..r1+++r.1|1m+1+m+rrr++rm1|..1.+.+r|.......|....|............
Asplenium rutifolium       r+..1r11rr+m+r|+rrr++1a+....+r|...1+.r.|.......|....|............
Senecio angulatus          +.1111+r.++m11|a.a.11..++++1..|r.a1....|....1..|....|............
Sideroxylon inerme         ..3a.a.a...r.4|a..b4b.rr..1a.1|..r...r.|....r..|....|............
Cassine tetragona          +1mr...r.aa..1|3b1aaa.1aa111ba|.ar.....|......1|....|............
```

Chionanthus foveolatus	1....1.+...r..	raa.rr1br.1ar1.	..a.....	....	....	....
Asparagus setaceus	a1..amam.11ma.	..r...r...1a...	r..1....	....	....	....
Species Group 4						
Carissa bispinosa	aa.r...m11a+..	1111ba11a...1rr	ra.1...1	.11.r..	....	....
Capparis sepiaria	.r+...1r.+r.1r	...1aa.r1r.++rr	.+.....r	r..r..1	....	....
Crassula pellucida marg.	....m1r.....ra	b++rra1+1...11r	.1..1.r+	.+....+	....	....
Polygala myrtifolia	.......11.....	...1r.rr.......	....	.....r.	....	......r.....
Myrsine africana	...........a..	....1..11...1..	....1...	.a...r.	....	....
Dypogon lignosus	..1r..........	.1r.....11...ar	.1......	......+	....	....
Crassula rupestris	............1r	........+...1r.	m...rbab	1b...am	....	.r..........
Rhus glauca	..b4..........	....1...b3a11b1	.a1..r..	r...r..	....	....
Senecio crassulaefolius	............r.	r1...r......r..	....1.r.	am...1.	....	....
Apodytes dimidiata	..........a...	....	...r....	......r	....	....
Oncinema lineare	....	...+1.++....1rr	.rr++...	....+.+	....	....
Siphonoglossa leptantha	....	+r+..+.........	....	..r....	....	....
Eriocephalus africanus	....	.............a1	.....r.r	1	....	....
Rhus crenata	....	.............1.	.....r..	....	....	....
Gasteria acinacifolia	....	....	.1+.....	..r....	....	....
Species Group 5						
Aloe arborescens	aa..rr1b4b3aa1	...1+...11arr..	a.aa+.1.	ar3ar..	1.11	....
Asparagus africanus	.raa++1rmr.rab	aammaa+ra1111ab	raa1.m1r	..1+r.r	r..1	....
Diospyros dichrophylla	..r.b..+1.1.ba	...aa.1.a1ab1..	rabb1...	..a1..1	..r.	....
Rhoicissus digitata	rra1.rr.1rr..a	1.1..1..1ara..1	.1....r.	..1....	..11	....
Bulbine latifolia	....rr+abaaabb	1m11aaaaaa1raab	abaaa111	rb1mraa	r.r.	........r...
Clutia pulchella	....1..r..1.1.	....	....	..r1...	..r.	....
Carpobrotus deliciosus	....	............r1.	.a......	.r.1.11	11rr	....
Passerina falcifolia	.......ar.....	....	....	..11...	13ab	....
Species Group 6						
Osyris compressa	....	..1.....1a1a3ab	..1a1r.a	.br.r1r	....	r.1rrar.r.1.
Chrysanthemoides monilifera	....	......b.aaa1...	.ba.....	....r.1	....	....r.aara..
Phylica pinea	....	..........aa...	1	rar.bab	a1rr	abbaab11aa11
Erica speciosa	.......a1.....	....	..r.....	..a41aa	3b3a	44b..bbb3b1b
Agathosma ovata	....	....	a...1...	r.rm111	aaa1	aaa1.aba...1
Tritoniopsis caffra	....	..............r	.....r.r	.r..+.r	.1..	++1r++...rr.
Virgilia divaricata	........1.....	..........1b...	..1.....	r.a.a..	....	a.a..a......
Crassula rubricaulis	............r.	...........+...	....1...	aa...a.	....	......r...r.
Centella affinus	....	..........r....	....1...	....	.+r.	1++rr.1.1ar.
Relhania calycina	....	........1......	.r......	.1..1aa	....	r..aaa11a1.r
Species Group 7						
Cassytha ciliolata	........r.....	....	....	..+a+..	11ar	++1+++....1a
Syncarpha paniculata	....	....	....	....r.1	....	.1raaa1r1r.1
Metalasia muricata	....	....	....	.1.....	r.1.	...1b.a1bb43
Ficinia nigrescens	....	....	....	..mm...	abba	111.........
Species Group 8						
Metalasia sp.	....	....	....	.....1.	....	...rr.......
Indigofera flabbelata	....	....	.r......	....	....	..1.......rr
Ischyrolepis gaudichaudiana	....	....	....	....	....	....+..a.+ra
Cliffortia stricta	....	....	....	....	....	....r...r..1
Tetraria cuspidata	....	....	....	....	....	......34b3..
Cliffortia cf. elata	....	....	....r...	.....r.	....	......11a1..
Erica cubica	....	....	....	....	....	......1a...a
Bobartia rubasta	....	....	....	....	....	.......br+..
Species Group 9						
Pterocelastrus tricusp.	331b13bba4a..b	5433a3aaaabb34b	ab3b5...	.1.r.r.	...a	.r....1.+1..
Cotyledon orbiculata	....r.a.1.r++.	.r1mm..rr1rrr++	arrm+m+a	+mmr1+m	r...	++.+r1r.r...
Commelina africana	....+r...r.++.	...+......+rr..	r.1++...	.+rr1+.	.+rr	........r...
Rhus lucida	..31.....1....	......abb1a.3.1	..a.1...	.brr1..	a1rr	........r1...
Euclea polyandra	...........1..	......1........	...a1...	.....r.	....	...1....1...
Protasparagus macowanii	r1............	....	....	..1....	....	....
Olinia ventosa	....14........	....	....	...r...	..r.	....
Stachys aethiopica	......r.......	.+.............	...1....	....	....	....

Ehrharta erecta var. *erecta*, *Senecio angulatus*, *Cassine tetragona* and *Asparagus setaceus*, as well as *Carissa bispinosa*, *Capparis sepiaria* and *Crassula pellucida* subsp. *marginalis* (Species group 4), although these species also have some representivity in the ecotone. The *Grewia occidentalis–Asplenium rutifolium* community (1.1) varies in height between 4 and 7 m (X = 5.7 m), compared to 3 and 5 m (X = 3.8) recorded for the *Agapanthus praecox* subsp. *minimus–Asplenium rutifolium* community (1.2).

The ecotone consists of both forest and fynbos species, representing the continuum from forest to fynbos vegetation, with no diagnostic species. It is distinguished by the absence of the diagnostic forest species *Grewia occidentalis*, *Putterlickia pyracantha*, *Agapanthus praecox* subsp. *minimus* and *Cussonia thyrsiflora* (Species groups 1 & 2), and fynbos species such as *Metalasia muricata* and *Syncarpha paniculata* (Species group 7). Two ecotone communities can be distinguished, although no diagnostic species exist. The *Asplenium rutifolium–Bulbine latifolia* Ecotone community (2.1) is species poor and characterised by the presence, although poorly represented, of forest species such as *Asplenium rutifolium* and *Ehrharta erecta* var. *erecta* (Species group 4), and the absence of fynbos species. The *Phylica pinea–Bulbine latifolia* Ecotone community (2.2) is distinguished by the presence of fynbos species such as *Phylica pinea*, *Erica speciosa* and *Agathosma ovata* (Species group 6).

The fynbos communities (3.1 and 3.2) are poorly defined. They are distinguished by the presence or absence of species from Species group 5 (forest) and 8 (fynbos). The fynbos group is further defined by the species *Phylica pinea*, *Erica speciosa* and *Agathosma ovata*, although they are also present in the ecotone. *Pterocelastrus tricuspidatus*, *Cotyledon orbiculata* and *Commelina africana* (Species group 9) span the forest/fynbos ecotone and are fairly well represented in the forest and fynbos groups.

Bulbine latifolia is well represented in the forest communities as well as in the ecotone (Plate 6.1c) and, together with *Aloe arborescens* and *Asparagus africanus*, forms part of a clearly defined species group spanning the ecotone (Species group 5). It was recorded in all plots representing the ecotone group, but absent in 10.3 and 93.8% of the forest and fynbos groups respectively, confirming its preference for the fynbos/forest ecotone and forest communities. These communities occur on steep slopes, ranging from 33-45º (X = 41.5º) for the ecotone to 30-45º (X = 36.7º) for the forest communities, tapering off into the fynbos. The deepest soils were recorded in the forest group (21-80 cm; X = 33.4 cm) and fynbos (8-75 cm; X = 31.2 cm), with more shallow soils recorded through the ecotone (5-25 cm; X = 23.5 cm). This is also consistent with the higher stone cover percentage, including protruding rock, recorded for the ecotone.

In terms of sociability, *B. latifolia* largely grows as single plants (recorded for 69% of the plots with *B. latifolia*), while forming small but dense clumps and small patches/cushions in 23.8 and 7.2% of the plots respectively. Sociability, however, varies between the communities with small patches/cushions recorded in only the forest communities (*Grewia occidentalis–Asplenium rutifolium* forest group).

6.6.2 Population dynamics

Mean corm diameter at the growth end is 18.9 mm compared to 18.7 mm at the root-end of the corm. This difference is not significant at $P < 0.05$ and the diameter at the growth end (which is easier to measure and more reliable should it be incorporated in harvest prescriptions) was used for further analysis of data.

In terms of corm diameter (plants ≥ 1 cm), the species has a bell-shaped (positively skewed) size class distribution (Figure 6.3a), with most plants falling in the 15-19 mm and 20-24 mm size classes. Mean corm diameter is 18.9 (SE ± 0.17) mm with 15.4% of the plants reaching a diameter of 25 mm or more, and the largest plant diameter 39 mm. There is, however, a significant difference in mean corm diameter between study sites ($P < 0.001$) (Figure 6.4),

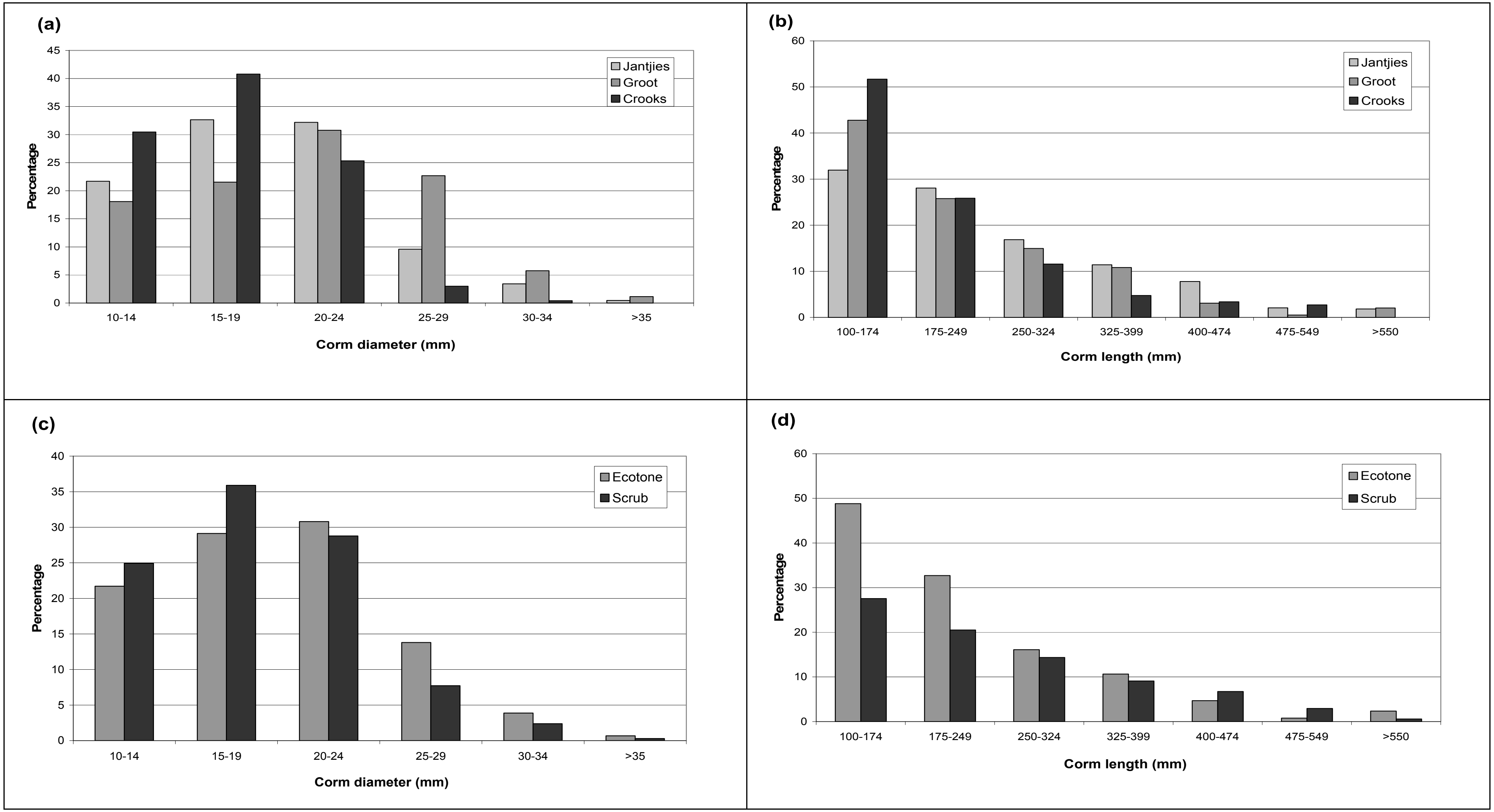


Figure 6.3. Size class distribution for *Bulbine latifolia* per study site (a and b) and vegetation type (study sites combined) (c and d) based on corm diameter and length respectively.

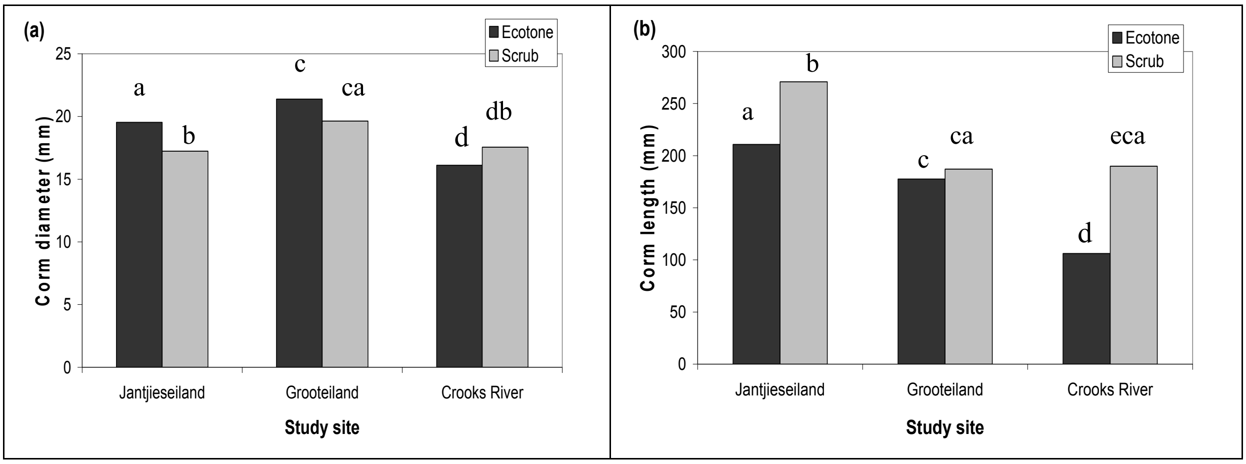


Figure 6.4. Corm diameter (a) and length (b) for *Bulbine latifolia* for ecotone and forest populations at different study sites. Bars labelled by the same letter are not significantly different from each other at 5% level of probability.

which is also reflected in the size class distribution. In terms of corm length the species depicts a typical inverse J-shaped size class distribution (Figure 6.3b). Mean stem length is 194.7 (SE ± 3.9) mm with 750 mm the maximum recorded. As with diameter, there is a significant difference in mean stem length between study sites ($P < 0.001$) varying from 226.6 mm for Jantjieseiland to 149.3 mm for Crooks River (Table 6.4).

When separated between vegetation types (ecotone and forest) the same size class distributions (bell-shaped for diameter and inverse J-shaped for length) were recorded for both types (Figures 6.3c and 6.3d). However, for corm length *B. latifolia* populations in the forest had a much flatter size class distribution compared to ecotone populations, while, based on corm diameter, the larger size classes are better represented for ecotone population. This is also reflected in the significant difference for both corm diameter ($P < 0.05$) and length ($P < 0.001$) between the ecotone and plants growing in forest, although the difference varies between study sites (Figure 6.4). Plants growing in the ecotone are thicker (mean corm diameter of 19.4 ± 0.2 compared to 18.2 ± 0.2 mm for the forest), but shorter in length (182.1 ± 4.7) than plants in forest (219 ± 6.0). A curvilinear relationship exists between corm diameter and length, with a flatter curve for forest when separated between vegetation types (Figure 6.5). Less than 10% of the plants had branching corms, with the largest percentage recorded for ecotone plots (Appendix 3).

Bulbine latifolia density varies between plots, vegetation type and position along the fynbos/ecotone/forest environmental gradient, and is most abundant in the ecotone (Figure 6.6). Only for Jantjieseiland was *B. latifolia* recorded in fynbos, which was old and moribund. The mean number of plants (≥ 10 mm diameter) per ecotone plot (25 m^2) varies between 28.3 (Crooks River) and 53.3 (Jantjieseiland), with a maximum of 103 plants for Jantjieseiland (Appendix 3). Mean number of plants for the forest varies from 10.9 (Crooks River) to 23.6 (Jantjieseiland). For Crooks River, however, the largest percentage of *B. latifolia* plants (51.5%) was recorded in forest with the species extending much deeper into the forest.

The ordination results are presented in Figure 6.7, showing the relationship between vegetation type (ecotone and forest plots), *B. latifolia* characteristics (number of plants, corm

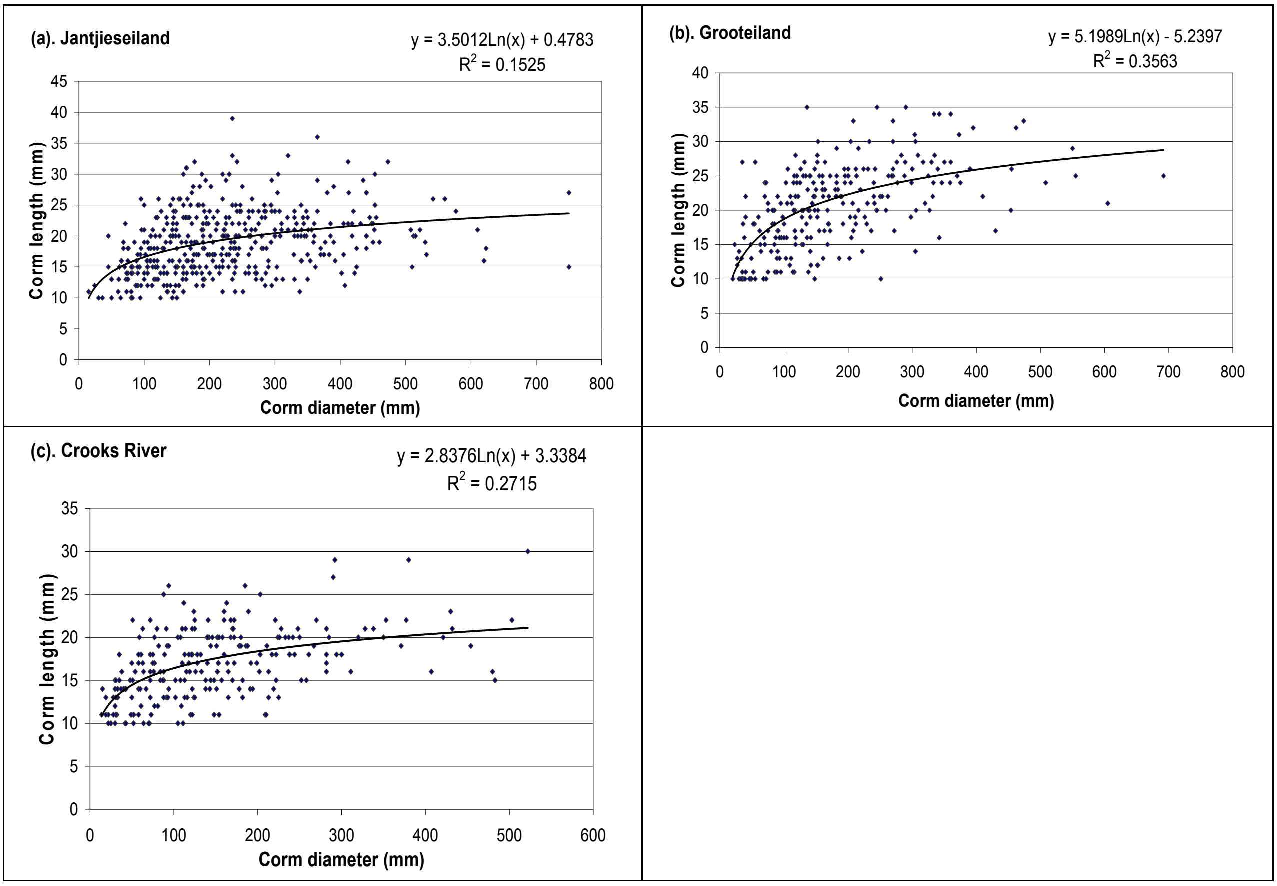


Figure 6.5. Curvilinear relationship between corm diameter and length for *Bulbine latifolia*, for three study sites.

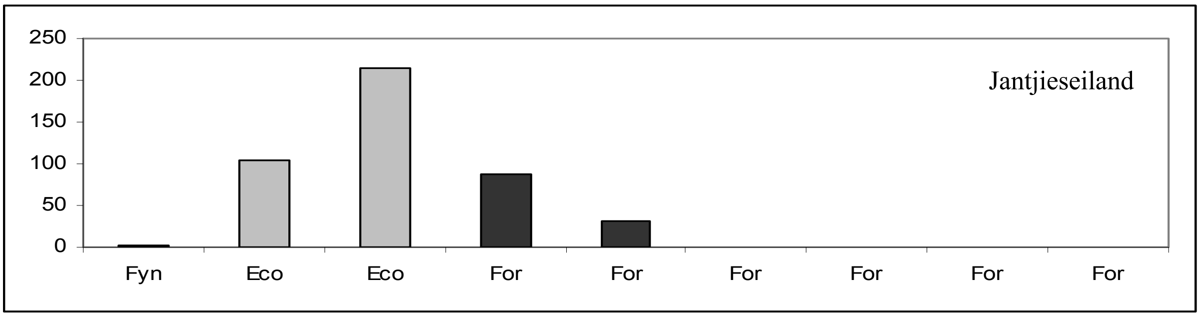
diameter, corm length) and environmental variables. Consistent with the direct gradient analysis results (Figure 6.6), the higher *Bulbine* numbers are associated with the ecotone plots, on more shallow and stony soils. Longer plants are associated with the forest plots.

6.7 DISCUSSION

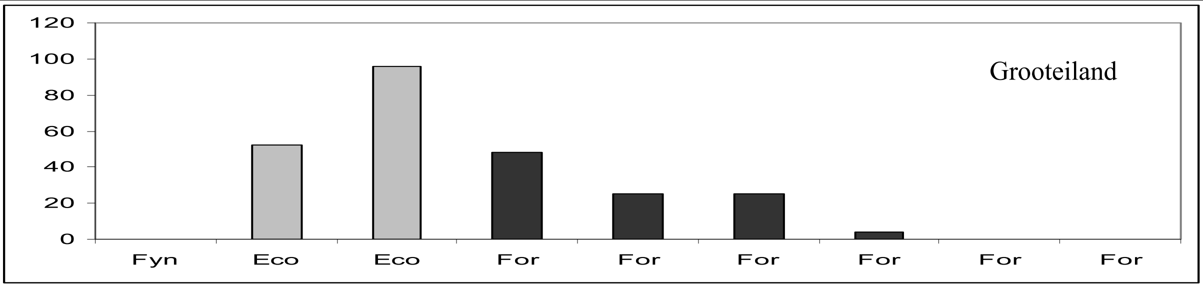
Resource availability of *B. latifolia* largely depends on the distribution and habitat characteristics of plant communities with which it is associated, while potential yield is influenced by the population dynamics of the species.

6.7.1 Distribution

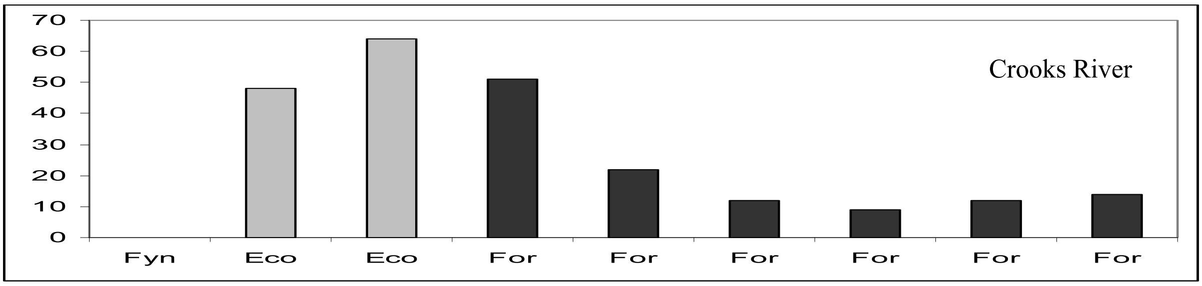
The results support observations by forest guards and findings by Baard (2002) that *B. latifolia* is largely confined to the coastal strip of Harkerville State Forest and to the upper slopes of river valleys cutting through the coastal plateau. This is consistent with findings by Geldenhuys (1993a) on the distribution and habitat of floristic communities in the southern Cape with which *B. latifolia* is associated. The species has a scattered distribution and populations are highly localised in dry Scrub-Forest.



Slope (◦)	16	35	33	32	31				
Stone %	-	27	1	1	5				
Soil depth (mm)	-	25	44	53	31				



Slope (◦)	-	37	35	37	40	44	43		
Stone %	-	42	9	1	2	1	0		
Soil depth (mm)	-	37	47	49	54	38	36		



Slope (◦)	-	44	45	45	44	45	45	45	45
Stone %	-	45	25	15	13	17	8	5	5
Soil depth (mm)	-	33	48	41	60	36	24	37	32

Y-axis = number of plants; X-axis = plot and vegetation type, and selected environmental data; Fyn = Fynbos; Eco = Ecotone - shaded in grey; For = Forest - shaded in black

Figure 6.6 Distribution of *Bulbine latifolia* along the continuous belt transects (transects combined) along the fynbos-forest environmental gradient for three study sites.

6.7.2 Community association and habitat

Von Breitenbach (1974) describes *Carissa bispinosa*, *Cassine tetragona*, *Capparis sepiaria* var. *citrifolia*, *Euclea racemosa*, *Scutia myrtina*, *Euclea schimperi* var. *schimperi* and *Aloe arborescens*, growing with *B. latifolia* in Scrub-Forest communities at Harkerville, as species typical of dry Scrub-Forest, while *Agathosma*, *Cliffortia*, *Cotyledon*, *Crassula*, *Erica* and *Metalasia* are associated with very dry Scrub-Forest. This further confirms the association of *B. latifolia* with the dry Scrub-Forest types in the southern Cape, which would define the

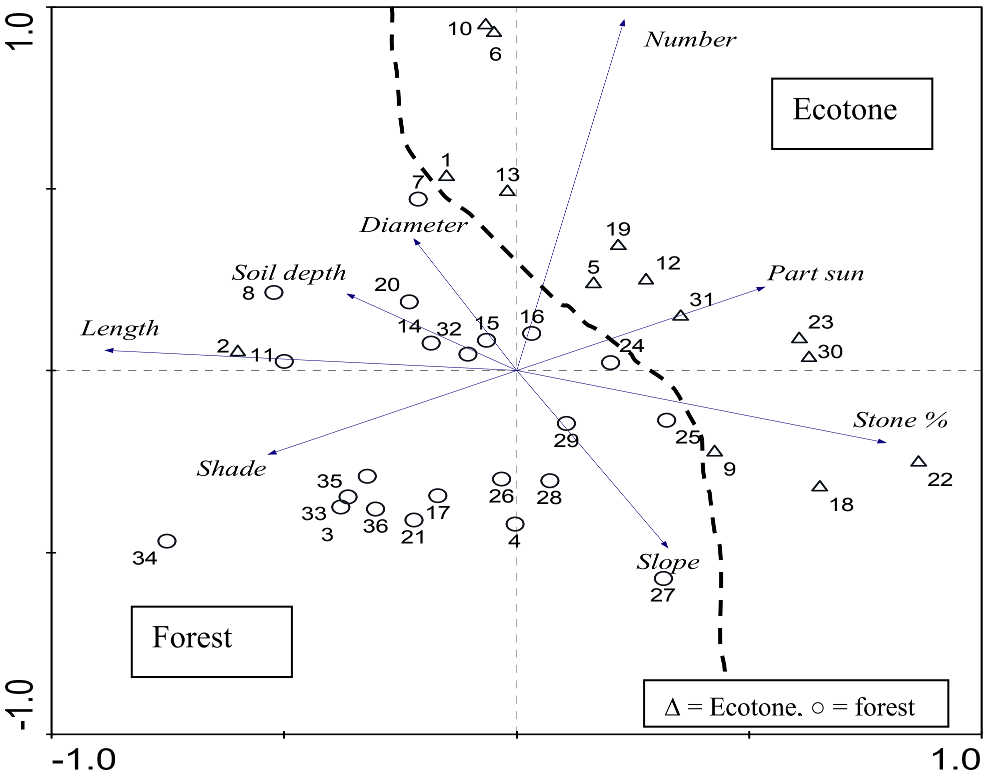


Figure 6.7. Relationship between vegetation type (ecotone and forest plots), *Bulbine latifolia* characteristics (number of plants, corm diameter, corm length) and environmental variables produced from CANOCO, using the PCA procedure.

distribution range of the species in the region. *Bulbine latifolia* is found in the fynbos/forest ecotone as well as deeper in the forest and only sporadically in fynbos.

Geldenhuys (1993a) conducted a comprehensive study on the composition and dynamics of plant communities in the southern Cape forests, and also only recorded *B. latifolia* in association with the dry forest types. The scrub forest communities identified in this study correspond with his *Sideroxylon inerme–Cassine aethiopica* Scrub-Forest Tree community. He recorded *B. latifolia* in the Understorey sub-communities (*Putterlickia pyracantha, Rumohra adiantiformis, Secamone alpinii, Dioscorea mundtii, Ornithogalum longibracteatum, Acanthaceae* species Scrub-Forest Understorey and *Cyrtorchis arcuata–Trichocladus crinitus–Angraecum pusillum–Tridactyle bicaudata* Scrub-Forest Understorey) associated with this tree community. These understorey sub-communities are also associated with his *Cassine peragua–Canthium inerme–Lachnostylis hirta–Rhus lucida–Rapanea melanophloeos–Olea capensis capensis* Dry Tall Forest and his *Olea capensis macrocarpa–Gonioma kamassi–Canthium inerme* Tall Dry Forest. The latter is considered to be transitional between scrub forest and the coastal platform forests, and is mostly found on the coastal scarp and river valley slopes (Geldenhuys 1993a). This confirms that *B. latifolia* in the southern Cape is large confined to the coastal scarp and river valley slopes where it is associated with a variety of dry forest communities.

The results of the direct and indirect gradient analysis show that *B. latifolia* is most abundant in the forest/fynbos transitional zone (ecotone communities) associated with particular dry Scrub-Forest communities. It is mostly found on warm and dry steep slopes, and especially in the ecotone, on shallow, sandy, rocky soils, as also indicated by Baard (2002) and Geldenhuys (1993a). The variation in environmental variables reflects a soil moisture availability gradient from the ecotone into the forest (Van Daalen 1980, 1984, Masson & Moll 1987). In more open areas in Scrub-Forest, where there is enough light penetration, *B. latifolia* could be abundant and is sometimes found as small cushions. Within populations, *B. latifolia* has a clumped or regular distribution. The clumped distribution could be attributed to the microenvironment (in the case of *B. latifolia* availability of light and protection against full-day direct sunlight), and reproduction characteristics (setting of seeds close to parent plants) (see Barbour *et al.* 1987).

Ramdhani (2002) argues that the "robust, rough and tough" leaves of broad-leafed *Bulbine* species such as *B. latifolia* may be a response to aridity, high irradiation, frost and fire under which it evolved (Smith & Van Wyk 1991). The species, though, seems to be vulnerable to direct sunlight and the leaves often turn brown during extended dry and hot spells (Vermeulen pers. obs.). Also, it is largely confined to forest vegetation or rocky slopes and outcrops in fynbos vegetation, where it occurs in shaded or partly-shaded areas and is protected against fire. Despite its succulent leaves, *B. latifolia* in the southern Cape thus seems to be vulnerable to fire, which would further confine it to forest and prevent its establishment in dry fynbos vegetation.

Useful species associated with B. latifolia

With the development of a management system for extractive resource use, all species in demand, or of user value, should be considered, especially in terms of the zonation of the harvest area. Species with medicinal properties growing with *B. latifolia*, as identified through the phytosociological study, include:

- the tree species *Grewia occidentalis* (Hutchings 1989, Grace *et al*. 2003), *Euclea schimperi*, *Sideroxylon inerme* (Arnold *et al*. 2002, Grace *et al*. 2003), *Tarchonanthus camphoratus* (Van Wyk *et al*. 1997, Arnold *et al*. 2002), *Rapanea melanophloeos* (Arnold *et al*. 2002, Grace *et al*. 2003), *Mystroxylon aethiopicum, Elaeodendron croceum* and *Pterocelastrus tricuspidatus* (Arnold *et al*. 2002, Grace *et al*. 2003);
- the shrubs *Agathosma ovata* (Arnold *et al*. 2002, Van Wyk & Gericke 2000) and *Carissa bispinosa* (Van Wyk & Gericke 2000); and
- herbs *Crassula orbicularis* (Hutchings 1989), *Viscum* sp. (Hutchings 1989, Van Wyk *et al*. 1997), *Agapanthus praecox* (Van Wyk *et al*. 1997, Van Wyk & Gericke 2000), *Aloe arborescens* (Van Wyk & Gericke 2000, Arnold *et al*. 2002), *Cotyledon orbiculata* and *Carpobrotus deliciosus* (Van Wyk & Gericke 2000, Arnold *et al*. 2002).

Species with uses other than medicinal, growing in association with *B. latifolia* include *Asparagus africanus*, *A. setaceus* and *Gasteria* spp. (used as vegetables), *Carpobrotus deliciosus* and *Chrysanthemoides monilifera* (fruits and berries), *Osyris compressa*, *Pterocelastrus tricuspidatus, Elaeodendron croceum* and *Rhus lucida* (dyes and tans), *Gasteria* sp. and *Viscum capense* (beverages) and *Sideroxylon inerme* (soaps and cosmetics) (Van Wyk & Gericke 2000).

There is currently a limited demand for access to these species in the southern Cape. However, with the zonation of dry Scrub-Forest for the harvesting of *B. latifolia*, most of these species would also be included. In this way resource use could be consolidated in a defined area as part of the multiple use forest management system (see Chapter 1).

6.7.3 Population dynamics

The results show that the dynamics of *B. latifolia* is complex, varying in and between populations. The population dynamics and distribution of plants are influenced by factors such as environmental conditions, resource availability, competition and disturbance (Barbour *et al.* 1987). The age or size class distribution of a population could be used as a predictive tool in population dynamics (Barbour *et al.* 1987) and is widely used in sustainable forest management planning (Cunningham 2001, Walker *et al*. 1986, Geldenhuys 1993c, Obiri 1997).

Population structure based on corm diameter

It could be argued (but not concluded without more detailed studies) that populations with a bell-shaped size class distribution are not reproducing sufficiently to maintain themselves (Barbour *et al*. 1987) and factors attributing to such a distribution thus need to be explored. The dynamics of a plant population has both deterministic and stochastic components that operate simultaneously (Lande *et al*. 2003) and a flat or bell-shaped size class distribution could thus be attributed to a species' reproductive strategy and site requirements (Cunningham 2001).

The dynamics of *B. latifolia* seems to have an environmental stochastic component (see Lande *et al*. 2003, Pfab & Witowski 2000), while it is also subject to disturbance by animals (Vermeulen pers. obs., see Chapter 7). For, especially, populations in the ecotone, the creation of conditions suitable for seedling establishment and growth is likely to occur sporadically (e.g. through disturbance on the forest edge or tree mortality), which could result in a bell-shaped size class distribution, as was recorded for the species (Figure 6.3). This distribution could be enhanced further by the "relay floristics" mode of succession, with different species establishing in seral communities as habitat is changed during succession (Barbour *et al.* 1987). Forest succession, following the establishment of *B. latifolia* after disturbance, could gradually render the habitat unsuitable for further seedling establishment. This is evident from the gradual decline in the number of plants, often of a smaller corm diameter, deeper in the scrub forest where light penetration is reduced (Figure 6.6), although also influenced by other environmental variables. However, where it is found in open forest, protected against direct sunlight but with optimum light penetration, constant regeneration could result in more stable populations.

For *B. latifolia*, the bell-shaped corm diameter class distribution applies to all the populations studied, as well as to the ecotone and forest vegetation when separated. The position and shape of the bell, however, vary between populations (Figure 6.3). This is also reflected by the difference in mean diameter of plants in the three populations, with the smallest recorded for Crooks River and the largest for Grooteiland (Table 6.4; Figure 6.4). This variation could be attributed to the different environmental conditions at the different study sites and the successional phase of the populations. Also when distinguishing between vegetation types (ecotone and forest), a bell-shaped size class distribution exists, but with a flatter curve and the bell towards the bigger diameter classes recorded for the ecotone compared to the forest populations (Figure 6.3), with, with the exception of Crooks River, mean diameter of the ecotone plants larger than for forest (Figure 6.4). Moore & Chapman (1986) also refer to this within-population variation in plant demography and that the heterogeneous nature of the habitat as experienced by individual plants in populations be considered with plant population studies.

Cunningham (2001) argues that species that are e.g. shade intolerant and exhibit a flat size class distribution would be much more vulnerable to overexploitation, especially when small plants are harvested, compared to species with an inverse J-shaped size class distribution. Depending on regeneration strategy, the same vulnerability could apply to species with a bell-shaped size class distribution such as *B. latifolia*. Stochastic fluctuations, and the interaction of stochasticity with exploitation of a resource, could also lead to the extinction of especially small isolated populations of a species (Lande *et al*. 2003). As emphasised by Pfab & Witkowski (2000), management recommendations should thus not only be based on deterministic matrix models, but should also accommodate the random and unpredictable changes in environmental conditions.

Population structure based on corm length

Understanding the population structure and dynamics of *B. latifolia* is further complicated by the fact that when corm length is used to define size, an inverse J-shaped size class distribution is obtained (Figure 6.3). This is common among e.g. shade-tolerant tree species (Geldenhuys 1993c, Peters 1996, Cunningham 2001). As these populations exhibit a continuous recruitment of young plants, they have a higher probability of maintaining themselves as part of a climax community (Barbour *et al.* 1987, Cunningham 2001), but this needs to be confirmed through more detailed studies.

As for diameter, the same distribution was recorded for all three populations studied, but with a significant difference in the mean corm length between the three study sites (Figure 6.4). Both in terms of corm diameter and length, Crooks River has the largest concentration of small plants. However, Grooteiland has the biggest plants when defined by diameter, and Jantjieseiland when size is measured in corm length (Table 6.4). This can be explained by the fact that for Grooteiland the largest percentage of plants are found in the ecotone, while for Jantjieseiland most are found in forest with a smaller diameter but longer corm. For Crooks River, there is a more equal distribution of plants in the ecotone and forest, with a smaller number of plants per plot but which extend deep into the forest (Figure 6.6; Appendix 3).

The same inverse J-shaped size class distribution presents itself when distinguishing between the ecotone and forest vegetation (Figure 6.3). However, the forest population has a flatter curve (fewer small plants), with mean corm length significantly higher than for ecotone plants. Thus, ecotone plants tend to be shorter but thicker than plants deeper in the forest. This could be attributed to the environmental differences between ecotone and forest, and the structure of scrub forest. Although it varies between sites, plants in forest are usually found on steeper slopes (Appendix 3). Owing to the growth form of *B. latifolia*, a longer corm could develop on steep slopes as a result of gravitational influences, while plants in the ecotone (especially closer to the fynbos boundary) grow more upright and are exposed to harsher conditions (a drier moisture regime with plants more vulnerable during drought), resulting in thicker plants.

The tendency of *B. latifolia* to grow more upright with a shorter corm on more level terrain is also evident from plants growing as pot plants or in gardens (Vermeulen pers. obs.). Also, Ramdhani (2002) reported that for his *Bulbine* sp. *affinis natalensis* taxon (equivalent to *B. latifolia* in the southern Cape), on steep rocky cliffs in the Eastern Cape the corm length:diameter ratio is usually greater than 6:1 with the corm anchoring the plant, allowing it to hang over the cliffs. This supports the view that slope could contribute to the higher mean corm length recorded for forest populations. Corm shape in the species, especially in terms of the corm length:diameter ratio, thus seems to be under environmental control rather than genetic as reported by Ramdhani (2002). From a resource-use perspective, this is of relevance when growing the species in medicinal plant gardens (Diederichs 2006) where optimum yield is determined by the ratio between corm length and diameter.

The reason for the difference in size class distribution when diameter and length are used to define plant size is difficult to explain and would require further investigation. For diameter growth it is postulated that a lack of secondary growth could result in a bottle-neck in the larger size classes and a bell-shaped size class distribution. Length growth is not subject to this constrain and a more gradual transition through the different length classes could be expected, attribution to an inverse J-shaped distribution. The relationship between corm diameter and length will impact on length *versus* diameter size class distribution (Figure 6.5). Although it varies between study site, ecotone plants are significantly higher in corm diameter but lower in corm length compared to forest plants. Ecotone plants, for example, are thus well represented in the shorter corm length classes (attributing to an inverse J-shaped length size class distribution), while better represented in the larger size classes in terms of corm diameter (attributing to a bell-shaped diameter size class distribution) for the same population. This requires further investigation but is complicated by the transitional nature of *B. latifolia* populations along the fynbos-ecotone-forest gradient. It, however, indicates that populations can maintain themselves where the habitat is suitable.

6.7.4 Heterogeneity, competition and metapopulation dynamics

Although the species occupies different microhabitats along the fynbos/forest environmental gradient, the ordination results (Figure 6.7) and floristic studies demonstrate the closer correlation of high *B. latifolia* densities with the ecotone and conditions of partial sun, more shallow and stony soils and flatter slopes, compared to forest populations. Population structure and dynamics of the species and corm characteristics vary between the two main habitat types (forest and ecotone). The performance of plants growing below tree canopies often differs from that of conspecifics growing in adjacent open spaces (Hastwell & Facelli 2003). For arid and semi-arid ecosystems, plants below the canopy often perform better (Callaway & Walker 1997), but this advantage diminishes in mesic ecosystems, and plants in open spaces may outperform shaded plants (Bertness & Callaway 1994). Furthermore, the differences in performance may change with seasonal conditions and climatic variation (Tielbörger & Kadmon 2000). Considering that *B. latifolia* is associated with the drier extreme of natural forest in the region, this variation in plant performance will impact on population structure and explain the complexities and variation in population dynamics reported for the species. This will be explored further in Chapter 7.

The level of change in species composition following disturbance is influenced by the combination of inter- and intraspecific competition among different plant species in the community (Ohsawa *et al*. 2003). The vulnerability of *B. latifolia* to harvesting would, thus, also be determined by the competition hierarchy within the community and where *B. latifolia* fits in (*vide* Ohsawa *et al*. 2003). However, the dynamics of competition over a spatial habitat can differ largely from the corresponding dynamics in each local site (Lehman & Tilman 1997), and accommodating the competition factor in a harvest system for a species such as *B. latifolia* would be difficult.

The scattered populations of *B. latifolia* could act as a metapopulation (see Hanski 1997, 1998, Chapman & Reiss 2006), but this will have to be confirmed by further studies on, for example, reproduction biology and spatial variation in life history parameters. This will not be explored further as part of this study. However, metapopulation dynamics is an important consideration in the management of plant species (Akcakaya 2000, Hui & Li 2004). These populations are considered to be vulnerable when their density falls below a certain threshold, or when the number of local populations is too small (Hui & Li 2004). Similarly could metapopulation dynamics be advantageous to the survival of a species should certain populations be overutilised or become extinct (Chapman & Reiss 2006). For *B. latifolia* this benefit will be further enforced by the fact that local populations inside the nature reserve will not be subjected to harvesting.

6.7.4 Implications of findings for management and resource use

The results of the study add to a better understanding of the distribution, community association and population dynamics of *B. latifolia*, in support of the process to develop a harvest system for the species. The following aspects are of relevance, to be considered with the formulation of harvest prescriptions for the species dealt with in Chapter 7:

- *Bulbine latifolia* is largely confined to the coastal strip of Harkerville State Forest on the upper slopes of river gorges cutting through the coastal plateau. Although locally abundant, it occurs as relatively small, isolated populations, which would present difficulties with defining the potential harvest area and assessing the harvest potential of the species.
- Considering the higher densities (up to 103 plants ≥ 10 mm in diameter recorded per 25 m^2 plot) of *B. latifolia* plants in the ecotone, ecotone populations hold the highest harvest potential. The potential yield, however, is difficult to define due to the large variation in densities along both the forest edge and the fynbos/ecotone/forest gradient.
- Populations in dry Scrub-Forest are less subjected to disturbance and are relatively stable where there is enough light to maintain the population. Populations in the ecotone are more subjected to disturbance and successional processes, as is also evident from the higher percentage of multi-stemmed plants in the ecotone. These differences should be taken into consideration when developing a harvest system and management prescriptions for the species.
- The skewed bell-shaped size class distribution recorded (corm diameter as a measure of size), with stochastic events that seem to be important drivers of the population dynamics of the species, will pose additional challenges with the development of a harvest system.
- Key considerations with the development of a harvest system would be the fact that the biggest plant recorded is only 39 mm in diameter, that less than 15% of plants in the population reach a diameter ≥ 25 mm, and that this varies between populations. Also, with corm diameter significantly larger for plants growing in the ecotone there may be a need to differentiate between ecotone and forest populations.
- The possibility that the scattered *B. latifolia* populations act as a metapopulation could be explored further, considering that small populations have a higher risk of extinction than larger ones (Hanski 1997) and are therefore more vulnerable to disturbance.
- Branching was observed for *B. latifolia* but, at least in some cases, seems to be the result of multiple sprouting when corms are damaged or broken off (see Chapter 7). This holds important implications for the harvest method.

- For *B. latifolia* in the southern Cape, mean corm diameter at the base is smaller than closer to the growth end, although not significantly so. It has been observed that the basal area of the corm rots away as the plant ages (Vermeulen pers. obs.), as also reported by Ramdhani (200) for some other *Bulbine* spp. Corm diameter closer to the growth end would thus be more reliable to quantify size and growth rate.
- A range of plant species with medicinal and other uses have been identified growing in association with *B. latifolia*. Should there be a demand for these, this should be considered with the development of the harvest system for *B. latifolia*, especially in terms of the zonation of the harvest area.
- The biggest section of the coastal strip of Harkerville State Forest forms part of Sinclair Nature Reserve. The reserve forms part of a system of nature reserves in the southern Cape forest complex where natural, ecological processes are to be maintained with the least human interference, and where consumptive resource use is prohibited (Seydack *et al*. 1982, Durrheim & Vermeulen 2006). This drastically limits the scope and potential for harvesting *B. latifolia* from the Harkerville State Forest.

6.8 CONCLUDING REMARKS

By adequately addressing the research questions, the study objective was achieved of gaining a better understanding of the habitat and distribution, community association and population dynamics of *B. latifolia*, and their relevance to the sustainable harvesting of the species. The results indicate that the species is abundant on the fynbos/forest ecotone, associated with dry scrub forest communities. It has an inverse J-shaped and skewed bell-shaped size class distribution when corm length and corm diameter are used as a measure of plant size respectively. This, together with variation between ecotone and forest populations, could complicate the development of harvest prescriptions. In terms of harvest system development, corm diameter is the better surrogate for age, as length is more variable and seems to be habitat induced.

Plant populations are dynamic and always changing (Barbour *et al*. 1987), and static surveys of population structure at one time are a limited approach (Chapman & Reiss 2006), as was demonstrated by Pfab & Witkowski (2000), Keith (2002), Sánchez-Velásquez *et al*. (2002) and Lienert & Fischer (2003). To fully understand the population dynamics of *B. latifolia*, the demography and life history patterns of the species also need to be studied. This is dealt with in Chapter 7.

6.9 ACKNOWLEDGEMENTS

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CHAPTER 7: THE DEMOGRAPHY AND REPRODUCTIVE PHENOLOGY OF *Bulbine latifolia* (L.F.) SCHULT. & SCHULT.F. HARVESTED FOR MEDICINAL USE FROM NATURAL FOREST IN THE SOUTHERN CAPE, AND GUIDELINES FOR SUSTAINABLE HARVESTING

7.1 INTRODUCTION

Harvest strategies and management systems to ensure sustainable use of medicinal plants and other non-timber forest products (NTFPs) from the wild are largely still lacking, and overutilisation is of growing concern worldwide (Cunningham 1993, 1997, Balick & Cox 1997, Ngulube 1999, Ouédraogo 2001, Walter 2001, Grace *et al*. 2002, Lawes *et al*. 2004b). Studies of population dynamics and plant demography in natural habitats are of critical importance in the conservation of endangered plant species and in the sustainable management of species subject to resource use (Pfab & Witkowski 2000, Sánchez-Velásquez 2002, Keith 2002, Raimondo & Donaldson 2003, Pfab & Scholes 2004).

Bulbine latifolia (L.f.) Schult. & Schult.f. has a wide distribution in South Africa (Germishuizen & Meyer 2003) and is commonly used for its medicinal properties (Watt & Breyer-Brandwijk 1962, Hutchings 1989, Hutchings *et al*. 1996, Van Wyk *et al*. 1997). However, concerns have been raised about overutilisation of *B. latifolia* and other *Bulbine* species from the wild (Ramdhani (2002). In the southern Cape, uncontrolled use of the species from Sinclair Nature Reserve at Harkerville State Forest has been dealt with through a process of participatory forest management (PFM) (Vermeulen 2005). An interim arrangement was made with the user group (Rastafarian community) for limited, controlled access, while applied research was initiated to develop harvest prescriptions for sustainable use.

Management strategies for the development of harvest systems for sustainable use of NTFPs are given by Van Daalen (1988a), Peters (1996), Geldenhuys (2000b), Grundy (2000) and Cunningham (2001), with requirements for improved sustainable use of forest resources provided by Geldenhuys (1999). A better understanding of the distribution and community association of the target species, its population dynamics and demography, is needed to provide scientific bases for harvest prescriptions and use potential (Peters 1996, Cunningham 2001). Reproduction (seed production, seed dispersal, seedling establishment and vegetative regrowth) is a critical component in the life cycle of plants (Morgan 1995, Geldenhuys & Van der Merwe 1988, Calviño-Cancela 2002, Galloway 2002). Understanding the reproductive phenology (phenological traits that relate to reproductive stage) of a species is therefore important when formulating harvest prescriptions.

7.2 STUDY OBJECTIVES

Chapter 6 dealt with the community association, distribution and population dynamics of *B. latifolia*. The current chapter addresses:

- Specific objective 7 "to gain insight, through applied research and monitoring, into the demography and reproductive phenology of *B. latifolia*, to inform the development of a harvest system and management prescriptions for the species"; and
- Specific objective 8 "to develop and present, based on applied research results, a management system for the sustainable harvesting of *B. latifolia* from natural forests in the southern Cape, and a planning approach for its successful implementation".

This requires long-term monitoring in permanent plots and of individual plants (Fair *et al*. 1999, Guárdia *et al*. 2000, Watkinson *et al*. 2000, Lennartsson & Oostermeijer 2001). Based on the results – together with findings on community association and population dynamics dealt with in Chapter 6 – a management system and harvest prescriptions for the species are proposed.

Associated research questions:

- What are the phenophases for *B. latifolia* and how do they relate to environmental variables such as rainfall and temperature?
- How successfully does it regenerate (from seed and vegetatively) and how is recruitment influenced by environmental variables such as rainfall and temperature?
- How does reproductive phenology differ between ecotone and scrub forest populations?
- What is the rate of renewal and recruitment and how does it differ between ecotone and scrub forest populations?
- How could reproductive phenology and rate of renewal inform harvest prescriptions?
- Based on the research results, what are the management options for sustainable harvesting of *B. latifolia* from natural forests in the southern Cape?

7.3 METHODS

7.3.1 Study area

The study was conducted on the coastal strip of Harkerville State Forest comprising dry forest types and coastal fynbos (see Chapter 6 for a more detailed description of the study area). Three *B. latifolia* populations occurring in dry Scrub-Forest, were selected, namely Jantjieseiland (western aspect), Grooteiland (northern aspect) and Crooks River (eastern aspect) (see Chapter 6). Jantjieseiland and Grooteiland occur within the boundaries of Sinclair Nature Reserve; the Crooks River site lies on the eastern boundary of the State Forest. None of the populations had previously been exposed to harvesting.

7.3.2 Plot layout

For demographic studies, 21 plots of 1x2 m were established in clusters of *B. latifolia* in the fynbos/forest ecotone (11 plots) and scrub forest (10 plots) at the three study sites (Jantjieseiland 8 plots, Grooteiland 8 plots, Crooks River 5 plots). Wooden poles connected with rope defined the plot area (see Plate 6.1d).

7.3.3 Data recording

Plants ≥ 10 mm in basal diameter (root-end) were tagged and numbered for successive measurements. The number of plants per plot varied from four for a forest plot at Crooks River to 22 for an ecotone plot at Jantjieseiland, with a total of 251 plants (140 ecotone, 111 forest). The corm diameter of each plant was recorded using a micro-caliper, and the point of measurement fixed by means of a thin painted line (Figure 7.1; see Plate 6.1e). The total length of the corm was measured as well as the distance from the painted line to the first (oldest) set of leaves (to monitor length growth).

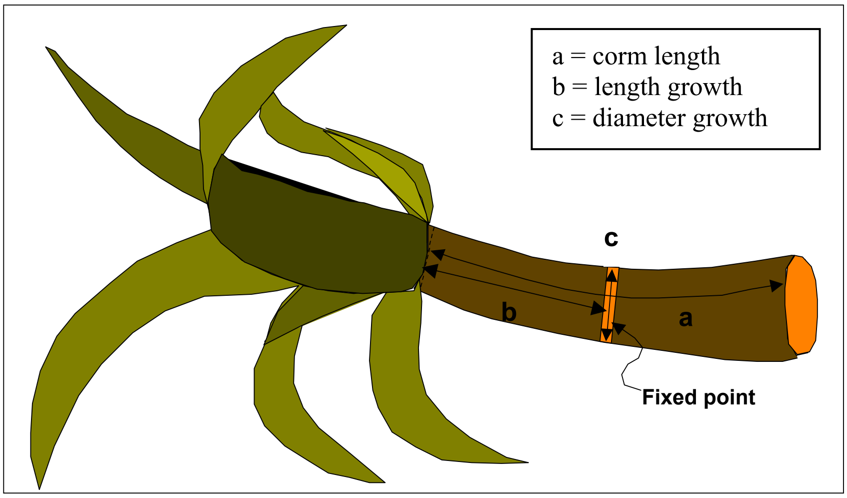


Figure 7.1. Schematic diagram showing measurements taken of the corm of *Bulbine latifolia*.

Each plant in the 0.5-1.0 mm basal diameter cohort was marked by planting a painted piece of wire close to it (see Plate 6.1f). Mortality, ingrowth and outgrowth (number of plants growing into or out of a cohort) were recorded. Re-measurements of diameter and length were conducted every six months over a period of three years.

The number of leaves was recorded for all plants ≥ 10 mm in basal diameter, and the youngest immature leaf of every second plant was marked with a painted dot. Leaf development was recorded monthly according to the following classes: leaf partly developed, leaf fully developed, leaf dying back, leaf dead.

The number of plants (seedlings) < 0.5 mm diameter in the plot was recorded monthly over a period of 41 months. For the tagged plants (plants ≥ 10 mm diameter) phenological events were recorded according to the following development stages: bud formation, flower production, fruit production, seed production. Flower heads that were damaged (e.g. by insects, mammals) to such an extent that they did not develop to produce seeds, were also recorded.

A brief study on seed production was conducted by the systematic collection of 25 inflorescences on the forest/fynbos ecotone at Grooteiland. The diameter of the peduncle of each inflorescence, the number of fruit per inflorescence and the number of seeds (from a minimum of 15% of the fruit per inflorescence, randomly selected) were recorded. Due to time constraints and lack of facilities, no germination studies were conducted.

7.3.4 Data analysis

An analysis of variance was conducted (multi-level ANOVA) using the Statistica 7 computer program (StatSoft Inc., Tulsa Oklahoma, USA) to test the hypothesis that there is a significant difference between forest and ecotone and between study sites, in terms of plant growth (corm diameter, corm length and leaf development) and seedling production. Significantly different "treatment" means (sites, ecotone/forest) were separated applying a post hoc Bonferroni test.

The non-parametric Spearman rank correlation analysis (Zar 1996) was conducted to test the hypothesis that regeneration (number of seedlings) is correlated with climatic variables (temperature and rainfall data recorded at George Airport, 220 metres a.m.s.l.), and that plant growth and flower production is influenced by corm characteristics (corm diameter and corm length).

7.4 RESULTS

7.4.1 Reproductive phenology

The results of 41 months of monitoring (July 2003 to December 2006) demonstrated that *B. latifolia* plants start producing flower buds in May with seed set completed by December. Although the trend was not consistent for 2005 (flowered earlier), most buds were produced in July and August. Flower production peaks in August and September, and fruit and seed production in October and November respectively; these phenological events coincide with lower temperatures (Figure 7.2). Bud production starts after the autumn rainfall peak. A drier period is experienced during the winter months, but is followed by increased rainfall from August and September after bud formation when the flowering peak is reached (Figure 7.3). In terms of the onset of phenological events, no clear difference exists between plants growing in the ecotone and scrub forest (data not shown).

Although plants as small as 10 mm corm diameter produced flowers and fruited, only 20.8% of these in the 10-14 mm diameter class flowered, compared to 78.3 and 100% of plants in the 25-29 and ≥ 30 mm cohorts respectively. Of the plants in forest, a smaller percentage produced flowers compared to ecotone plants, for all the diameter classes up to 30 mm (Figure 7.4a). In total, only 51.8% of plants monitored produced flowers.

There is a significant positive correlation between number of flower heads per plant and corm diameter ($r = 0.601$, $P < 0.01$) and length ($r = 0.298$, $P < 0.01$). In terms of plants that flowered, the number of flower heads ranges from a mean of 1.6 (10-14 mm corm diameter class) to 7.0 for plants ≥ 30 mm (Figure 7.4b).

The percentages of inflorescences damaged or that did not develop to produce seeds, as recorded for the different development stages, are presented in Figure 7.5 for three years of

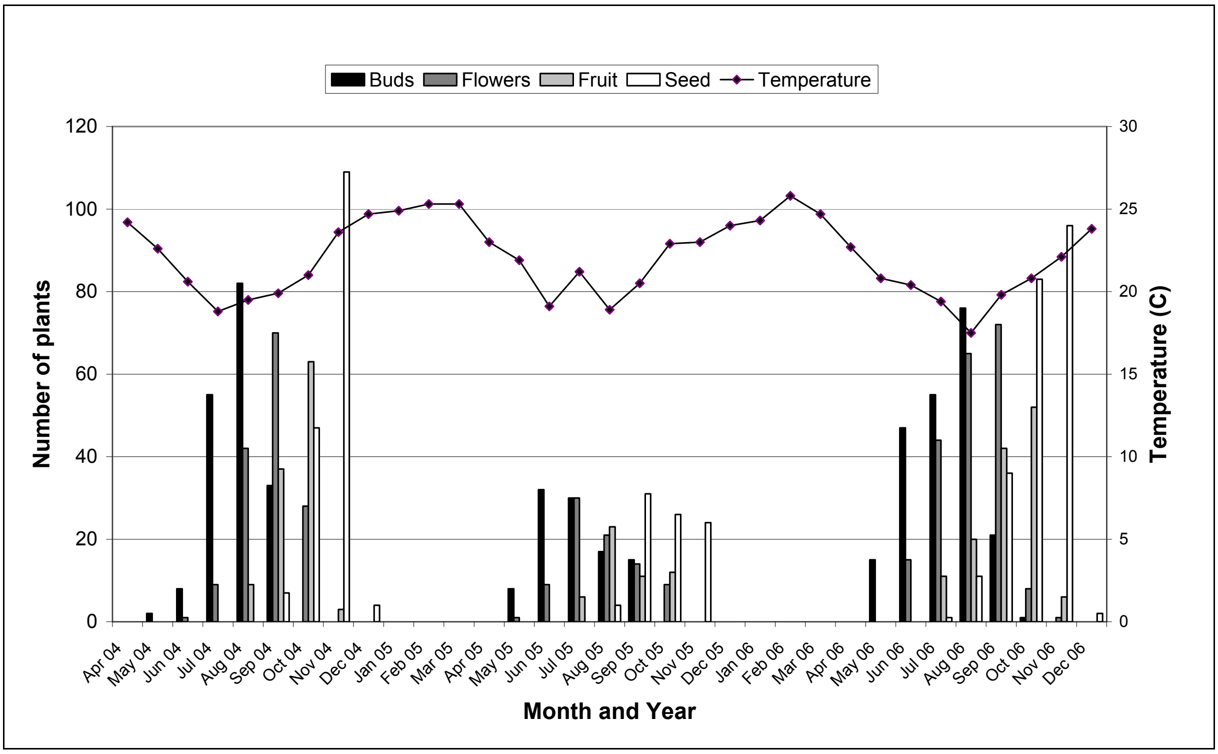


Figure 7.2. Seasonal trends in bud, flower, fruit and seed production for *Bulbine latifolia* at Harkerville State Forest in relation to monthly temperature variation.

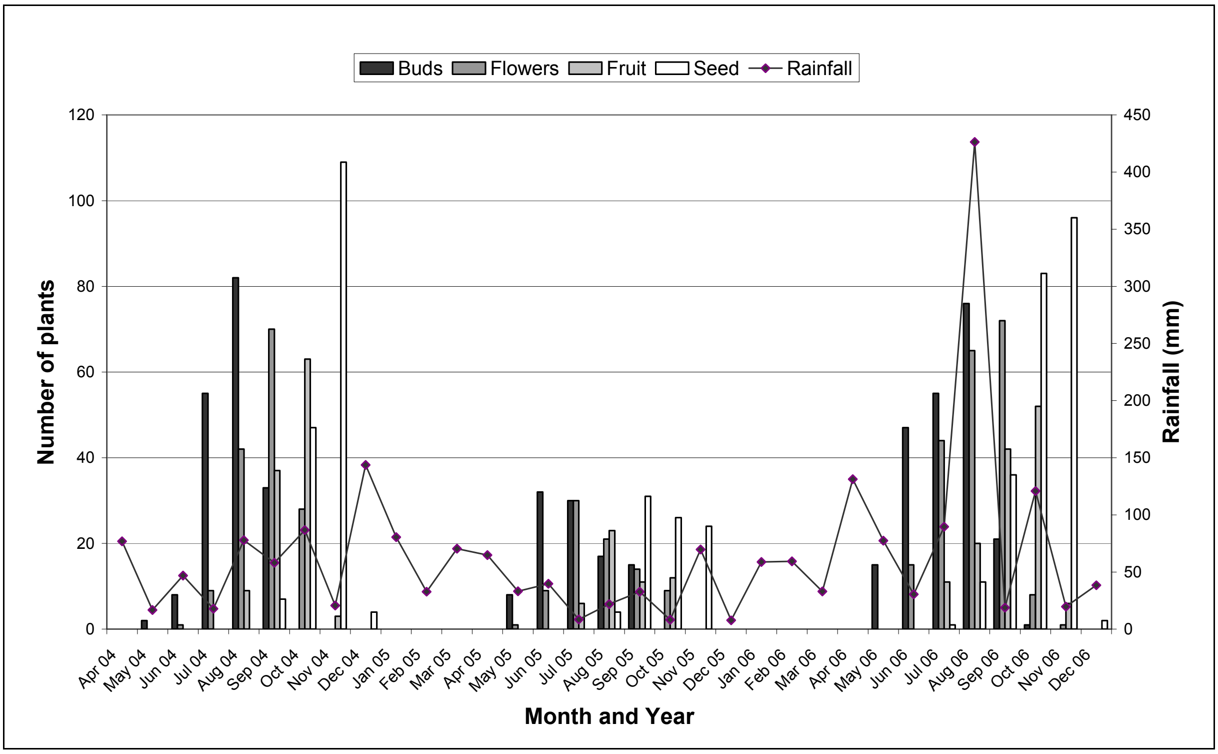


Figure 7.3. Seasonal trends in bud, flower, fruit and seed production for *Bulbine latifolia* at Harkerville State Forest in relation to monthly rainfall variation.

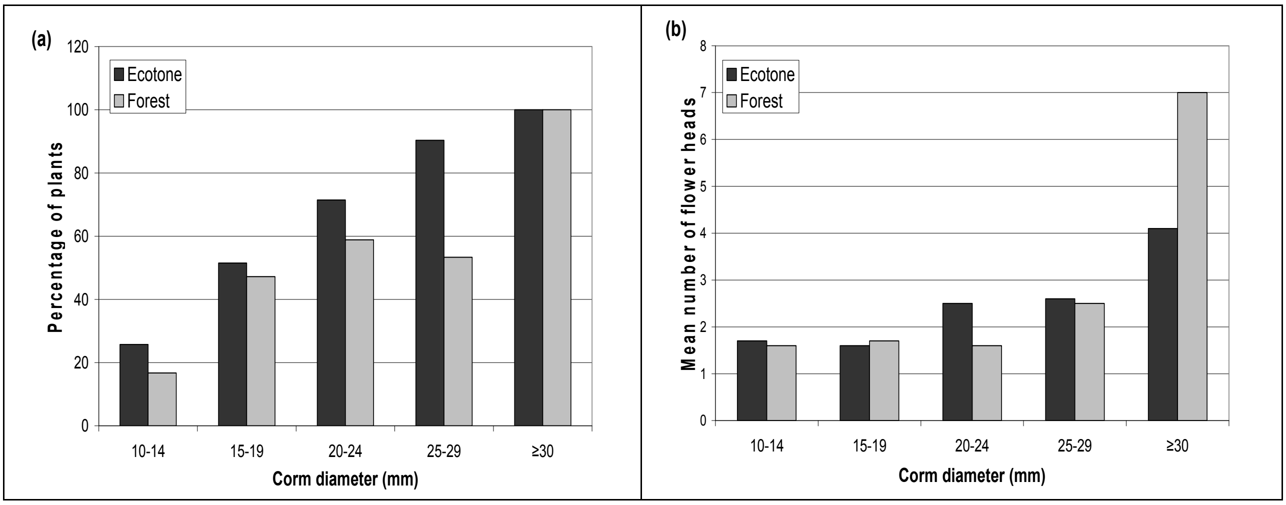


Figure 7.4. Percentage of *Bulbine latifolia* plants producing flowers (a) and mean number of flower heads (b), for different diameter classes per vegetation type.

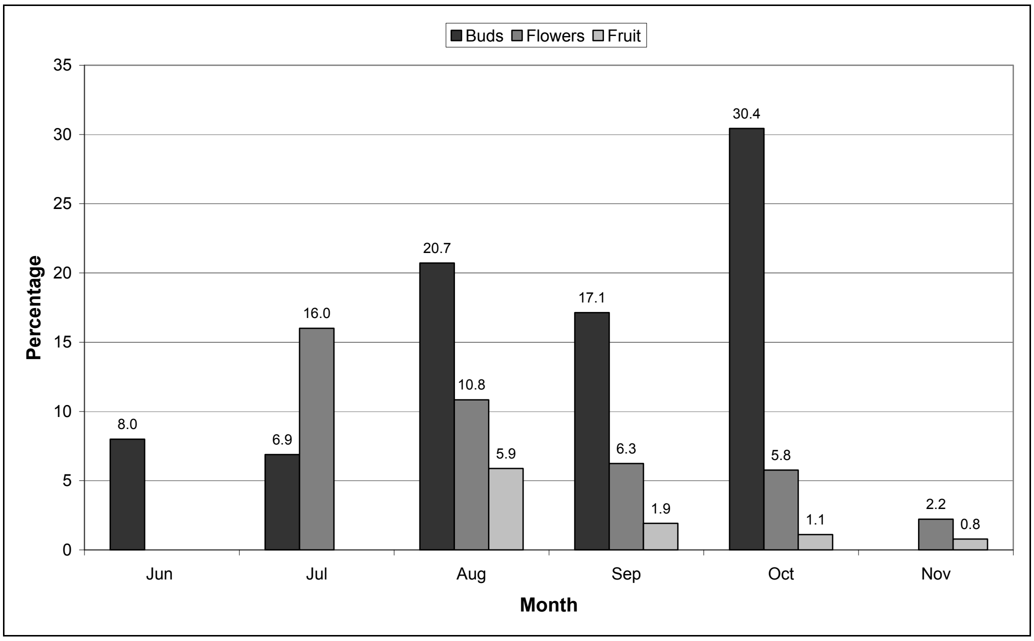


Figure 7.5. Monthly variation in the percentage of damaged *Bulbine latifolia* inflorescences in the different development stages, combined for three years of monitoring.

monitoring combined. Survival and success rates differed between stages and varied from year to year. For buds, 30.4% present in September were dead or damaged in October, compared to 8% of buds produced in May. For flowers, 16% present in June did not reach the fruit stage, with a higher percentage survival for flowers produced later in the season.

7.4.2 Seed production, regeneration and population development

The number of fruits produced depends on the size of the inflorescence, and varies between 15 and 231 (X = 63.5 ± 9.3; n = 25; peduncle diameter 1-4 mm). An average of 6.7 ± 0.1 seeds is produced per fruit (n = 577), ranging from 1 to 17.

An average of 11.5 ± 3.1 seedlings (plants < 5 mm in corm diameter) per plot was recorded over the 41-months monitoring period, 15.1 ± 3.3 and 10.1 ± 4.5 for ecotone and forest plots respectively. The seedling/adult ratio for the different plots varied from 0.0 to the highest of 5.2 seedlings for an ecotone plot at Jantjieseiland, with a mean of 1.3 ± 0.5 and 0.9 ± 0.2 for ecotone and plots respectively. For none of the seed production variables were the difference between vegetation type and study site significant at P < 0.05.

Seedling densities varied over time and followed seed set in October and November (Figure 7.6). Seedling establishment and survival in relation to mean monthly temperature and rainfall partly differed between forest and ecotone populations. For the ecotone, there was a significant negative correlation between seedling densities and temperature (r = -0.496, P < 0.01), while for forest the correlation is positive but not significant. In terms of rainfall, no significant correlation was recorded with seedling densities at P < 0.05.

Findings on population turnover in the larger diameter classes (plants ≥ 10 mm corm diameter) are summarised in Table 7.1. Over the 36 month monitoring period a mean annual ingrowth (plants growing into the ≥ 10 mm corm diameter cohort) of 3.6%, and an annual mortality rate of 5.3%, was recorded. This varies between study sites and over time, with the highest annual mortality rate recorded at Grooteiland for the period July 2003 to July 2004 (Table 7.1). Over the 36-month monitoring period, the population turnover (all study sites combined) was -5.6%, indicating higher mortality than ingrowth. Plants broken off by animals (presumably baboons) accounted for 22.5% of mortality, although 55% coppiced (Table 7.2). Mortality was distributed over most of the diameter classes, with the bigger plants more subject to damage by animals (Figure 7.7).

7.4.3 Leaf development

The number of leaves per plant in the monitoring plots varies from three to 21 with an average of 12.3 ± 0.2. A significant positive correlation exists between number of leaves and both corm diameter (r = 0.596, P < 0.01) and corm length (r = 0.529, P < 0.01). It took on average 5.5 ± 0.12 months for a leaf to develop to maturity, ranging from two to eight months, and another 4.3 ± 0.1 months to die back completely (total of 9.8 ± 0.2 months). No difference exists between ecotone and forest plants, or between study sites. Also, there was no correlation between rate of leaf development to maturity and total die-back, and corm diameter, corm length or the number of leaves on a plant at P < 0.05.

7.4.4 Corm diameter and length growth

In terms of corm diameter, *B. latifolia* plants grew at a rate of 0.65 ± 0.03 mm per annum, with no significant difference at P < 0.05 between plants in the ecotone and forest, or between study sites. Also, no correlation was recorded between diameter growth, and corm diameter and length.

For corm length, a growth rate of 9.6 ± 04 mm/annum was recorded. Ecotone plants grew significantly slower at 8.3 ± 0.5 mm/annum, compared to 11.1 ± 0.6 mm/annum for forest plants (P < 0.001). This difference is largely attributed to the significantly higher growth

Table 7.1. Summary of population turnover for *Bulbine latifolia* (plants ≥ 10 mm corm diameter) over a period of 36 months at three study sites

		Study site			
Period		**Jantjieseiland**	**Grooteiland**	**Crooks River**	**Combined**
July 03	n	110	101	40	251
July 03– July 04	I	3 (2.7)	4 (4.0)	1 (2.5)	8 (3.2)
	M	5 (4.5)	13 (12.9)	4 (10.0)	22 (8.8)
	N	108	92	37	237
	% turnover	-1.8	-8.9	-7.5	-5.6
July 04– July 05	I	4 (3.7)	1 (1.1)	2 (5.4)	7 (3.0)
	M	4 (3.7)	1 (1.1)	3 (8.1)	8 (3.4)
	N	108	92	36	236
	% turnover	0.0	0.0	-2.7	-0.4
July 05– July 06	I	3 (2.8)	5 (5.4)	3 (8.3)	11 (4.7)
	M	2 (1.9)	7 (7.6)	1 (2.8)	10 (4.2)
	N	109	90	38	237
	% turnover	+0.9	-2.2	+5.6	+0.4
July 03– July 06	I	10 (9.1)	10 (9.9)	6 (15.4)	26 (10.9)
	M	11 (10.0)	21 (20.8)	8 (20.0)	40 (15.9)
	N	109	90	38	237
	% turnover	-0.9	-10.9	-5.0	-5.6
Annual mean	I (%)	3.0	3.3	5.1	3.6
	M (%)	3.3	6.9	6.7	5.3
	% turnover	-0.3	-3.6	-1.7	-1.9
n = initial number of plants; I = ingrowth with % in brackets; M = mortality with % in brackets; N = net number of plants at end of period					

Table 7.2. Causes of mortality (broken off or die-back) and resprouting capacity (response when broken off) for *Bulbine latifolia* over 36 months

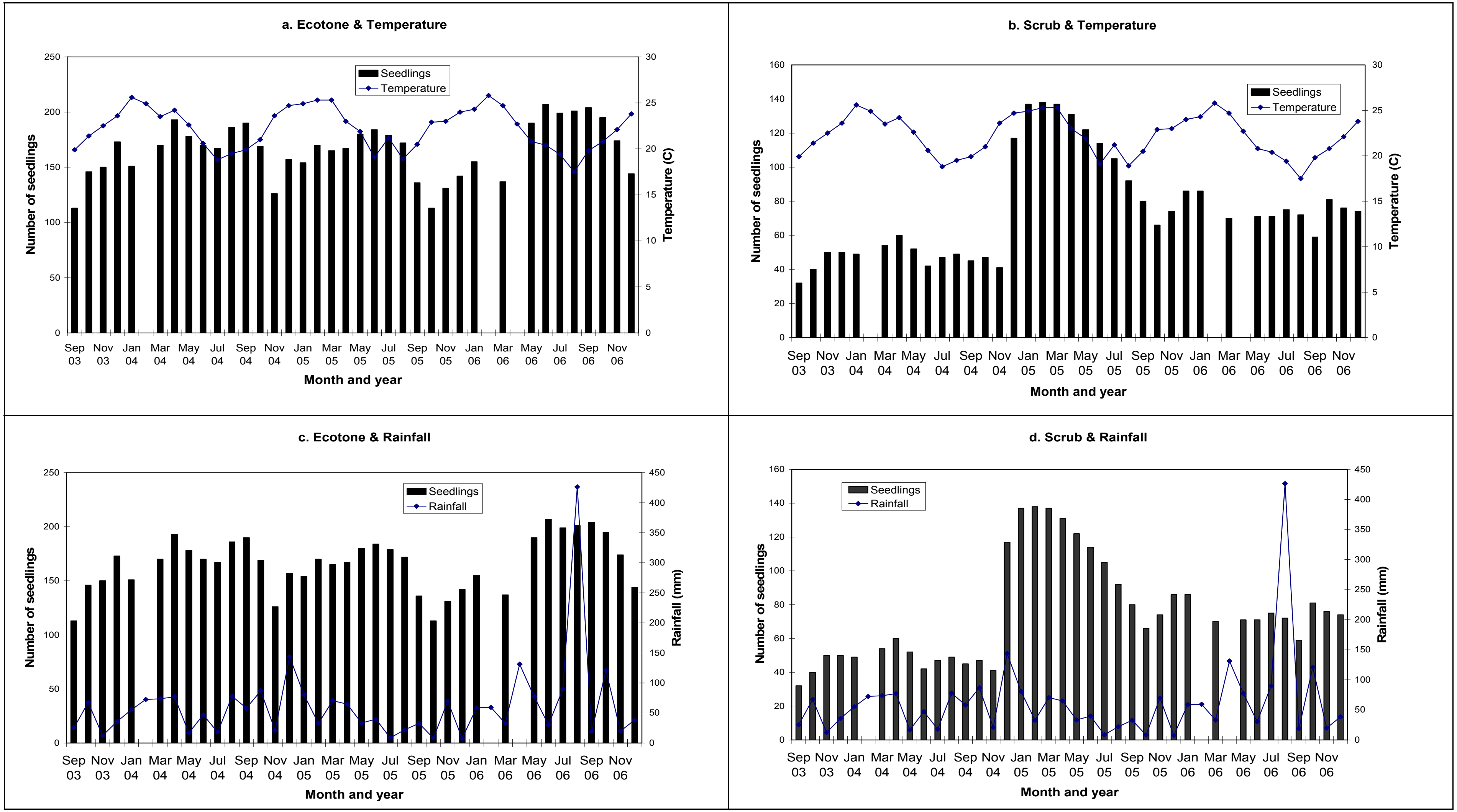
	Mortality (number)[1]			Broken off (number)[1]		
	Died back	Broken off[2]	Total	Coppice	Died[2]	Total
Jantjieseiland	9	2	11	7	2	9
Grooteiland	15	6	21	4	6	10
Crooks River	7	1	8	0	1	1
Combined	31 (77.5)	9 (22.5)	40	11 (55.0)	9 (45.0)	20

[1] The figure in brackets indicates the percentage of plants for the specific class
[2] Plants broken off and did not resprout

recorded at Crooks River for forest plants ($P < 0.001$). The highest growth was also recorded at Crooks River (11.3 ± 1.8 mm/annum), but the difference between study sites is not significant. The rate of corm length growth is significantly positively correlated with corm length ($r = 0.468$, $P < 0.01$) and corm diameter ($r = 0.216$, $P < 0.01$) (Figure 7.8). No correlation was found between corm diameter growth and corm length growth.

7.5 DISCUSSION

Results of the studies on reproductive phenology, regeneration, growth and population turnover are to inform harvest prescriptions and the management system for *B. latifolia*, together with findings on population structure (see Chapter 6).



Note: Seedling densities for February 2004, February 2006 and April 2006 not available

Figure 7.6. Monthly seedling densities of *Bulbine latifolia* for ecotone and forest populations compared with monthly rainfall and mean maximum temperatures.

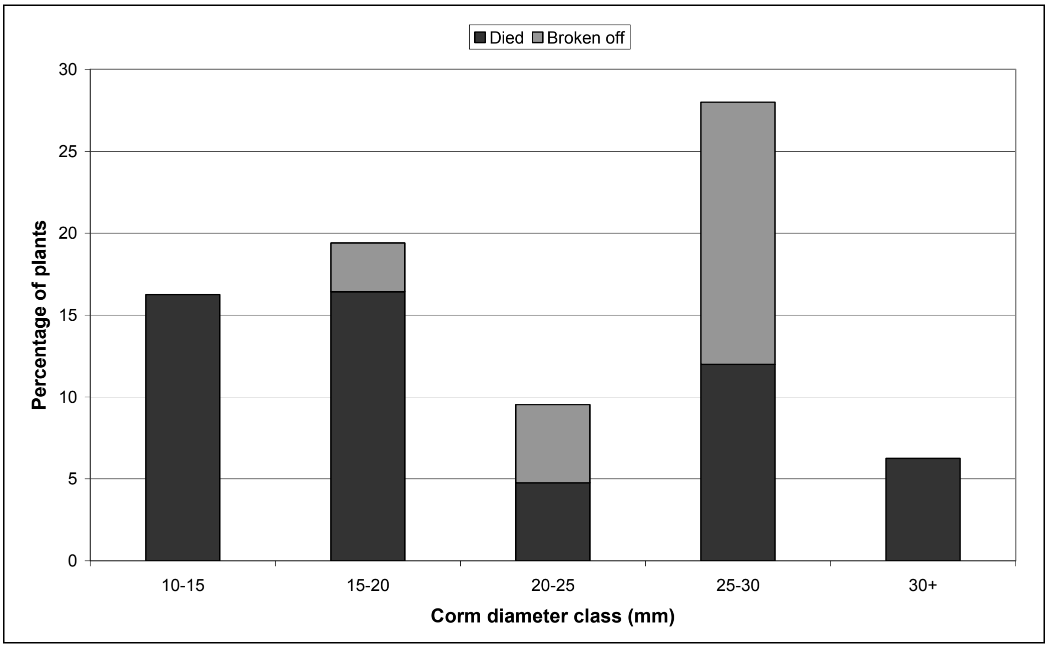


Figure 7.7. Size class distribution for mortality (plants that died or were broken off and did not resprout), at Harkerville State Forest for *Bulbine latifolia* over a period of 36 months (n = 40).

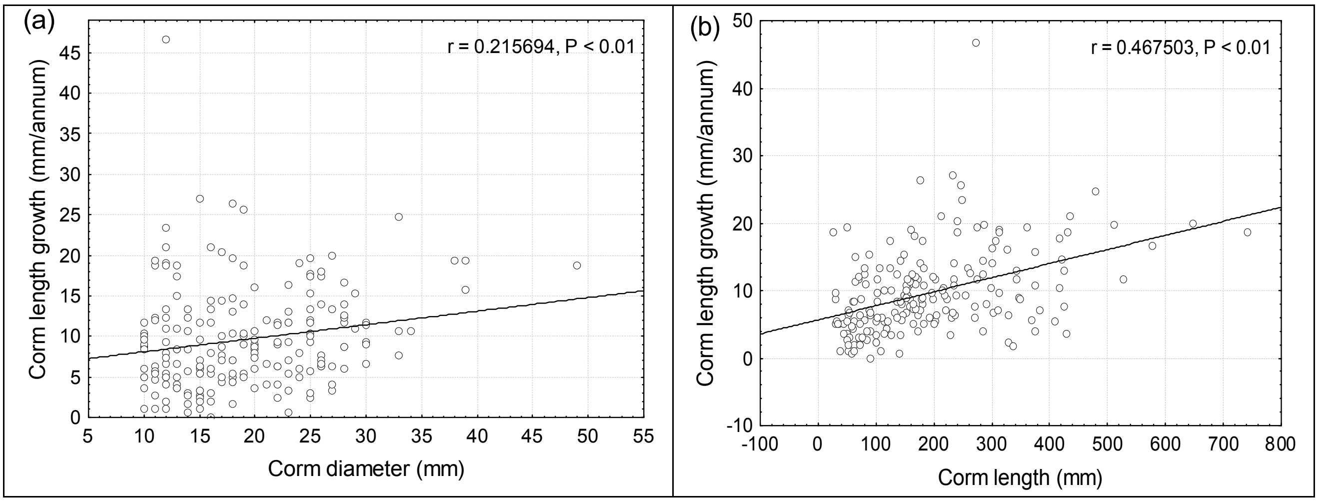


Figure 7.8. Correlation between *Bulbine latifolia* corm length growth and (a) corm diameter (b) and length.

7.5.1 Reproductive phenology

Phenology is an important adaptive trait which not only determines the duration and growing season of certain species, but also the period of reproduction (Pierce 1984, Reich *et al*. 1992 cited in Chuine *et al*. 2000). For sustainable use, the potential impact of harvesting on seed production and regeneration is important when developing harvest systems, and periods sensitive to harvesting should be identified and accommodated in harvest prescriptions.

Bulbine latifolia flowers in winter and spring (Figure 7.2), which is consistent with the period of June to November recorded by Baard (1994) for the southern Cape, and June to October for the Grahamstown area in the Eastern Cape (Ramdhani 2002). The poor flowering season for *B. latifolia* in 2005 coincided with a dry spell during the flowering period following budding (Figure 7.3), further demonstrating the importance of rainfall in successful seed production. These results are consistent with findings for most plant species that flowering and seed production coincide with seasonal variation in temperature and rainfall (Pierce 1984, Geldenhuys & Van der Merwe 1988, Morgan 1995).

Phenophases are species specific (Pierce 1984, Barbour *et al*. 1987) and, as recorded by Baard (1994) for forest species in the southern Cape, flowering can occur throughout the year (e.g. *Dietes iridioides*), or be confined to four or fewer months (e.g. *Aristea ensifolia*). Most taxa of the broad-leafed *Bulbine* bloom twice a year (Ramdhani 2002), but not so for natural southern Cape populations of *B. latifolia* – although blooming at different times of the year has been observed where it grows as pot plants (Vermeulen pers. obs.). Ramdhani (2002) attributes the biferous flowering recorded for some *Bulbine* spp. to the availability of rain and seasonal changes. The fact that the southern Cape has year-round rainfall (although bimodal) with less pronounced peaks (Scriba 1984) could explain the annual bloom for *B. latifolia* in the southern Cape.

The age of first reproduction is important in population dynamics (Manders & Cunliffe 1987) and sustainable harvesting. *Bulbine latifolia* is not solely dependent on the bigger plants for reproduction as the entire range of diameter classes (≥ 10 mm corm diameter) produced flowers, although bigger plants produce more flower heads (Figure 7.4). However, because a much smaller percentage of plants in forest produces flowers compared to the ecotone, harvesting in scrub forest could have a bigger effect on reproduction. Also, although phenological events are influenced by aspect, and could be retarded or delayed e.g. on cooler southern slopes (Barbour *et al*. 1987), monthly monitoring did not reveal any clear differences between study sites.

The failure of flowers to develop to the fruiting and seeding stage (Figure 7.5), could be attributed to damage by animals (insects and browsing) (Vermeulen pers. obs.), as well as to flowers that abscised due to a lack of pollination. Considering the high seed production recorded for *B. latifolia* in this study, the failure rate of flowers to develop to the seeding stage does not seem to have a huge impact on reproduction success. This, though, needs to be confirmed through further studies on, for example, the pollination biology of the species.

7.5.2 Regeneration and recruitment

Although no germination studies were conducted on *B. latifolia*, field observations of the presence of many seedlings following seedset, point to a high germination rate (Vermeulen pers. obs.). This is supported by a germination percent of 80% for *Bulbine* species grown in medicinal plant gardens reported by Crouch *et al*. (2006). It indicates a lack of dormancy with *B. latifolia* seeds, and that the species relies on annual flowering success for regeneration rather than a persistent seedbank.

A spatiotemporal variation in recruitment through seedling establishment was recorded for *B. latifolia*. Seedlings are present throughout the year, but numbers vary, influenced by the combined effect of seedset and variation in rainfall and extreme temperatures (Figure 7.6).

This spatiotemporal heterogeneity in plant recruitment could complicate the understanding of population dynamics of a species (Houle 1998).

Spatial variation

The lower seedling densities (number of seedlings per plot and the seedling/adult ratio) in scrub forest compared to the ecotone are consistent with the lower percentage of forest plants producing flowers. This could indicate that conditions in the forest are not optimal for seed production and regeneration. However, the difference in regeneration was not significant, largely because of variation in regeneration between plots. This could be attributed to microhabitat heterogeneity in both the ecotone and scrub forest, with some plots more exposed to sunlight than others, depending on forest structure. For ground flora in closed-canopy forest, light is generally the primary limiting factor (Coomes & Grubb 2000) and these species rely on the "sunfleck" component of the light climate for photosynthesis (Whitmore 1992). Also, the variation in size and distribution of sunflecks at temporal scale (Brown & Parker 1994 cited in Gilliam 2006) could influence the spatial distribution of seedlings and recruitment. Thus, in dense scrub forest, microclimate or light conditions could be a limiting factor for regeneration of *B. latifolia* and this could render such populations more vulnerable to harvesting. Conservative disturbance of the canopy could be a management tool to enhance regeneration.

The lack of correlation between the number of seedlings and adult plants supports the finding by Schupp (1995) that spatial patterns of seed dispersal do not always coincide with patterns of adult establishment. However, total population size could also affect regeneration. Vergeer *et al*. (2003) found that for the herbaceous perennial *Succisa pratensis*, there is a significant positive correlation between germination rate, percentage of productive plants and seed production, and population size. Also, Lienert & Fischer (2003) reported reduced rates of establishment, survival and reproduction of isolated populations of *Primula farinosa*. Should this also apply to isolated populations of *B. latifolia*, they would be more affected by resource use.

Temporal variation

Bulbine latifolia flowers produced very early in the season were more susceptible to damage or development failure; the highest percentage of buds that failed to develop was produced very late in the season. Galloway (2002) reported greater seed production and seedling survival for the herbaceous plant *Campanula americana*, for flowers produced early in the flowering season. This could also be the case with *B. latifolia*, with offspring from early flowers established by spring and early summer before the onset of extreme summer temperatures. Thus, early and late budding are more likely to result in reproduction failure, and an optimal period for budding exists (June to August for *B. latifolia*) that would result in the highest regeneration success. Damage to buds during harvesting operations during this period would thus impact most on successful regeneration.

A dry spell hampered budding and flower production of *B. latifolia* in 2005, although it had little effect on regeneration as measured by the presence of seedlings. However, the results indicate that seedlings in forest and the ecotone are affected differently by rainfall and temperature patterns. In the ecotone, where populations are more exposed, high temperatures had a significant negative effect on regeneration. For forest populations where light is a limiting factor (Whitmore 1992), high temperatures positively influenced *B. latifolia* regeneration.

Physical appearance of *B. latifolia* seedlings during hot and dry months was consistent with plants under stress from desiccation; leaves turned yellow-brown, as was also reported by Crouch *et al*. (2006) for water-stressed *Bulbine* spp. in medicinal plant gardens. In the forest hot summer conditions does not impact on *Bulbine latifolia* recruitment, while seedlings in the more exposed ecotone habitat is more vulnerable, as indicated by the significant negative correlation between ecotone seedling densities and temperature. Thus, although *B. latifolia* is found in its highest densities on the fynbos/forest ecotone (see Chapter 6), this is also where regeneration failure is more likely to occur during hot spells and prolonged drought. In terms of regeneration, this is where the focus of monitoring should be to assess harvest impact on the resource.

7.5.3 Growth rate and population turnover

The rate of population turnover is a key factor in assessing the sustainable yield of a forest product and in developing harvest prescriptions (Peters 1996, Cunningham 2001). Depending on the product, turnover could be measured in terms of increment (Van Daalen 1991, Seydack *et al.* 1990), ingrowth or mortality percent (Van Daalen 1991, Seydack *et al*. 1995), number of leaves, fronds, fruit, etc. produced (Geldenhuys & Van der Merwe 1988, Cunningham & Shackleton 2004, Muchiri & Chikamai in prep.), regrowth after harvesting of a plant part (McKean 2004, Venter 2000, Twine 2004, Geldenhuys *et al*. 2007; see Chapters 4 and 5), etc.

Diameter and length growth, and leaf development

Bulbine latifolia is a slow-growing species as indicated by corm diameter growth of 0.65 mm/annum and considering that individual plants can reach 40 mm in corm diameter. Similarly, corm length growth of 9.6 mm/annum is slow, considering mean corm length was 194.7 mm for the three study populations (see Chapter 6). However, with a few exceptions, monocotyledons such as *B. latifolia* lack vascular cambium and do not have secondary growth (Weier *et al*. 1974, Fahn 1985), neither do they increase in girth after their initial period of rapid growth (Weier *et al*. 1974). This should be taken into consideration when interpreting *B. latifolia* growth data. Although diameter growth could be expected to slow down towards the end of the initial growth period due to a lack of secondary growth, no correlation was found between diameter growth rate and corm diameter. This could indicate consistent growth until a maximum diameter (> 30 mm) is reached.

A significant positive correlation was recorded between length growth and corm diameter and length (Figure 7.8), while forest plants grow significantly faster. As high corm length is often associated with forest populations and steeper slopes (see Chapter 6), the faster length growth could be habitat induced, with gravitational forces benefiting such growth. This has implications for the growing of *B. latifolia* in medicinal plant gardens. Also, plants on flatter slopes on the ecotone are more erect, while forest plants are more consistently of the corm-like growth form (Vermeulen pers. obs.). In addition, shading has multiple effects that may simultaneously benefit and impair plants (e.g. effect on photosynthesis and evaporation rates) with the overall balance determining observable change (Hastwell & Facelli 2003). For *B. latifolia*, corm diameter is thus a less variable indicator of plant growth. This is of relevance when considering whether corm diameter or length should be the measurement for plant size when developing harvest prescriptions.

Consistent with the slow diameter and length growth recorded for the species, leaves also mature slowly. Rate of leaf development could be an alternative measure to quantify turnover for use in a harvest system, seeing that the number of leaves positively correlates with corm diameter and corm length, but it is less practical. However, because *B. latifolia* leaves are also used for medicinal purposes (Hutchings 1989, Van Wyk *et al*. 1997), the rate of leaf production is an important criterion in the formulation of management prescriptions for leaf harvesting (see Ross 2005 for the harvesting of *Aloe marlothii*).

Mortality and ingrowth

The annual mortality of 5.3% for the ≥ 10 mm diameter cohort (Table 7.1) could be regarded as low, compared with 8.2% of long-lived canopy tree species in the southern Cape (Seydack *et al*. 1990). Annual ingrowth of only 3.6% of plants into the ≥ 10 mm diameter cohort indicates an even lower population turnover.

With, for example, a population growth of 8.3% for Crooks River (July 2005 to July 2006) compared to a population decline of 8.9% for Grooteiland (July 2003 to July 2004), a spatiotemporal variation in turnover seems to be characteristic of *B. latifolia.* Spatial and temporal variations in mortality are major components of the population dynamics of plants and influence the stability and persistence of populations (Clauss & Venable 2000). Suzuki *et al*. (2003) reported that large variations in seasonal and annual mortality are frequently observed in herbaceous plant populations.

Bulbine latifolia mortality due to die-back was recorded for most of the corm diameter classes, but bigger plants were more subject to damage by animals (Figure 7.7). Intraspecific competition generally causes mortality of smaller individuals within areas of high local density (Suzuki *et al*. 2003). Studies also indicate better performance (recruitment, yields, mortality, etc.) of plant populations growing under heterogeneous conditions (Day *et al*. 2003). This should benefit species such as *B. latifolia* found along an environmental gradient but with core populations in the fynbos/forest ecotone as well as in the scrub forest.

The population structure of *B. latifolia* is dynamic and, at least at local scale, varies over time and between populations (see Chapter 6). This could be attributed to stochastic events (Lande *et al*. 2003) such as disturbance by e.g. animals, and hot, dry spells that affect regeneration differently in ecotone and forest. These unpredictable events could complicate the development of harvest prescriptions that ensure a steady flow of the product to consumers. The fact that a large percentage of plants resprouted after being broken off (Table 7.2), has implications for the method of harvesting from the wild, and opens up options for vegetative propagation in medicinal plant gardens (Crouch *et al*. 2006).

7.6 TOWARDS A HARVEST SYSTEM FOR *Bulbine latifolia*

Population transition models can be used effectively to simulate harvest scenarios, or to assess the threat to endangered plant species to inform management (e.g. Peters 1996, Cunningham 2001, Pfab & Witkowski 2000, Lawes & Obiri 2003, Raimondo & Donaldson 2003, Pfab & Scholes 2004). However, resource managers seldom have the scientific expertise or resources to develop such models (also see Lawes *et al*. 2004b), further aggravated by the wide range of species and products used and for which harvest systems need to be developed (see Lawes *et al*. 2004a, Shackleton & Shackleton 2004).

Therefore, the approach followed here is to interpret results of the studies on *B. latifolia*, and incorporate the relevant information into a harvest system with interim harvest prescriptions, adhering to the following basic principles:

- Harvest intensity should be aligned with natural recruitment rate or rate of turnover, as reflected in e.g. corm diameter and length growth, ingrowth or mortality percent.
- Minimal disturbance of plant populations and interference with recruitment and reproductive phenology.
- Provision should be made (within sustainable yield limits) for a consistent flow of the product to users with minimal fluctuation in available volumes over time.

Based on research results, the following systematic planning approach and interim harvest prescriptions are proposed:

a. Defining user groups and beneficiaries

The user group and number of beneficiaries need to be clearly defined. This would enable better quantification of the demand and could be done through the PFM structures established in the region to engage with stakeholders (Horn 2002, Durrheim & Vermeulen 2006). Dealing with the user group as a whole rather than with individuals would ease the successful implementation of a harvest system and enforcement of prescriptions (also see Grundy 2000, Geldenhuys 2004b, Michell 2004, DWAF 2005a). However, a representative of the user group should be selected/identified to act as a mouthpiece (for the group) and through whom requests for access to resources could be channeled.

b. Delineation of harvest area

Distribution of the species in the coastal area of Harkerville State Forest outside Sinclair Nature Reserve should be mapped accurately to form the potential harvest area. As the species is habitat specific and occurs as scattered populations, the use of GIS as a tool to identify populations (Baard 2002) should be followed up with thorough field surveys. The specific habitat characteristics (aspect, slope) of each population should be recorded, as well as the dominant forest and groundflora species it is associated with. This would help in the interpreting yield trends over time and the differences between specific habitats. The presence of other useful species could also be recorded for future incorporation in the harvest system should the need arise.

In line with the policy and objectives of forest management in the region (Durrheim & Vermeulen 2006, Herd 2006), Sinclair Nature Reserve should not be exposed to harvesting but should serve as a control area. Although this would largely limit the potential harvest area, rezoning for resource use would compromise biodiversity management objectives for the forest area as a whole; the development of alternatives should rather be explored to add to the resource base for the species.

c. Harvest prescriptions

Research results on population dynamics and demography, should inform harvest prescriptions. Important aspects include minimum harvestable size, and harvest intensity, rotation and season.

i. Harvestable size

As there is large variation in corm length, die-back at the basal part of the corm and lack of correlation with diameter (Chapter 6), corm diameter rather than length should be used to quantify plant size for harvest purposes. Considering the differences in size class distribution and maximum corm diameter reached (Chapter 6), harvest prescriptions should differentiate between ecotone and forest populations in terms of harvestable size. In terms of harvest intensity, no distinction is necessary if corm diameter growth is used as an indicator of rate of turnover (there was no difference in corm growth rate between forest and ecotone populations). A minimum corm diameter of 15 and 20 mm should apply to forest and ecotone populations respectively. Consultation with the Rastafarian community revealed that corm size is not critical although bigger plants are preferred.

ii. Harvest intensity

The mortality/ingrowth percent, corm diameter growth rate, corm length growth rate, as well as rate of leaf production could be used as indicators of turnover for *B. latifolia*. Considering that corm diameter is being used as a measure of plant size and that the entire plant is harvested, mortality/ingrowth percent and/or corm growth rate would be the most appropriate indicators. Based on the recorded population turnover, between 4 and 5% of harvestable plants could be harvested annually, distributed amongst all diameter classes. This, however, does not make provision for irretrievable mortality, and long-term monitoring is thus essential. To implement the harvest system would require a full count of all plants $\geq$ 15 or 20 cm diameter, which would form part of the long-term monitoring programme in harvest areas.

Harvesting of all plants above a certain minimum diameter (turnover based on growth rate, with only plants in the very large diameter classes harvested) would have been an alternative management option, but considering that mortality occurs in all size classes, this would lead to loss through irretrievable mortality and underutilisation of the resource.

iii. Harvest rotation and season

An interim harvest cycle of three years is recommended which (based on a population turnover of between 4 and 5% per annum) would entail a harvest intensity of between 12 and 15% every three years. This would limit the number of visits for harvesting and reduce habitat disturbance. Also, loss through irretrievable mortality would be reduced compared to that for a longer harvest rotation. The harvest area should be allocated proportionally to the three harvest years to ensure an equal spread of yield over harvest cycles.

Flowering and seed production take place between May and November, which makes this period the most sensitive for harvesting. Of further relevance is the fact that buds that are produced early and late during the flowering season are less likely to develop and produce seeds. Harvesting should therefore be conducted between December (after seedset) and June (before the peak for budding) to allow for seedset and reduce the impact on regeneration.

This restriction should not impact negatively on user needs, as corms could be dried and used at a later stage (Dixon, pers comm. 2007).

d. Harvest method

Plants coppice after they have been broken off and the harvest option thus exists to cut plants and leave part of the corm intact, rather than harvesting whole plants (see Plate 6.1g). However, this would result in smaller volumes of corm becoming available for use. Also, although not studied, coppice shoot development seems to be slow, with (based on the observed die-back of shoots) strong competition between shoots. This, together with the fact that the basal part of the plant often rots away as the plant ages, reduces the potential for a second harvest on the same plant. A differential approach is thus recommended; for areas with fairly dense populations of *B. latifolia* (e.g. on the ecotone), whole plants could be harvested; for areas where the species is sparsely distributed, plants could be cut or broken off to allow for coppice regeneration. Also, the plant produces roots all along the corm where it touches the ground (Vermeulen pers. obs.). On steep slopes where the corm has recumbent characteristics and longer corms are produced, harvesting the basal part of the corm (leaving the growth end intact), could thus be considered. However, the effect and viability of the different harvest methods need to be monitored.

Bulbine latifolia is found on steep slopes and sandy soils and trampling and disturbance during harvesting are a real threat. Therefore, the number of harvesters involved with the harvesting operation should be restricted.

e. Monitoring and adaptive management

As was demonstrated with *Rumohra adiantiformis* (Chapter 3), monitoring forms an integral part of a harvest system and continued, goal-orientated monitoring of *B. latifolia* is required to refine harvest prescriptions through adaptive management (see Chapter 2). The following is recommended/of relevance:

- The monitoring programme should include the impact of harvesting on the resource, as well as further baseline monitoring of growth and mortality in undisturbed areas. The former is especially important, as it would be difficult to pre-empt mortality with a harvest system and additional mortality to the harvest, could render harvesting unsustainable.
- Coppice growth following harvesting should be monitored to determine the potential of new shoots to develop into harvestable plants. This is required to compare and select the most appropriate harvest method (whole-plant harvesting *versus* cutting).
- Accurate records (to include number of plants and corm diameter) should be kept of plants harvested from the different areas. Trends in yield would be a good indicator of whether the harvest prescriptions provide for a sustainable supply of plants from a particular harvest areas.
- Proposed interim harvest prescriptions (12-15% of plants every three years) would require a full count of plants of the harvestable size class during the harvest operation. This would provide baseline data for monitoring in harvest areas.
- Seed production and germination are not limiting factors for the maintenance of *B. latifolia* populations. However, seedling survival and growth into larger size classes are influenced by climatic conditions and variations in temperature and rainfall, especially for ecotone populations. As this cannot easily be accommodated in harvest prescriptions, it should be looked at as part of the monitoring programme in harvest areas.

f. Commercialisation and alternative resources

With the limited distribution of *B. latifolia* in the potential harvest area and its relatively slow growth rate and low population turnover, it is unlikely that supply from the wild would meet demand, especially for commercial use. Harvesting at Harkerville should be for domestic use only, or for users to whom harvesting from the wild also forms part of a spiritual ritual (see Cocks & Dold 2006).

The good seed production and germination rate, as well as an ability to reproduce vegetatively, allow for the successful growing of the species in medicinal plant gardens (*vide* Crouch *et al*. 2006). This was proposed after the initial analysis of data indicated slow growth and low sustainable yields for the species from the wild (Vermeulen 2004b). Both corm diameter and corm length determine the yield from harvestable plants and the fact that plants on steeper slopes produce longer corms with faster length growth needs to be considered when establishing medicinal plant gardens. The volumes of corm that would become available could be quantified for commercial purposes using the corm diameter/length ratio identified as part of this study.

Bulbine latifolia leaves are also used medicinally, although for different purposes than the corm (Hutchings 1989, Van Wyk *et al*. 1997). Despite the slow rate of leaf production, leaf harvesting is less destructive and is more viable harvest option. Should the compounds with healing properties also be present in the leaves, this would open up further management options. Ethical bioprospecting should thus be encouraged, whereby indigenous knowledge is recognised and the principle of benefit sharing applies (Nash 2001, Jäger *et al*. 2004).

7.7 CONCLUDING REMARKS

In support of the study objective, the research questions on reproductive phenology and demography of *B. latifolia* have been answered effectively to provide insight into the phenology and rate of renewal of the species. Together with information on community association and population dynamics (Chapter 6), these provide a scientific background for the formulation of harvest prescriptions. The species has a limited distribution in the management area with a slow rate of renewal, limiting harvest. The difference between ecotone and forest populations, in terms of population dynamics and regeneration phenology, requires that consideration be given to differential harvest prescriptions for populations in the fynbos/forest ecotone and scrub forest.

The proposed harvest system and management prescriptions should be formalised and implemented in consultation with the Rastafarian community, the key user group involved with the research. Although the research results provide a sound scientific basis for harvest prescriptions, long-term sustainability in dynamic ecosystems cannot be guaranteed and continued monitoring and refinement of prescriptions are essential. Although knowledge gaps still exist, further research and technical input (apart from monitoring) should now focus on the development of alternatives to harvesting from the wild, considering the limited distribution and harvest potential of the species at Harkerville Forest.

7.8 ACKNOWLEDGEMENTS

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CHAPTER 8: SYNTHESIS, CONCLUSION AND RECOMMENDATIONS FOR THE DEVELOPMENT AND IMPLEMENTATION OF HARVEST SYSTEMS FOR NON-TIMBER FOREST PRODUCTS

8.1 INTRODUCTION

Despite the importance of non-timber forest products (NTFPs) in rural livelihoods and for economic growth (FAO 1995b, Mahapatra & Mitchell 1997, Shackleton *et al*. 2000, Neumann & Hirsch 2000, Van On *et al*. 2001, Walter 2001, Du Toit 2002, Chipeta & Kowero 2004, Clarke & Grundy 2004, Hiremath 2004, Lawes *et al*. 2004a, , Shackleton & Shackleton 2004, Sunderland *et al*. 2004, Ticktin 2004, Vedeld *et al*. 2004, Sheil & Liswanti 2006, Croitoru 2007, Mudekwe 2007, Shackleton *et al*. 2007, Akhter *et al*. 2008, Hembram & Hoover 2008), the development of harvest systems for their sustainable use has been neglected worldwide. Overshadowed by timber harvesting, forest management systems seldom make provision for either the protection of utilisable NTFPs or an integrated management approach to accommodate such uses. Hence, sustainable harvest strategies and management systems for NTFPs are largely still lacking, and overutilisation is of growing concern in South Africa and further afield (Balick & Cox 1997, Cunningham 1997, Ngulube 1999, Walter 2001, Grace *et al*. 2002, Lawes *et al*. 2004b, Ticktin 2004, Bitariho *et al*. 2006, Mudekwe 2007, Ndangalasi *et al*. 2007).

The overall objective of the study was to explore the science needed to underwrite management for the sustainable use of NTFPs by scrutinising the systematic process of developing harvest systems and requirements for its successful implementation, while also considering the socio-economic and political dimensions of sustainable use. This was achieved using case studies, of three different forest products harvested from natural forest in the southern Cape, namely fronds of the fern *Rumohra adiantiformis* used as greenery in the florist industry, medicinal tree bark and the corm of the geophyte *Bulbine latifolia* for medicinal use. The study was motivated by the management objective of ensuring optimum, sustainable harvesting of NTFPs from these forests under management of South African National Parks (SANParks), with due consideration of other management objectives and land-uses.

In this concluding chapter, the study approach and achievement of specific and overall study objectives are reflected upon. The process to develop systems and management prescriptions for the sustainable harvesting of NTFPs, based on lessons learnt from the three case studies, is discussed, and requirements and restrictions for their successful implementation are elaborated on. This includes aspects of ecological, social and economic sustainability, taking into account management constraints within a changing socio-political environment in South Africa, and the integration of NTFP harvesting with traditional practices for sustainable forest management.

8.2 REFLECTION ON STUDY APPROACH AND ACHIEVEMENT OF STUDY OBJECTIVES

The case studies provided an opportunity to scrutinise the generic process of developing harvest systems for a range of products, species, growth forms and scenarios. A system for *R. adiantiformis* fronds was largely already in place, which allowed for an interrogation of the adaptive management approach, as well as scrutiny of the harvest prescriptions, and assessment of the value of long-term monitoring. In contrast, little information was available for *B. latifolia* (a species subject to whole-plant harvesting) and all aspects of the generic process had to be addressed, from floristic studies and defining the habitat to recruitment studies. With the harvesting of medicinal bark, where the critical component is tree response to bark stripping, proposed harvest systems had to be integrated with the current forest and timber harvesting management system in the southern Cape. By selecting six different tree species, the conceptual framework and decision tree presented to identify the most appropriate bark harvest options, could be tested and applied following experimental harvesting.

In achieving the **overall study objective**, the research approach enabled valuable insight into the complexities of developing harvest systems for NTFPs, the input and expertise required to conduct applied research, and the variation in approach required for different products and plant growth forms. This is discussed further in Par 8.3 and 8.4. The approach and scope of the study not only provided for ecological research of the target species and forest resource, but also put strong emphasis on the implementation of harvest systems and integration thereof into the existing forest management system in the region. The research was taken to its conclusion to be reflected in future forest management plans. The study approach ensured that results contribute towards the sustainable harvesting of NTFPs from natural forests in the southern Cape, an important **management objective** supported by the study.

The discussion in each chapter indicates to what extent the specific study objective and research questions have been met and answered. This information is briefly summarised as follows:

8.2.1 Harvesting of *Rumohra adiantiformis*

The study was aimed at scrutinising the adaptive management approach followed with the development of harvest prescriptions for *R. adiantiformis*, and at assessing the importance of long-term monitoring for sustainable use. Specific objective 1 was "*To review the adaptive management approach followed with the development of harvest prescriptions for R. adiantiformis, and to present lessons learnt of relevance to the development of harvest systems for NTFPs*". The study demonstrated that the adaptive management approach was followed effectively and that it can be applied wider with the development of harvest prescriptions for NTFPs provided that the precautionary principle is applied and that there are monitoring programmes to obtain the relevant data for system refinement.

Specific objective 2 was "*To assess whether harvest prescriptions developed for R. adiantiformis provide for the sustainable harvesting of the species, and to review the importance of long-term monitoring in informing harvest prescriptions for NTFPs*". The study demonstrated that goal-orientated, long-term monitoring, assessing harvest impact on the resource and natural fluctuations in population dynamics, are essential to verify that harvest prescriptions are scientifically sound and ecologically sustainable. Lessons learnt have wider application and are invaluable for new NTFP monitoring programmes.

Long-term monitoring showed that fern harvesting is ecologically sustainable with the current harvest prescriptions. However, it was also demonstrated that, if all relevant aspects are covered, the input required to develop and refine harvest systems through such monitoring may be extensive. Because sustainability also has an economic and social dimension, this could render many resource-use ventures economically unviable should the costs of ensuring ecological sustainability be absorbed by the commercial harvester, especially for a low-value product; hence the importance of creating alternative resources and commercialisation. *Rumohra adiantiformis* harvesting led to a whole sustainable industry with huge socio-economic benefits, as the bulk of fronds are now harvested from plants grown in shade houses and commercial pine plantations.

8.2.2 Medicinal bark harvesting

The overall objective of the bark study was i) to explore options for the sustainable supply of medicinal bark from natural forests in the southern Cape, based on experimental harvesting conducted on target species, and ii) to integrate medicinal bark harvesting into the current forest management system. Specific objective 3 was "*To assess, through experimental research, the response of different species to bark stripping of relevance to the sustainable harvesting and management of medicinal bark species*". The results show that tree species respond differently to bark stripping, in terms of both bark regrowth and susceptibility to fungal and insect damage. Through experimental stripping, species-specific results on tree response can be obtained in a relatively short period to assess harvest options and to allow for the development of harvest prescriptions that could be refined further with continued monitoring. Substantial seasonal variation in response to bark stripping was recorded, which makes the optimum time for bark harvesting difficult to define, especially considering the wide range of environmental and other factors affecting tree response to bark removal.

Specific objective 4 was "*To develop a conceptual framework and decision tree based on experimental research; to identify the most appropriate harvest options for the sustainable supply of medicinal bark for target species; and to guide the formulation of harvest prescriptions*". A conceptual model was presented, with a decision tree, to demonstrate that tree response to bark stripping could be used effectively when choosing a management system for bark harvesting, and in informing harvest prescriptions. Specific objective 5 was "*To assess and demonstrate how sustainable medicinal bark harvesting could be integrated with the existing forest management system in the southern Cape, with due consideration of other management objectives and land uses*". The study showed that systems for medicinal bark harvesting, as well as alternative options to meet the demand, can be successfully integrated with the existing multiple-use forest management system. Although largely based on timber exploitation considerations, the current forest management system proved to be flexible enough to accommodate harvest systems for medicinal bark and other NTFPs.

8.2.3 Harvesting of *Bulbine latifolia*

Research on *B. latifolia* was aimed at a better understanding of the ecology and dynamics of the species to inform harvest prescriptions. With little information available on the species, it was the ideal case study to assess the process of developing harvest systems for NTFPs.

Specific objective 6 was "*To gain a better understanding, through applied research, of the habitat and distribution, community association and population dynamics of B. latifolia and their relevance to the sustainable harvesting of the species in the southern Cape*". The study showed that the species is abundant on the fynbos/forest ecotone, where it is associated with a number of dry scrub forest communities. However, it has a limited distribution outside the forest nature reserve (where extractive resource use is prohibited), which restricts the potential harvest area and the ability to meet the demand for the species from the wild. It has an inverse J-shaped and skewed bell-shaped size class distribution when corm length and corm diameter respectively are used as a measure of plant size. This, together with variation between ecotone and scrub populations, could complicate the development of harvest prescriptions.

Specific objective 7 was "*To gain insight, through applied research and monitoring, into the demography and reproductive phenology of B. latifolia, to inform the development of a harvest system and management prescriptions for the species*". The study was necessary to fully understand the population dynamics of the species, and demonstrated the slow rate of renewal in terms of corm diameter and length growth; this limits the harvest potential. The difference between ecotone and scrub forest populations – in terms of population dynamics, plant demography and regeneration phenology as influenced by rainfall and temperature – requires that consideration be given to differential harvest prescriptions for *B. latifolia* populations in the fynbos/forest ecotone and scrub forest.

Specific objective 8 was "*To develop and present, based on applied research results, a management system for the sustainable harvesting of B. latifolia from natural forests in the southern Cape, and a planning approach for its successful implementation*". Harvest prescriptions were developed and proposed for the species, adhering to the basic principles that harvest intensity should be aligned with natural recruitment rate of turnover for the species; that there should be a minimal disturbance of plant populations and interference with recruitment and reproductive phenology; and that the harvest system should adequately make provision for a consistent flow of the product to users, within sustainable yield limits. The proposed harvest system and management prescriptions need to be formalised and implemented in consultation with the Rastafarian community which, as the key user group, was also involved with the research. However, although the research conducted on *B. latifolia* provides a sound scientific basis for harvest prescriptions, continued monitoring and system refinement is essential. The species has a limited distribution and harvest potential in Harkerville State Forest; therefore, scientific and technical input should now focus on developing of alternatives to harvesting from the wild.

8.3 PROCESS TO DEVELOP HARVEST SYSTEMS FOR ECOLOGICAL SUSTAINABILITY AND LESSONS LEARNT FROM SOUTHERN CAPE CASE STUDIES

The generic process of sustained yield determination for forest products and the development of harvest systems and management strategies have been well documented (Van Daalen 1988a, FAO 1995b, Peters 1996, Geldenhuys 2000b, Grundy 2000, Cunningham 2001, DWAF 2005b,c).

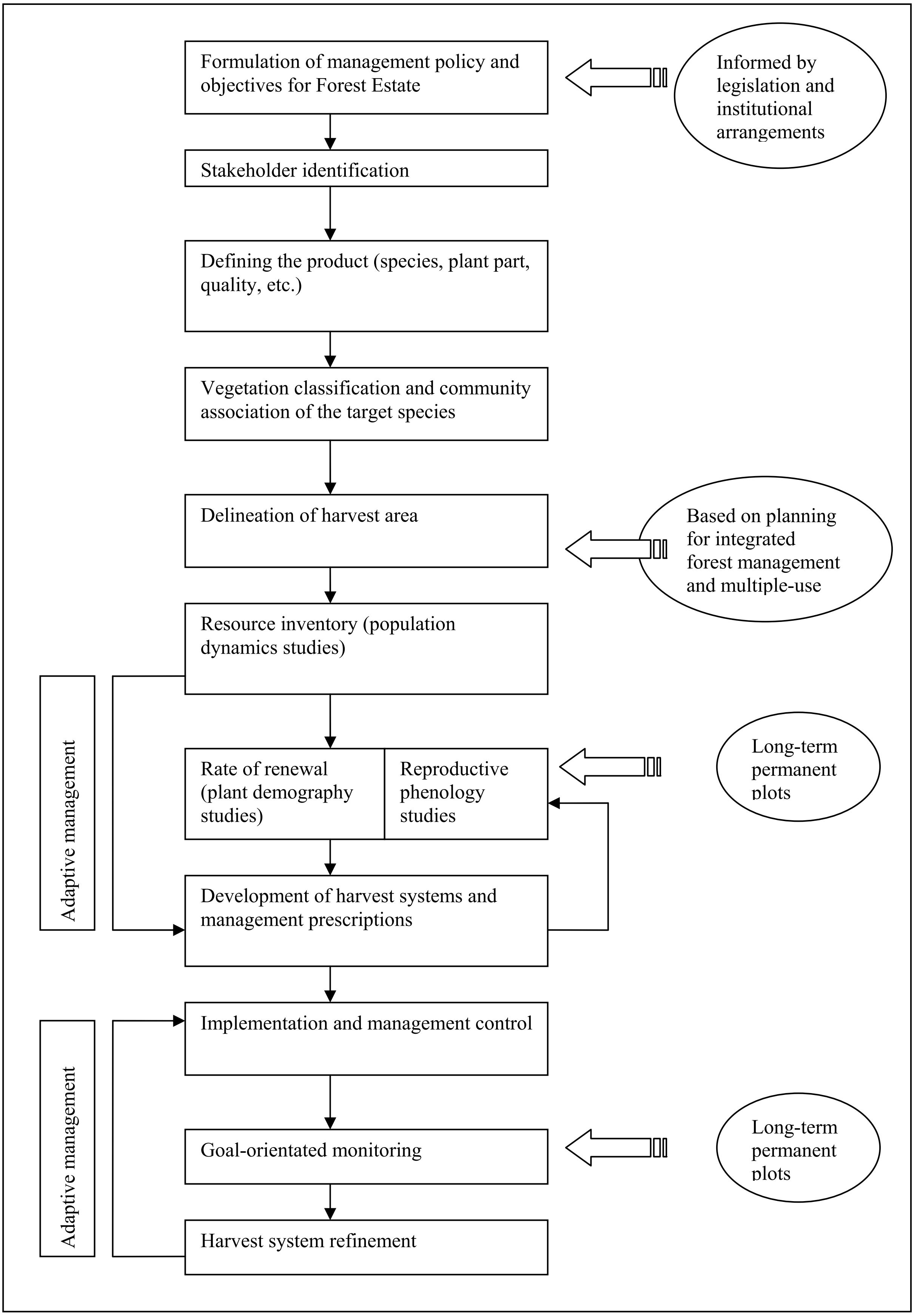

Figure 8.1. Flow diagram indicating the generic process for the development of harvest systems and management prescriptions for NTFPs.

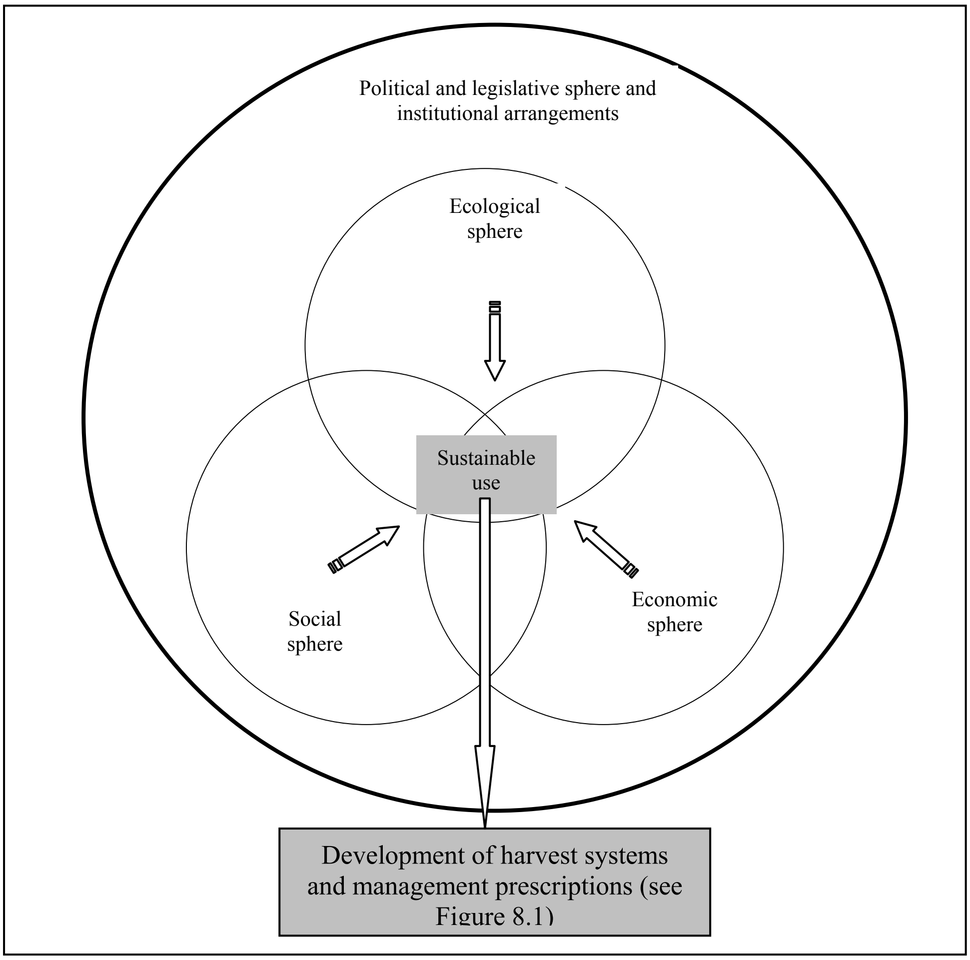

Figure 8.2. Graphic demonstration of the multi-disciplinary nature of sustainable forest management and different spheres influencing the development of harvest systems and management prescriptions for sustainable harvesting of forest products (adapted from Cunningham 2001).

Results demonstrate that the process can be followed effectively in the development of harvest systems and management strategies for NTFPs. This systematic process, with the focus on ecological sustainability of a specific species or product, is simplified in Figure 8.1, based on experience with the case studies in the southern Cape. Sustainable resource use should be addressed at the confluence of the social, economic and ecological spheres, within a political framework (Cunningham 2001, Geldenhuys 2002) (Figure 8.2). Further requirements for improved sustainable use are discussed by Dasmann (1985), Shea (1993), Cunningham (1994), FAO (1995b), Geldenhuys (1998a) and Ros-Tonen *et al*. (1998).

The generic process of harvest system development (Figure 8.1) will not be presented in detail here; the focus will be on lessons learnt from the southern Cape case studies.

8.3.1 Identification of user groups and stakeholder consultation

The obvious first step in the systematic process to develop harvest prescriptions for a specific species or product is the identification of the key user groups and an assessment of user needs, i.e. what is the market (Figure 8.1). Knowledge of the characteristics of the specific user group is also essential. With little recognition of the importance of NTFPs and stakeholder needs prior to the implementation of a participatory approach with forest management, stakeholder consultation in terms of the three NTFPs dealt with in this study was triggered by illegal harvesting rather through pro-active engagement with user groups.

The commercial value of *R. adiantiformis* fronds, the increasing demand and the limited resource outside State Forests and other protected areas resulted in an escalation of illegal harvesting on State Forest land (Chapter 2). To counteract this and to ease law enforcement, entrepreneurs with a business drive, financial capacity and a vested interest in the resource were included as stakeholders. The Rastafarians were identified as the key stakeholder group for *Bulbine latifolia* (Chapter 6). The participatory forest management (PFM) forums established in 2000 (Horn 2002) provided an essential platform for engagement with the user group, and the initiation of collaborative research on the species. Research into the sustainable harvesting of medicinal bark was partly triggered by uncontrolled harvesting on State Forest land in the Eastern Cape (Vermeulen 2002, Cocks & Dold 2000) and KwaZulu-Natal (Geldenhuys 2004b). The sporadic, illegal harvesting of bark in the southern Cape, however, allowed resource managers to be proactive in accommodating the need for medicinal bark (Chapter 4), and the Southern Cape Traditional Healers Association was identified as an important stakeholder.

Communicating user rights and ensuring that PFM structures are in place for interaction between resource managers and stakeholders is an important aspect of sustainable forest management. The alternative is illegal harvesting, which may be regarded by user groups as the only way to gain access to resources, as was the case with medicinal bark harvesting in the southern Cape (Chapters 4 and 5). Engagement with specific user groups – rather than the community at large – was most effective in initiating development and implementation of harvest prescriptions in a collaborative way. This was also demonstrated by Ham & Theron (1998) with community forestry projects and by Geldenhuys (2004b, 2007) with the development of a system for medicinal bark harvesting from the Umzimkulu forests in KwaZulu-Natal. Where local stakeholders develop a sense of ownership of a resource, beneficiaries often partner with resource managers in combating illegal and unsustainable use (Horn 2002), although this has not yet been demonstrated with the harvesting of *B. latifolia* and medicinal bark in the region.

The southern Cape forests have not been as extensively exposed to NTFP harvesting as those in the Eastern Cape and KwaZulu-Natal. As few, if any, communities living around forest areas in the southern Cape depend on forest resources for their daily livelihoods (Anon. 2000, Watts & Holmes-Watts 2007), stakeholder engagement was thus simplified. However, population demographics in the region are rapidly changing (Reuther & Gebhardt 2005, Anon. 2007), and more people who culturally make use of natural resources such as medicinal plants (Cocks 2006) are moving into the area. Resource-use patterns are changing and there is a growing demand for NTFPs and general access to forest resources, particularly surrounding settlements.

8.3.2 Defining the product

Users and markets need specific products, and the products need to be clearly defined (Figure 8.1). With commercial harvesting, the minimum requirements for economic viability, as demanded by market forces, need to be described in consultation with the buyer. This was the case with the harvesting of *R. adiantiformis* fronds (Chapters 2 and 3). While the product was not clearly defined, there was indiscriminate harvesting and wastage, with an unnecessary additional impact on the resource. The clear definition of a pickable frond was an important management tool in controlling picking operations and enforcing harvest prescriptions. This was not only to prevent overpicking, but also underpicking by the successful tenderer and consequent financial losses to the State.

The *B. latifolia* corm has various medicinal uses, leading to destructive, whole-plant harvesting. Consultation with the Rastafarian community revealed that, in contrast to commercial fern harvesting, corm size is not critical although bigger plants are preferred (Chapters 6 and 7). Rather, corms of a deep orange colour are considered to be most effective for medicinal use and most in demand; however, this is too restrictive to accommodate in harvest prescriptions. Measurements of plants confiscated from illegal harvesters (Vermeulen, Unpublished data) suggest substantial variation in corm size. This approach of taking actual measurements of resources harvested has also been effectively used to define product requirements for *Secamone* sp. harvested for the construction of sledges in the Eastern Cape (Vermeulen *et al.* 2004).

Medicinal bark species in demand were identified through observations of illegal bark stripping, formal resource surveys and structured interviews with traditional healers (Chapter 5). Field observations of harvesting were the most time- and cost-effective method of identifying species being used. However, to ensure that real stakeholder needs are addressed in harvest systems, additional quantitative and qualitative data – such as demand in terms of volumes, high-priority species, commercial value and receptiveness for alternatives – need to be obtained through inventories (Geldenhuys 2004b) and interviews with healers.

8.3.3 Community association of target species and delineation of harvest area

Information on the habitat and vegetation type where the target species is found, needs to be gathered to enable identification and mapping of the potential harvest area (Figure 8.1).

A site-based, forest type classification proved to be indispensable for sound management planning where multiple-use management objectives are pursued (Chapter 1). This classification not only provides the ecological foundation for forest management, but could also be used to assess the distribution of a target species if its habitat preference is known. For example, *B. latifolia* is associated with dry Scrub-Forest in the southern Cape (Chapter 6); assessment of the distribution and potential harvest areas could be narrowed down to the dry forest types with the type maps that are available for the management area. The same applied to *Rumohra adiantiformis* associated with moist and wet High-Forest (Chapter 2). With the abundance of tree species also related to a specific forest type (Von Breitenbach 1968a, Geldenhuys 1993a), the forest type classification proved critical in assessing harvest options for medicinal bark and in integrating bark harvesting into the management system for the southern Cape forests (Chapter 5).

However, within forest types, species such as *R. adiantiformis* and *B. latifolia* have a patchy distribution, making it difficult to accurately map and clearly define the potential harvest area (Chapters 2 and 6). The same applies, for example, to *Ocotea bullata* in the coastal platform forests (Reynell 1989, Geldenhuys 1993a), an important species for medicinal bark harvesting

(Chapter 5). In addition, for especially *R. adiantiformis*, there is a temporal variation in density driven by natural succession and disturbance patterns (Chapters 2 and 3). This demonstrates that for some species the potential harvest area cannot be fixed but has to be dealt with at landscape level, aligned with and adjusted to spatio-temporal variations of populations of the target species. This is particularly true when the target species occurs in widely scattered individuals or clumps.

As was conducted for *B. latifolia*, a phytosociological classification of the vegetation in the target area not only allows for more accurate mapping of the potential harvest area, but could also be of great benefit where there is a demand for a range of species in the same forest area (Chapter 6).

8.3.4 Resource inventory and population dynamics

Once the distribution of the target species and potential harvest area has been identified, a more detailed inventory of the target species is required (Figure 8.1). This provides information on the abundance and dynamics (e.g. population density and size class distribution) of the species and, as supported by this study, is essential in the development of harvest systems.

For *B. latifolia*, reconnaissance visits indicated that it is most abundant on the fynbos/forest ecotone; therefore line transects were used to sample populations (Chapter 6). For inventories of timber tree species also in demand for their medicinal bark, systematic sampling techniques have traditionally been used in the southern Cape, targeting the forest type where the target species is most abundant (Van Laar & Geldenhuys 1975, Seydack *et al.* 1990). However, for the important medicinal bark species *O. bullata* with a cluster-like distribution (Reynell 1989), adaptive cluster sampling should result in more accurate results (Acharya *et al*. 2000), while stratified random sampling would be more appropriate for *Ilex mitis* abundant along river courses, when standing bark volumes are to be quantified (Chapter 5). For less abundant species, sampling intensity could also have a major effect on the reliability of sampling data, as was demonstrated by Reynell (1989) and Seydack *et al.* (1990) for canopy species in the southern Cape.

Information on the distribution pattern of the target species is essential in planning for surveys and inventories, as it influences plot layout and the inventory method, as has been reported by Wong *et al*. (2001). The inventory of products such as fruit, seed, bark volume or other plant parts would obviously require a different sampling approach to whole plants (Cunningham 2001, Wong & Pouakouyou in prep).

8.3.5 Plant demography

The rate of production indicates how much of the resource (as determined by the resource survey) can be harvested on a sustainable basis (Figure 8.1). In terms of rate of renewal for species and products studied in the southern Cape, rate of frond production was determined for *R. adiantiformis* (fronds harvested) (Chapters 2 and 3), corm diameter and length growth, and mortality percent for *B. latifolia* (whole-plant harvesting) (Chapter 7), and rate of wound closure for assessing sustainable yield for medicinal bark harvesting (Chapter 4). Where diameter growth is monitored, the point of measurement needs to be fixed. This is especially important with slow-growing species where reliable increment measurements need to be recorded over a relatively short period, as was the case with *B. latifolia*.

For *B. latifolia*, a narrow line was painted on the corm to fix the point of measurement, and proved effective for the three years during monitoring (Chapter 7). Initially a pinhead was used, but this resulted in rotting and the method had to be abandoned. This demonstrates that methods cannot be fixed in guidelines, and researchers have to find innovative ways to address such issues.

Monitoring plots should be located in both harvested and undisturbed (control) areas, as demonstrated with *R. adiantiformis*. This emphasises the importance of zonation and setting aside areas where consumptive resource use is prohibited, as was done in the southern Cape with the establishment of a Nature Reserves management class (Seydack *et al*. 1982, Durrheim & Vermeulen 1996).

8.3.6 Reproductive phenology

Where permanent plots are established, information on the reproductive biology and phenology of the target species should also be collected (Figure 8.1).

As for many species, flowering and seed production of *B. latifolia* is a seasonal event, synchronised with temperature and rainfall fluctuations, and could easily be incorporated in harvest systems (Chapter 7). However, for *R. adiantiformis*, it is more complex, as both the peak period for presence of mature fronds (to ensure optimum harvesting) and the budding peak (sensitive period for harvesting) needed to be considered in the development of a harvest system (Chapters 2 and 3). Budding and frond production are less clearly synchronised with climatic patterns than, for example, is flower production. Bark regrowth is influenced by both the seasonal variation in cambium activity and the efficiency of a tree's defence mechanism following damage through bark stripping (Chapter 4); hence the importance of gaining insight into seasonal growth patterns of forest trees to inform bark harvest systems. This is further complicated by the fact that prevailing climatic conditions during the time of bark stripping could also influence the type and extent of bark regrowth.

Information on the phenology of the target species is important to identify the times of the year that the population is most sensitive to harvesting, for incorporation into harvest systems – see, for example, restrictions on the harvesting of wild American Ginseng (*Panax quinquefolius*) (AHPA 2006). The relevance of phenology, however, would obviously depend on the plant growth form and plant part harvested. Also, growth and phenology of groundflora species are more likely to be influenced by extremes of weather (e.g. drought) (Meilleur *et al*. 1992).

8.3.7 Development of a harvest system and management prescriptions, following applied research

Key aspects to the harvest system would include harvest rotation, the number or percentage of plants that could be harvested from the population, minimum harvestable size and harvest method, as have been incorporated in, for example, harvest prescriptions for wild American

Ginseng (*Panax quinquefolius*) (AHPA 2006). However, the study demonstrated that there is no fixed way of converting the relevant research and survey results into harvest prescriptions.

Prescriptions for *R. adiantiformis* (Chapters 2 and 3) presented difficulties, especially in dense populations where individual plants have to be identified. Although harvest prescriptions to remove this requirement proved to be more practical, the sustainability of the approach still has to be tested (Vermeulen *et al*. 2005, Chapter 3). For *B. latifolia*, a differential harvest approach was recommended considering the differences in population dynamics between scrub forest and ecotone populations (Chapter 7). For medicinal bark, the harvest system had to be integrated with the multiple-use management system in place for the southern Cape forests (Chapter 5). Selection of the most appropriate variables as indicators of plant size would also require an understanding of the ecology and dynamics of the target species. For example, for *B. latifolia*, corm diameter was selected rather than corm length, as the former is less variable and correlates better with plant growth, while the latter tends to be habitat dependent.

The harvest method also requires careful consideration as it can influence the impact of harvesting on the resource. For *B. latifolia*, monitoring revealed that most plants resprout after being broken off. This presented the option of either removing whole plants or leaving part of the corm intact to allow for vegetative reproduction. However, with the corm dying back at the root end and uncertainty about the rate of regrowth to allow for a second harvest (Chapter 7), the most viable method can only be determined through continued monitoring following harvesting. Medicinal bark harvesting is destructive and the harvest method is thus even more crucial to reduce damage and enhance recovery through bark regrowth. Following the experimental harvesting in the southern Cape, it was recommended that a tool with a thin blade be used, inserted at an angle to ensure that the bark is lifted only at the wound side of the edge (Chapter 5). Also, with full-tree harvesting for medicinal bark, tree felling could be conducted in a way that encourages coppice development for potential leaf harvesting and/or rotational harvesting of the developing stems (full-stem harvesting of leaf and bark) (e.g. *Ocotea bullata*) (Chapter 5).

An additional potential threat to sustainability is trampling and unintended damage to the target population during the harvest operation, as was observed by Milton & Moll (1987) with *R. adiantiformis*. The same would apply to *B. latifolia* where it grows in dense clusters on sensitive, steep slopes. This could be counteracted by a long harvest rotation to reduce the number of site visits, and by limiting the number of harvesters during harvest operations.

The formulation of harvest prescriptions following applied research is complex and involves accommodating all aspects of population dynamics and reproductive phenology in a harvest system. Population transition models could be used to better understand population dynamics and the potential harvest impact on the resource (e.g. Pfab & Witkowski 2000, Lawes & Obiri 2003, Raimondo & Donaldson 2003, Pfab & Scholes 2004), but is not a quick solution to the development of harvest prescriptions.

8.3.8 Continued monitoring and adaptive management

Continued monitoring is required to allow for adaptive management of harvest prescriptions (Figure 8.1). This should include (a) long-term monitoring outside harvest areas to gather further baseline data on population dynamics and plant demography, (b) monitoring plant populations exposed to harvesting to assess harvest impact, and (c) monitoring the yield (quantity and quality) from harvest areas (Chapters 2 and 3). The pressing demand for access to forest resources often does not allow scientifically sound harvest systems to be developed before access for consumptive use is granted. The solution therefore is an adaptive management approach whereby conservative, interim harvest prescriptions based on existing knowledge are implemented together with applied research and monitoring programmes (Figure 8.1). This approach was followed successfully with the harvesting of *R. adiantiformis* fern fronds (Chapter 2), and it also allowed for conservative harvesting of *B. latifolia* while applied research was conducted on the species (Chapters 6 and 7). For medicinal bark harvesting, the conceptual framework that guides harvest prescriptions (Chapter 5), enables interim prescriptions to be formulated based on existing knowledge of species response to bark stripping.

The biggest delay in harvest system development is the monitoring required to obtain reliable information on rate of renewal and recruitment. Short-term, static studies on population dynamics, however, provide useful information for the development of interim harvest prescriptions, and these can be refined as demographic data from long-term monitoring become available (Figure 8.1). In the absence of demographic information, life history characteristics such as the ability of species to sprout or low recruitment levels could also be indicators of slow population growth rates (Bond & Midgley 2001, Raimondo & Donaldson 2003), to be used in harvest prescriptions while more detailed demographic studies are conducted.

8.4 GENERAL DISCUSSION AND CONCLUSION

Sustainability has an environmental, social and economic dimension and needs to be addressed within a political framework, also influenced by institutional arrangements (Cunningham 2001, Von Maltitz & Shackleton 2004, Willis 2004). The complexities of integrating the development of harvest systems for ecological sustainability with social and economic sustainability (especially when harvested for commercial use) have been demonstrated in flow diagrams and models by e.g. Geldenhuys (2002), and remain a major challenge. As advocated by CBD (2004), interdisciplinary research into all aspects of the use and conservation of biological diversity is required to support sustainable use.

8.4.1 Ecological dimension

The simple generic process to develop harvest systems for ecological sustainability – as described by e.g. Van Daalen (1988a) and Peters (1996) and incorporated in guidelines (DWAF 2005c) and procedures (DWAF 2005b) for sustainable forest management in South Africa – has been applied successfully with the development of harvest prescriptions for *R. adiantiformis* and *B. latifolia* in the southern Cape. The process is simple and ensures that research is focused on the relevant fields, from the user-needs survey to population dynamics and plant demography studies. However, considering (a) the complexities of vegetation ecology and population dynamics, (b) the difficulties with the interpretation of research results and conversion into harvest prescriptions, (c) the requirement of continued monitoring to refine harvest prescriptions, and (d) the range of products and species being harvested, it is questionable to what extent this process could be widely implemented to culminate in scientifically sound harvest prescriptions for NTFPs in South Africa.

Complexities of vegetation ecology and population dynamics

The complexities of vegetation ecology and population dynamics do not make for "easy" research. From a resource-use perspective, this is evident from the following:

- Harvest systems should accommodate both temporal and spatial variation in population dynamics, and stochastic events (CBD 2004). As pointed out by Geldenhuys (1997) and Ellery *et al*. (2004), and partly found with *B. latifolia*, it is especially difficult to determine sustainable harvest levels and to simplify them in harvest systems when the target species grow in unpredictable environments or produce variable yields in space and time, which is the case with many species (Neumann & Hirsch 2000). Also, as pointed out by IUCN (2000), consideration of sustainability should not be based on assumptions that ecosystems are stable, nor on expectations that there will always be a productive annual renewal of whatever has been harvested. For example, environmental extremes may result in extreme annual variation in rates of renewal by wild populations, especially in semi-arid and arid ecosystems (IUCN 2000), as experienced with *R. adiantiformis* during years of relatively extreme droughts.
- As reported by Lande *et al*. (2003), failure to account for the basic features of stochasticity in harvest systems – especially with small, single populations such as *B. latifolia* dealt with in this study – has been partially responsible for the overexploitation and collapse of numerous living resources, e.g. commercial fisheries. Harvest systems could thus not only be based on deterministic models, but should also take into account unpredictable changes in environmental conditions and other stochastic events.
- The level of change in species composition following disturbance and the order of species extinction are influenced by a combination of inter- and intraspecific competition among different plants species in the community (Ohsawa *et al*. 2003). The vulnerability of a species to harvesting would thus also be determined by the competition hierarchy within the community and where the target species fits in (Ohsawa *et al*. 2003). For example, *R. adiantiformis* forms part of a successional stage and its harvesting may enhance shrub growth, a further stage in the succession.
- For species that occur as metapopulations, population dynamics is not only defined by factors of population size, life history parameters and environmental stochasticity; the spatial variation in these factors, the number and geographic configuration of habitat patches and the dispersal and spatial correlation among these patches are also important considerations in understanding the population dynamics of such species (Akcakaya 2000).

Interpretation of results and conversion into harvest prescriptions

Interpretation of research results and conversion into a harvest system and management prescriptions are not always clearly definable, and require insight into the fields of both vegetation ecology and forest management. Harvest prescriptions need to be simple, and little scope exists to incorporate all the ecological drivers and population dynamics characteristics of a species in the key prescriptions of harvest rotation and intensity. Ideally, harvest prescriptions should also cater for additional losses due to natural mortality. Whereas this is possible with timber yield regulation through the identification of dying trees (Seydack 1995), it is, as demonstrated with *B. latifolia*, more difficult with NTFPs. Of relevance here would be the degree of mortality, and the life history and longevity of the target species – all adding to the complexities of developing harvest systems for NTFPs. Furthermore, few forest managers and scientific support staff have either the background or access to resources to use tools such as matrix models – see, for example, Pfab & Witkowski (2000), Raimondo & Donaldson (2003) and Pfab & Scholes (2004) – to provide deeper insight into the potential impact of harvesting at different levels on a particular species or product. Accommodating spatio-temporal variation in population dynamics, and stochastic events in harvest systems for NTFPs is also more complex than for timber harvesting, considering that non-wood species are more likely to be influenced by weather fluctuations (Meilleur *et al*. 1992).

Ongoing monitoring and harvest system refinement

As demonstrated with the harvesting of *R. adiantiformis* fronds, the development and refinement of a harvest system for a target species or product is ongoing, supported by applied research and goal-orientated monitoring. These studies cannot easily be outsourced, as is the growing trend in South Africa, but require in-house expertise. This is particularly important for slow-growing species, or species slow to reproduce, which are also the species most vulnerable to overutilisation. For example, to obtain reliable information on the turnover of *B. latifolia*, monitoring had to be conducted over three years, while the harvest prescriptions for *R. adiantiformis* were refined over a decade. With medicinal bark harvesting, the long-term impact of bark stripping on tree survival is not known, and ideally requires ongoing monitoring and research on harvest impact. In the case of commercial use, the need could also arise to redefine the product (e.g. in terms of minimum size) to accommodate market demands. This could necessitate the revision of harvest prescriptions (and additional monitoring) as was the case with *R. adiantiformis* fronds in the southern Cape (Vermeulen *et al*. 2005).

Different levels of monitoring are required for different species and products harvested (Peters 1996, Botha 2001, Cunningham 2001). Considering the extent of resource use, it is likely that sound monitoring programmes can only be implemented for the more vulnerable species. Although Botha (2001) argues that monitoring of less vulnerable species could be confined to harvest and trade records at user level, sustainability should be monitored at ecosystem and population level to comply with the principles of sustainable forest management (DWAF 2005b). Also, because plant populations are dynamic, monitoring systems for sustainability should be developed taking into consideration long-term natural fluctuations and disturbance patterns as was recorded for *R. adiantiformis*.

Diversity of products and species harvested

A wide range of products and species are being harvested from natural forest in South Africa (Lawes *et al*. 2004a). Geldenhuys (1998a) recorded 140 tree and shrub species harvested for different purposes from natural forest in South Africa. Grace *et al*. (2003) listed 174 tree species harvested for medicinal bark in KwaZulu-Natal. The process to develop harvest systems and the nature of required research could vary greatly between different plant species, growth forms and plant parts (Cunningham 2001). As was experienced with the case studies, expertise or knowledge is required in the different fields of botany (e.g. phytosociology, autecology, population dynamics, plant anatomy and physiology), from project design and experimental layout to data analysis and interpretation of results (Höft *et al*. 1999). Differences in growth patterns between monocotyledons and dicotyledons could add to these complexities.

Considering the above, and with plant ecology being a specialised field, it is unlikely that resource managers trained as foresters would be able to take the process far beyond the user-needs and resource inventory study components. Horn & Clarke (2002), for example, identified a huge lack of skills in planning and implementation of sustainable forest management amongst forest managers and scientific support staff, which would require specialised input to support the efforts of resource managers in the sustainable harvesting of NTFPs. This is also evident from the thorough research on population dynamics and demography on *R. adiantiformis* that had to be conducted by specialists in their fields (Chapter 2) to put the harvesting of the species in the southern Cape on the path of sustainable use.

8.4.2 Socio-economic dimension

Socio-economic circumstances could seriously hamper the successful development and implementation of harvest systems for sustainable use of NTFPs in South Africa. Issues of relevance are (a) the high level of dependence of especially rural communities on forest resources, and unrealistic expectations in terms of potential benefits from NTFPs, (b) the costs of developing harvest systems to ensure ecological sustainability, (c) the limited potential for successful NTFP-based commercial ventures, with trade chains not formalized or clearly defined, (d) the demand for, especially, commercial NTFPs outweighing supply, (e) where there is uncontrolled use, an attitude of “cut before outsiders do” and the “use-it-or-loose-it” school of thought, and (f) the lack of social skills amongst forest managers to engage with communities.

Dependence on forest resources and expectations

Considering the level of dependence of rural communities on forest resources for their daily livelihood (Cunningham *et al*. 1988, Shackleton *et al*. 2000, Chipeta & Kowero 2004, Clarke & Grundy 2004, Lawes *et al*. 2004a, Shackleton & Shackleton 2004, Cocks 2006) and the extent of commercialisation that has already taken place (see, for example, Clarke & Grundy 2004, Mander 2004), it would be a major challenge to obtain buy-in from stakeholders and user groups for the implementation of sustainable harvest systems where this could negatively affect the current levels of supply of forest products. This is aggravated by the fact that in many instances current levels of harvesting are unsustainable, but harvest trends are already well established and cannot easily be reversed. For example, in the historical development of the forest management system in the southern Cape (Von Breitenbach 1968a), woodcutters were so dependent on timber harvesting that, guided by socio-economic and political considerations, restrictions on harvesting were seldom enforced. The commercial value of NTFPs could be quantified objectively (e.g. Mander 1998, Shackleton *et al*. 2000, 2007, Williams 2004; Adepoju & Salau 2007, Croitoru 2007, Gubbi & MacMillan 2008,), but extrapolations are more than likely based on harvest levels that cannot be sustained. Therefore, more people entering the commercial market may become dependent on forest resources that are already overutilised.

With the promulgation of the new National Forests Act (Act No. 84 of 1998) (NFA) and the implementation of a national forest policy that promote benefit sharing (Chapter 1), communities often have unrealistic expectations of the potential economic benefits that NTFPs could provide (Horn & Clarke 2002, DWAF 2004, Marshall *et al*. 2003). Forest managers, lacking experience and skills in social forestry, sometimes also create unrealistic expectations with the implementation of PFM policies (Horn & Clarke 2002). Furthermore, where communities already have uncontrolled access to resources, prescriptions to bring use on a par with harvest levels that can be sustained, could reduce the flow of benefits; this would not be well received by beneficiaries.

The perception often arises among user groups that harvest restrictions are about conservation only, limiting access to resources in the process. When engaging with communities, it should be stressed that social and economic benefits cannot be maintained if harvesting is not ecologically sustainable.

Costs of developing and implementing harvest systems

One of the Addis Ababa principles for sustainable use of biodiversity is that costs of management be internalised within the area of management, and that some of the benefits from use flow to the local resource management authorities (CBD 2004). Considering the expertise and resources required, the costs of developing, implementing and monitoring sustainable harvest systems are substantial. Where harvesting is for domestic use by rural communities dependent on the resource, these expenses should, arguably, be regarded as part of management's cost to sustain social benefits. However, for commercial harvesting, these costs should be absorbed by the economic venture. This would require that the product fee covers the costs to resource managers, as management input would not be required if it were not for the economic venture. However, many NTFP harvest ventures could be rendered economically unviable (see e.g. Neumann & Hirsch 2000, Marshall *et al*. 2003, Kusters *et al*. 2006, Belcher & Schreckenberg 2007) unless the product has high value, as was the case with *R. adiantiformis*. Where justified, economically unsustainable ventures may have to be subsidised by management institutions and the expenses incurred (to ensure sustainable use) regarded as part of the costs of integrated, sustainable forest management. This would require management agencies to clearly define their social responsibilities in terms of supporting especially rural communities living around natural forests.

Commercialisation potential of NTFPs and trade chains

Horn & Clarke (2002) expressed the concern that forests offer limited economic opportunities for significant benefit flows to local, poor people, considering the restrictions necessary to achieve the overriding goal of sustainable forest management. This is further highlighted by Neumann & Hirsch (2000), Marshall *et al*. (2003), Kusters *et al*. (2006) and Belcher & Schreckenberg (2007), indicating that many attempts at NTFP commercialisation have failed to deliver expected benefits. The economic success of commercial harvesting of *R. adiantiformis* fronds is the exception rather than the rule; also, the true value of the product was vested in commercialisation of the species outside its natural environment (Chapter 2). Based on studies in the Amazonia, Homma (1992), however, cautioned about the fragility of resource economics and that it should be considered when extraction is promoted as viable model for development, preservation and conservation of natural resources. He argues that forest product extraction may be ecologically sustainable, but that social and economic sustainability in the long-term is often doubtful and largely restricted to regions of low population density. Furthermore, the extent to which management institutions would be willing or able to engage in meaningful economic benefit sharing where income generation and financial self-sufficiency is a core objective of the management agent, is questionable. Horn & Clarke (2002) consider this a serious threat to the successful implementation of PFM.

As experienced with *R. adiantiformis* and also reported by Wilkie *et al*. (2001), there is a growing trend of overharvesting in the wild as a NTFP increases in value. Hall & Bawa

(1993) indicated the concern that economic sustainability is not consistent with ecological sustainability; although resources could decline, the scarcity of the product and persistent demand could keep the market value constant. This was also experienced with *R. adiantiformis*, with the income generated from harvesting increasing despite a decrease in harvest volumes (Chapter 2). In economic terms, the effects of overutilisation could thus take a long time to detect (Hall & Bawa 1993).

In terms of commercial use and trade in, especially, medicinal plants, the industry is not well formalised and trade chains are not clearly defined (Geldenhuys 2000c). The consequences are insufficient use of harvested products, while their value cannot easily be defined; the net result is undervaluation and wastage of products from forest resources already under pressure. Horn (2002) reports that commercial operators often exploit local people's poverty, paying them to illegally, and often destructively, harvest forest products on their behalf. Only once a species becomes scarce in the wild, is the value of the product appreciated, as appears to be the case with *Warburgia salutaris* and *Siphonochilus aethiopicus* harvested for medicinal use (Mander 1997, 1998, Botha 2001, Williams 2003).

Geldenhuys (2004b, 2007) provides a commercialisation model for the medicinal bark species *Ocotea bullata*, indicating (a) the focus areas for development of technology and skills, (b) management requirements and potential partners for commercialisation, and (c) a research framework showing the relationship and interactions between the different components. Although systems that ensure ecological sustainability can be developed, as demonstrated with this study, addressing the various components in the trade chain is essential for reducing pressure on resources and ensuring sustainability from resource to market (also see Sunderland *et al*. 2004 and Belcher & Schreckenberg 2007).

Demand versus supply

The *B. latifolia* case study demonstrated that the species has a small resource base in the management area and that the increasing demand cannot be met from the wild. It is often argued that, based on indigenous knowledge and practices, rural people have harvested natural resources on a sustainable basis for centuries, but this is unlikely to prevail with high population growth (Godoy & Bawa 1993) and commercial incentives. Fong (1992) found that a scarcity of resources and an increased demand resulted in local people increasingly trying to maximise their immediate returns, regardless of the long-term costs of overexploitation. These concerns are shared by Dasmann (1985) who states that the low level of resource exploitation under sustainable harvest systems will not satisfy the demands of increasing populations, and that resources will be depleted progressively (Godoy & Bawa 1993, Wilkie *et al*. 2001).

The demand for NTFPs is likely to outweigh the supply in many localised forest areas in South Africa. With the high level of dependence of rural communities and other beneficiaries on forest resources, alternatives to harvesting from the wild (as proposed for *B. latifolia*) have to be high on the agenda in the efforts to achieve sustainable forest management. Although there will always be a demand for access to wild resources to accommodate cultural practices (Cocks 2006), the environmental costs of uncontrolled harvesting of forest resources for such uses should be appreciated (Cocks & Dold 2003).

"Use-it-or-loose-it" scenario

Whereas there is often conflict between biodiversity conservation and consumptive resource use (Hiremath 2004, Ticktin 2004), legal and responsible use can also enhance conservation under certain circumstances (IUCN 2000). Benefits through resource use, including non-consumptive components, add value to natural forest – as was experienced with *R. adiantiformis* harvesting in the southern Cape – and are likely to encourage stakeholders to take responsibility for the resource (Horn 2002, Kusumanto *et al*. 2005). This is supported by Dasmann (1985) who argues that sustainability appeals most to people who see some continuity with the past and the future, more often people attached to the "bio-region that they recognise as home territory". For example, the Southern Cape Traditional Healers Association is a key user group of medicinal bark (Chapter 5) and has vested interests in ensuring that the resource is not exhausted by commercial "bark collectors" for short-term gain. However, where there are uncertainties in sustaining livelihoods, an "open access" situation could develop, resulting in an attitude of "cut the tree before outsiders do" (Kusumanto *et al*. 2005). This is a huge threat (where commercial benefits are at stake, e.g. the trade in medicinal plants) to the implementation of systems for the sustainable harvesting of NTFPs in certain forest areas in South Africa.

It is further emphasised by the "use-it-or-loose-it" school of thought. They maintain that tangible market-based usage provides the best option to link forest conservation with sustainable development, while "no-use-is-best-use" proponents claim that non-tangible benefits such as soil and water conservation, and clean air outweigh any financial value (Price & Butt 2000). Although likely that the indirect values of forest and woodland resources outweigh the benefits of consumptive use (Pearce 1998, Peel *et al*. 2004, Vermeulen 2004a), in South Africa the "use-it-or-lose-it" scenario is more likely to prevail considering the socio-economic conditions and dependence of rural communities on forest resources. Furthermore, considering the complexities with ecotourism development in rural areas, Laws (2004) warns that "sociologists and environmentalists should tread with caution in touting tourism as a panacea for sustainable use".

Required social skills for community engagement

There is no single recipe for the effective implementation of participatory management of forest resources for multiple use, especially in rural areas (Grundy 2000). In more complex or dynamic situations, social skills would be required to engage with communities and develop harvest systems, and take implementation to its conclusion (Botha 2001, Horn & Clarke 2002; *vide* Plowden 2008), as was partly the experience with the development of harvest systems for medicinal bark (Chapter 5) and *B. latifolia* (Chapter 7). This is a further stumbling block in achieving sustainable harvesting of NTFPs as there is a lack of social and social development skills amongst forest managers and scientific support staff (Horn & Clarke 2002, Willis 2004). Furthermore, local people are often also insufficiently organised or empowered to effectively engage with PFM and related issues such as resource use (Horn & Clarke 2002). One of the Addis Ababa principles for sustainable harvesting of biodiversity, is that local users should be empowered and supported by rights to take accountability for the management of their resources (CBD 2004).

8.4.3 Institutional arrangements and policy directives

Institutional arrangements and legislation strongly influence forest management objectives. The NFA provides the legal framework for forest management in South Africa. In terms of institutional arrangements the Department of Water Affairs and Forestry (DWAF) has a policy and regulatory function, while management agents such as SANParks, Provincial authorities and private companies are responsible for management implementation. The NFA makes provision for local communities to access forest resources for domestic use, and for community development through commercial use, subject to sustainable management principles. To realise this, DWAF formulated a policy of PFM (DWAF undated, 2004), providing for shared responsibility with forest management and ensuring a sustained flow of benefits to key stakeholders (DWAF 2005a). Access to resources and the development of harvest systems for sustainable use need to be accommodated with due consideration of national policy and legislation that allows for implementation.

Having in place policies, laws, and institutions at all level of governance with effective linkages between these levels is one of the Addis Ababa principles for sustainable use of biodiversity (CBD 2004). Dasmann (1985) argues that, because of political realities, long-term investment in sustainability is often neglected as it only pays off politically if the public values it more than short-term profit – which is seldom the case in poverty-stricken rural areas. As indicated, the current legislation and policies that govern forest management in South Africa are very much pro resource use (DWAF 1996, 1997, 2004); access to forest resources for livelihood purposes and community development is actively promoted. However, it is critical that the necessary capacity is built by management institutions, and that human and financial resources are available for the development and implementation of systems for sustainable use. Currently capacity and resources are lacking (Horn & Clarke 2002, Grundy & Michell 2004) which, together with the high demand and overutilisation in many areas, puts major pressure (that could be difficult to reverse) on forest resources. It is highly likely that such pressure will increase, despite practical measures that could be followed to develop and implement harvest prescriptions for sustainable use.

The ease with which the generic process of sustained yield determination can be applied is therefore also influenced by the socio-economic dynamics in the region, and by the policy and socio-political aspirations of relevant institutions.

8.5 GENERAL RECOMMENDATIONS FOR THE DEVELOPMENT AND IMPLEMENTATION OF HARVEST SYSTEMS FOR NTFPs IN SOUTH AFRICA

Based on experience with this study, and considering (a) the socio-economic circumstances in many forest areas in South Africa; (b) constraints with the development of ecologically sustainable harvest systems; (c) the high level of commercialisation based on unsustainable harvest levels; and (d) lack of skills and financial resources to ensure the effective implementation of PFM, management agents face many difficulties in ensuring sustainable harvesting of NTFPs. To lay the foundation for successful development and implementation of harvest systems, and to ensure that the benefits of NTFPs are realised in the long term, the following are paramount:

Integrated and adaptive forest management: Harvest systems for NTFPs and their implementation need to be integrated with existing forest and conservation management systems to ensure compatibility with other management objectives such as biodiversity conservation and ecotourism, and other stakeholder (national and international) needs. Current overutilisation could be addressed through an adaptive management approach, based on precautionary principles, also one of the Addis Ababa principles for sustainable use of biodiversity (CBD 2004). This would require formulating and enforcing interim harvest prescriptions based on existing knowledge. Little progress has been made in this regard even though scientific research is not a prerequisite for the implementation of this approach.

Participatory forest management (PFM) and law enforcement: Where access to forest resources was fairly restricted in the past, new national legislation makes ample provision for it. This is further enhanced by the PFM policy implemented by DWAF for State Forest land. There is, however, a lack of law enforcement in areas where PFM initiatives have failed, and a disregard for rules and principles for sustainable harvesting. The implementation of PFM and the provision of access should thus run parallel with policing and law enforcement, especially where resources are destroyed for the benefit of a few (De Villiers & White 2000, Von Maltitz & Fleming 2000, De Villiers 2004, Grundy & Michell 2004).

Species and product prioritisation: Considering the wide range of NTFPs being harvested and the backlog with the development of harvest systems, species, species groups and products should be prioritised at local and national level for applied research to support harvest system development. This would require more effective networking with a consolidated effort from all different role players. Formal criteria for the selection of high-priority species or products should be developed to capture species that are, for example, high in demand, slow growing, habitat specific with limited distributions and exposed to destructive harvest techniques.

Control and setting of realistic targets for commercial harvesting: With the formulation of management policies, the input required and benefits accrued from consumptive versus non-consumptive use need to be weighed up objectively. Seydack (2007) demonstrated the high input and low output of consumptive resource use (plants), compared to ecotourism and wildlife. This should be recognised by policy makers so that realistic targets could be set for benefits from the harvesting of NTFPs. As reported by Neumann & Hirsch (2000), Sunderland *et al*. 2004, Kusters *et al*. (2006) and Gubbi & MacMillan 2008, the commercial potential of NTFPs should not be overestimated; neither should unrealistic expectations be created of the potential for forest-based economic development. Where resource use has become highly commercialised, such as the medicinal plant trade, the market chain needs to be formalised. The inherent value of the product should be appreciated and the wastage of raw material along the trade chain minimised. Also of concern, as reported by Prance (1998), is that those involved in the long chain of intermediaries between the producer and the market become rich with a minimal benefit to forest communities. This is exacerbated by the fact that many beneficiaries are involved for short-term gain, with little concern for the problem of destructive, unsustainable harvesting. Considering the dependence of, especially, rural communities on forest and woodland resources for their daily livelihoods, NTFPs are undervalued. This needs to be corrected to prompt policy and decision makers to provide the resources for the development and implementation of harvest and monitoring systems for sustainable use.

Development of alternatives: Considering the demand for access to resources and the small area of natural forest in South Africa, alternatives to resource harvesting from the wild must be developed. Although cultural practices and indigenous knowledge should be respected, less destructive harvest techniques for, among others, medicinal plants must be explored in consultation with stakeholders (Chapter 6). Mind-sets will have to change from traditional practices to, for example, using plant parts such as leaves (rather than bark) to ease sustainable harvesting. It, however, needs to be supported by goal-orientated bioprospecting to isolate active ingredients in different plant parts and, as suggested by Geldenhuys (2007), by the pharmaceutical production of affordable medicine. The same would apply to other uses, such as construction where users need to explore the option of using exotic species, where available, before indigenous resources are depleted. Currently, it appears that alternatives are only considered once the available indigenous resource has been depleted.

Socio-economic development: The socio-economic circumstances of especially rural people dependent on forest resources need to be improved for there to be successful implementation of sustainable harvest systems and a meaningful reduction in uncontrolled and unsustainable use. Considering all the constraints, there is limited potential to address this by providing access to natural forest resources; hence, forest projects should form part of other local economic development initiatives and be streamlined with Integrated Development Plans, assisted by external support (DWAF 2004). Horn & Clarke (2002) also emphasised that forestry initiatives should not be isolated from broader and cross-sectoral development. Alliances should be initiated with, for example, the departments of Agriculture, Land Affairs, and Trade and Industry, and be institutionalised. As advocated by Watts & Holmes-Watts (2007) forest-based poverty reduction initiatives should form part of a coordinated, multi-lateral approach to eradicate rural poverty and provide services. Unless socio-economic conditions are improved through development in all spheres in rural areas, there will be continued pressure on forest resources.

The above is supported by the fact that dependence on NTFPs is regarded by some anthropologists as the "livelihood of last resort" (Anon. 2005), and that foraging is often regarded as an "inferior, temporary occupation" until something better comes along (Godoy & Bawa 1993, Gubbi & MacMillan 2008). Although cultural practices are also a driving force (Cocks 2006), Wilkie *et al*. (2001) argue that the harvesting of wild NTFPs is "typically a symptom of poverty rather than a cure for it". Prance (1998) argues that it is therefore doubtful whether the harvesting of NTFPs will sustain a greater standard of living for harvesters, while Neumann & Hirsch (2000) report that there is ample evidence that involvement in NTFP extraction perpetuates rural poverty. Meaningful benefits lie rather in the commercialisation of products (e.g. biochemical products) based on indigenous knowledge, and the paying of royalties to local people. Success stories of such benefit-sharing initiatives are, however, scanty.

Budget requirements and skills development: A lack of expertise/personnel and financial resources were identified by Pérez *et al*. (1997) as a major constraint for research on NTFPs to support sound management of resources in Southern and Eastern Africa. Horn & Clarke (2002) reported that the absence of a supporting budget for PFM critically hinders both successful implementation of PFM and relating issues such as the development of harvest systems to ensure a sustainable flow of benefits. This includes financial as well as human resources for forest management in a participatory way (De Villliers 2004). The problem would be exacerbated should the management of natural forests be delegated to other management agents without there being a budget for sustainable forest management in all spheres, as captured in the Principles, Criteria, Indicators and Standards (PCI&S) for sustainable forest management in South Africa (DWAF 2005b). Achieving sustainability involves an ongoing process of improved management of the resource (IUCN 2000). Social and biological skills and expertise thus need to be developed in-house to ensure sustainable harvest systems, and long-term refinement thereof. Outsourcing is not a viable management option, although certain aspects of the process of system development could be outsourced. It is often argued that forest management in South Africa in the past has failed to conserve the resource because it made limited provision for stakeholder involvement and benefit sharing. However, the creation of expectations and easy access to resources could be a big threat to sustainability should the necessary human and financial resources not be made available to manage for benefit sharing in a participatory way.

8.6 CONCLUDING REMARKS

In achieving the overall objective of the study, the process to develop systems and prescriptions for sustainable harvesting of NTFPs has been scrutinised and described, based on the three case studies. Requirements for successful implementation, considering the socio-economic and political dimensions of sustainable use, have been assessed and described. The results contribute towards the management objective that motivated this study, namely optimum, sustainable harvesting of NTFPs from natural forests in the southern Cape. Although it is often argued that long-term sustainability cannot be guaranteed (IUCN 2000, Fabricius 2004), studies of the population dynamics and demography of plant species allow for the development of management prescriptions to increase the probability that use is sustainable – prescriptions that can be refined over time through an adaptive management approach.

In terms of implementation within the socio-economic and political sphere in South Africa, it has been demonstrated that, considering the wide range of NTFPs used and the dependence of especially rural communities on resources, a major challenge awaits forest managers to develop harvest systems through applied research, its implementation and continued monitoring to allow for system refinement. Policy and decision makers need to appreciate the skills, expertise and financial resources required to realise this. However, sustainable utilisation of NTFPs in South Africa is unlikely to be achieved in many areas unless the socio-economic circumstances that many user groups find themselves in are addressed in a consolidated way as a matter of priority.

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Appendix 1. Historical overview of *Rumohra adiantiformis* harvesting from natural forests in the Southern Cape and Tsitsikamma.

Year	Event	Harvest prescriptions / Comments	References
1970s	Harvesting on private land is licensed under the Cape Provincial Ordinance. Continued illegal harvesting on State Forest land.		Stehle (1987), Milton & Moll (1988)
1980	First interest shown in gaining legal access to State Forest land for commercial fern harvesting for the export market. Illegal harvesting on State Forest land continues.	The Department of Forestry resists efforts to gain access to State Forest land for fern picking, maintaining that commercial harvesting would not be in the interest of forest conservation, and the fear that it could lead to increased commercial pressure and unsustainable use. Law enforcement to control illegal harvesting on State Forest land is intensified.	Stehle (1987)
1981	Illegal harvesting on State Forest land escalates as the product becomes more valuable. Formal request is received to open up State Forest land for commercial harvesting for the European market. As a result of political pressure and recommendations from scientists at the Saasveld Forestry Research Centre near George and the University of Cape Town, a decision is taken to open up the forest for experimental commercial harvesting.	It is argued that, apart from the financial benefits, it would reduce incidences of illegal harvesting.	Stehle (1987), Geldenhuys & Van der Merwe (1988)
1982	A one-year tender (1 December 1982 to 30 November 1983) is awarded for harvesting at Harkerville and Fisantehoek State Forests.	Harvesting is restricted to an area of 4 100 ha. Contractor does picking under strict supervision of forestry staff. Harvest cycle of five weeks is applied.	Stehle (1987), Van der Merwe (1988), Milton & Moll (1988), Milton (1991)
1983	Tender renewed for a further two years, to include Diepwalle and Gouna State Forests. Applied research is initiated by the Department of Forestry (South African Forestry Research Institute). The contractor appoints an ecologist to commence with ecological research on *R. adiantiformis*. *Rumohra* Research Committee consisting of academics, researchers, forest managers and resource users is established.	Harvest area is extended to 7 028 ha and the harvest cycle to eight weeks. Fee structure for two categories of frond size implemented i.e. fronds < and > 250 mm. The successful tenderer is given the option of renewing the contract subject to successful tariff negotiations.	Stehle (1987), Geldenhuys & Van der Merwe (1986, 1988)
1984	Continued fern harvesting under existing contract. Interim results of research by the appointed ecologist are presented at a *Rumohra* Research Committee meeting (October 1984).		Dean 1984 cited in Geldenhuys & Van der Merwe 1986, Stehle (1987)

	Concerns are raised about a too short harvest cycle and excessive damage caused by trampling during picking operations.		
1985	Claims by the contractor that much larger numbers of fern fronds are required to ensure that fern harvesting is economically viable, put pressure on the department to open up more areas for harvesting. Fern harvesting is extended to the Tsitsikamma Forest region as a separate tender. At a second meeting of the *Rumohra* Research Committee it is recommended that the harvest cycle be extended and the harvest area expanded to compensate for the longer cycle. Monitoring programme is implemented by management in fern-picking areas (monitoring of yield, population health and compliance with harvest prescriptions). Competition for the right to harvest on State Forest land increases with more commercial harvesters entering the market.	The harvest area is extended to 14 500 ha and the harvest cycle to 16 weeks. Picking intensity is restricted to 50% of pickable fronds from each rhizome. Ecologically sensitive areas, as well as outdoor recreation areas in a picking area are excluded from harvesting.	Stehle (1987)
1986	Continued fern harvesting in the Southern Cape and Tsitsikamma under separate contracts. The artificial growing of the fern under shade cloth to reduce pressure on natural populations is advocated. Extensive research results presented at a meeting of the *Rumohra* Research Committee show a reduction in frond size due to a short harvest cycle. In addition, a plant only produces one to two fronds per annum A harvest cycle of 26 weeks is recommended.	Harvest cycle is extended to 52 weeks (implemented 1 December 1986). Minimum pickable frond size is fixed at 250 mm. In addition to the too short harvest cycle, fern populations were also negatively affected by a severe drought during the year.	Geldenhuys & Van der Merwe (1986), Stehle (1987), Milton & Moll (1988)
1987	First research results formally published: • Growth of seven-weeks fern (*Rumohra adiantiformis*) in the southern Cape forests: Implications for management (Milton 1987a) • Effects of harvesting on four species of forest ferns in South Africa (Milton 1987b) • Utilisation potential of *Rumohra adiantiformis* in the southern Cape forests (Milton & Moll 1987) The problem of fern theft has still not been satisfactorily resolved, resulting in financial losses to both the contractor and government.	The harvest area is extended with another 1 600 ha to a total of *ca*. 16 100 ha.	Stehle (1987)
1988	Further research results published: • Population structure and growth of the fern *Rumohra adiantiformis* in relation to frond harvesting in the southern Cape forests (Geldenhuys & Van der Merwe 1988) • Effects of harvesting on frond production of *Rumohra adiantiformis*	Geldenhuys & Van der Merwe (1988) suggest a criterion of a minimum stalk length of 40 cm to ensure sustainable harvesting.	

	(Pteridophyta : Aspidiaceae) in South Africa (Milton & Moll 1988)		
1989		Harvest cycle is increased to 15 months for the Tsitsikamma.	
1991	Results of longer-term experimental research are published (Milton 1991). Findings are that mean length of commercially picked fronds decreased between 1983 and 1988, but frond numbers and size have stabilised since 1989 when harvest frequency and intensity were reduced, but are still below pre-exploitation size. It is therefore concluded that *R. adiantiformis* growing in the southern Cape is relatively unproductive and fronds are slow to return to normal size after complete or partial defoliation.	Milton (1991) reports that it is not yet known whether the current levels of off-take are sustainable. Long-term monitoring is thus essential.	
1992	Contract breach by the successful tenderer is partly attributed to competition from other suppliers and sources, and consequently lower international prices.	Harvest rotation of 15 months is implemented in the Southern Cape.	
1994	Last research findings are written up (Geldenhuys & Van der Merwe 1994) - at the existing harvest intensity (50% of fronds/plant on 15-month rotation), frond density is not negatively affected by harvesting; neither are the production of buds and mature fronds. Review of studies on *R. adiantiformis* is conducted (Geldenhuys 1994a).	Recommend the continuation of long-term monitoring by resource managers.	
1998	Concerns are raised about a continued decline of fern fronds yielded from picking areas in the Southern Cape since 1992. Results of long-term monitoring by resource managers are written up (Heyns 1998, Kok 1998). No evidence is found that harvesting at existing prescriptions cannot be sustained.	The lower yield is attributed to a combination of factors such as under-picking (Baard & Wannenburg 1998), probably due to changes in market demands and natural changes in fern population densities and production (Stehle 1998, Kok 1998).	
2000	Waning interest in fern tenders as alternative sources are found (pine plantations, shade nets) and market demands shift towards larger fronds. Last formal tender for fern harvesting awarded, comes to an end.	No tender for fern harvesting is awarded, for the first time since the initial tender was awarded in 1982.	Kok (1998, 2004)
2002	Fern harvesting continues on small scale as part of a community development project, in line with the DWAF policy of participatory forest management.		Vermeulen *et al*. (2005)
2003	Community fern harvesting project phased out as it is not economically viable.		

Appendix 2. Summary of results of the assessment of tree response to bark stripping for selected tree species in the southern Cape, for different seasons of treatment, pooled for tree size classes and strip widths. Data are presented as means and ± standard error, with median in brackets

***Ocotea bullata* (36 months after treatment)**		
Tree response	**Dry season (n = 45)**	**Rainy season (n = 44)**
Crown condition (class average)	4.7 ± 0.09 (5)	4.7 ± 0.13 (5)
Crown condition (change in class average)	-0.04	0.05
Tree mortality (%) (seasons combined)	1.1 (n = 1)	
Bark lift (% class)	Not recorded	
Bark lift (mm)	Not recorded	
Edge visible (% class)	8.7 ± 0.21 (9)	8.6 ± 0.15 (9)
Edge total (%)	Not recorded	
Rate of wound closure through edge growth (mm/annum)	16.2 ± 1.42	12.1 ± 1.30
Sheet growth (% class)	0.0 ± 0.00 (0)	0.0 ± 0.00 (0)
Fungi (% class)	1.4 ± 0.14 (1)	1.2 ± 0.09 (1)
Pinholes (class average of trees with pinholes)	2.5 ± 0.22 (2) (n = 35)	2.2 ± 0.23 (2) (n = 23)
Pinholes (% of trees)	77.3	53.5
Agony shoots (average number, of trees with shoots)	1.0 ± 0.0 (n = 3)	1.6 ± 0.40 (n = 5)
Agony shoots (% of trees)	6.8	11.6
***Rapanea melanophloeos* (36 months after treatment)**		
Tree response	**Dry season (n = 48)**	**Rainy season (n = 44)**
Crown condition (class average)	4.5 ± 0.18 (5)	4.5 ± 0.16 (5)
Crown condition (change in class average)	0.29	0.25
Tree mortality (%) (seasons combined)	5.4 (n = 5)	
Bark lift (% class)	Not recorded	
Bark lift (mm)	Not recorded	
Edge visible (% class)	0.3 ± 0.15 (0)	0.0 ± 0.00 (0)
Edge total (%)	Not recorded	
Rate of wound closure through edge growth (mm/annum)	-2.3 ± 0.44	-1.9 ± 0.38
Sheet growth (% class)	0.0 ± 0.00 (0)	0.0 ± 0.00 (0)
Fungi (% class)	1.9 ± 0.19 (2)	2.1 ± 0.21 (2)
Pinholes (class average of trees with pinholes)	3.2 ± 0.19 (4) (n = 41)	3.0 ± 0.18 (3) (n = 39)
Pinholes (% of trees)	91.1	92.9
Agony shoots (average number, of trees with shoots)	1.0 ± 0.00 (n = 6)	2.5 ± 0.50 (n = 6)
Agony shoots (% of trees)	13.3	13.0
***Curtisia dentata* (Groenkop) (36 months after treatment)**		
Tree response	**Dry season (n = 45)**	**Rainy season (n = 45)**

Crown condition (class average)	4.9 ± 0.05 (5)	4.6 ± 0.14 (5)
Crown condition (change in class average)	-0.07	0.25
Tree mortality (%) (seasons combined)	1.1 (n = 1)	
Bark lift (% class)	Not recorded	
Bark lift (mm)	Not recorded	
Edge visible (% class)	4.3 ± 0.41 (4)	3.6 ± 0.38 (3)
Edge total (%)	Not recorded	
Rate of wound closure through edge growth (mm/annum)	-0.5 ± 0.39	-1.6 ± 0.55
Sheet growth (% class)	1.3 ± 0.28 (1)	3.0 ± 0.50 (1)
Fungi (% class)	1.9 ± 0.17 (2)	1.2 ± 0.06 (1)
Pinholes (class average of trees with pinholes)	1.7 ± 0.29 (1.5) (n = 7)	2.1 ± 0.46 (1.5) (n = 10)
Pinholes (% of trees)	15.6	22.7
Agony shoots (average number, of trees with shoots)	1.6 ± 0.24 (n = 15)	3.1 ± 1.28 (n = 7)
Agony shoots (% of trees)	33.3	15.9
***Curtisia dentata* (Witelsbos) (36 months after treatment)**		
Tree response	**Dry season (n = 45)**	**Rainy season (n = 45)**
Crown condition (class average)	4.8 ± 0.13 (5)	4.9 ± 0.13 (5)
Crown condition (change in class average)	0.05	0.14
Tree mortality (%) (seasons combined)	2.2 (n = 2)	
Bark lift (% class)	Not recorded	
Bark lift (mm)	Not recorded	
Edge visible (% class)	5.6 ± 0.37 (6)	3.3 ± 0.36 (3)
Edge total (%)	Not recorded	
Rate of wound closure through edge growth (mm/annum)	2.0 ± 0.31	-2.0 ± 0.38
Sheet growth (% class)	0.4 ± 0.10 (0)	0.8 ± 0.21 (0)
Fungi (% class)	1.6 ± 0.14 (1)	1.3 ± 0.09 (1)
Pinholes (class average of trees with pinholes)	2.1 ± 0.26 (2) (n = 20)	2.2 ± 0.21 (3) (n = 19)
Pinholes (% of trees)	46.5	45.2
Agony shoots (average number, of trees with shoots)	3.2 ± 0.65 (n = 13)	2.1 ± 0.49 (n = 14)
Agony shoots (% of trees)	30.2	32.6
***Ilex mitis* (12 months after treatment)**		
Tree response	**Dry season (n = 10)**	**Rainy season (n = 11)**
Crown condition (class average)	Monitoring period too short	
Crown condition (change in class average)	Monitoring period too short	
Tree mortality (%)	Monitoring period too short	
Bark lift (% class)	5.9 ± 0.89 (5.3)	6.7 ± 0.85 (7.5)
Bark lift (mm)	2.7 ± 0.85	4.4 ± 0.75
Edge visible (% class)	3.3 ± 0.86 (2.3)	1.7 ± 0.38 (1.5)
Edge total (%)	4.6 ± 0.93 (4)	3.3 ± 0.70 (3)
Rate of wound closure through edge growth (mm/annum)	-2.00 ± 2.76	-6.84 ± 1.42

Sheet growth (% class)	4.6 ± 0.69 (5)	6.9 ± 0.98 (6)
Fungi (% class)	1.4 ± 0.16 (1)	1.4 ± 0.13 (1.5)
Pinholes (class average of trees with pinholes)	0.5 (0.5) n = 1	1.5 ± 0.58 (1.5) n = 3
Pinholes (% of trees)	10.0	27.3
Agony shoots (average number, of trees with shoots)	0.0 (0) n = 0	4.3 ± 0.2.8 (2) n = 3
Agony shoots (% of trees)	0.0	27.3
***Prunus africana* (12 months after treatment)**		
Tree response	**Dry season (n = 10)**	**Rainy season (n = 11)**
Crown condition (class average)	Monitoring period too short	
Crown condition (change in class average)	Monitoring period too short	
Tree mortality (%)	Monitoring period too short	
Bark lift (% class)	1.5 ± 0.27 (1)	1.1 ± 0.45 (0.5)
Bark lift (mm)	0.6 ± 0.38	0.9 ± 0.35
Edge visible (% class)	8.9 ± 0.38 (9)	9.8 ± 0.11 (10)
Edge total (%)	9.4 ± 0.15 (9.5)	9.9 ± 0.10 (10)
Rate of wound closure through edge growth (mm/annum)	9.7 ± 2.82	-2.9 ± 1.76
Sheet growth (% class)	0.7 ± 0.19 (0.5)	6.2 ± 0.74 (6)
Fungi (% class)	2.4 ± 0.54 (1.8)	1.5 ± 0.19 (1.5)
Pinholes (class average of trees with pinholes)	0.0 (0) n = 0	0.5 (0.5) n = 1
Pinholes (% of trees)	0.0	10.0
Agony shoots (average number, of trees with shoots)	0.0 (0) n = 0	0.0 (0) n = 0
Agony shoots (% of trees)	0.0	0.0
***Rhus chirindensis* (12 months after treatment)**		
Tree response	**Dry season (n = 10)**	**Rainy season (n = 9)**
Crown condition (class average)	Monitoring period too short	
Crown condition (change in class average)	Monitoring period too short	
Tree mortality (%)	Monitoring period too short	
Bark lift (% class)	0.4 ± 0.14 (0.3)	3.1 ± 0.90 (3)
Bark lift (mm)	0.3 ± 0.17	1.6 ± 0.47
Edge visible (% class)	4.8 ± 0.62 (4.5)	4.0 ± 1.12 (3)
Edge total (%)	4.8 ± 0.62 (4.5)	5.9 ± 0.95 (6)
Rate of wound closure through edge growth (mm/annum)	3.26 ± 1.24	0.06 ± 1.72
Sheet growth (% class)	0.5 ± 0.15 (0.5)	0.1 ± 0.11 (0)
Fungi (% class)	1.8 ± 0.32 (1.5)	3.9 ± 0.83 (3.5)
Pinholes (class average of trees with pinholes)	1.5 ± 0.21 (1.5) n = 10	1.0 ± 0.27 (0.5) n = 7
Pinholes (% of trees)	100.0	77.8
Agony shoots (average number, of trees with shoots)	5.8 ± 3.09 (3) n = 4	5.3 ± 2.00 (4) n = 4
Agony shoots (% of trees)	40.0	44.4

Appendix 3. Abundance, corm length and diameter of *Bulbine latifolia* along fynbos/ecotone/forest gradient for three study sites (continuous line transect consisting of 5x5 m plots), and environmental variables.

		Plot 1	Plot 2[1]	Plot 3[1]	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9
Jantjieseiland										
Line 1	Vegetation type	Fynbos	Ecotone (1)[2]	Ecotone (2)	Forest (3)					
	No. of plants	3	47	15	21					
	Mean corm length	191.7	187.9	366.9	249.1					
	Mean corm diameter	19.7	18.4	23.4	14.9					
	Slope	16	29	31	33					
	Exposure	Sun	Part sun	Part sun	Shade					
	Stone cover %		0	1	1					
	Soil depth		35	37	29					
Line 2	Vegetation	Fynbos	Ecotone	Ecotone	Forest (4)					
	No. of plants	0	0	0	3					
	Mean corm length				140.0					
	Mean corm diameter				17.3					
	Slope				29					
	Exposure				Shade					
	Stone cover %				1					
	Soil depth				29					
Line 3	Vegetation	Fynbos	Ecotone (5)	Ecotone (6)	Forest (7)	Forest (8)				
	No. of plants	0	41	103	50	31				
	Mean corm length		221.3	215.3	223.5	370.2				
	Mean corm diameter		20.7	20.1	17.5	18.0				
	Slope		33	31	30	31				
	Exposure		Part sun	Shade	Shade	Shade				
	Stone cover %		25	1	1	5				
	Soil depth		21	20	51	33				
Line 4	Vegetation	Fynbos	Ecotone (9)	Ecotone (10)	Forest (11)					

	No. of plants	0	17	97	13				
	Mean corm length		182.6	194.3	252.5				
	Mean corm diameter		20.1	18.3	17.9				
	Slope		43	37	37				
	Exposure		Part sun	Shade	Shade				
	Stone cover %		55	1	0				
	Soil depth		19	75	100				
Total (plots along gradient)	**No. of plants**	3	105	215	87	31			
	%	0.7	23.8	48.6	19.7	7.0			
Total (vegetation groups)	**Ecotone**	% of plants	73.1	Mean no. of plants	53.3	% multi-stemmed	7.1		
	Forest	% of plants	26.9	Mean no. of plants	23.6	% multi-stemmed	5.9		
Grooteiland									
Line 1	Vegetation	Fynbos	Ecotone (12)	Ecotone (13)	Forest (14)	Forest (15)	Forest (16)	Forest (17)	
	No. of plants	0	40	53	20	23	25	4	
	Mean corm length		166.8	211.1	188.8	183.4	152.1	164.5	
	Mean corm diameter		22.4	21.9	22.5	20.4	19.7	19.0	
	Slope		35	37	40	44	44	43	
	Exposure		Part sun	Part sun	Part sun	Part sun	Part sun	Shade	
	Stone cover %		29	5	0	2	1	0	
	Soil depth		35	41	38	46	38	36	
Line 2	Vegetation	Fynbos	Ecotone (18)	Ecotone (19	Forest (20)	Forest (21)			
	No. of plants	0	12	43	28	2			
	Mean corm length		111.3	157.3	223.9	184.5			
	Mean corm diameter		15.5	21.3	17.0	19.5			
	Slope		40	33	33	37			
	Exposure		Part sun	Part sun	Shade	Shade			
	Stone cover %		55	12	2	1			
	Soil depth		38	53	59	63			
Total (plots	**No. of plants**	0	52	96	48	25	25	4	(250)	

along gradient)	**%**	0.0	20.8	38.4	19.2	10.0	10.0	1.6		
Total (vegetation groups)	**Ecotone**	% of plants	59.2	Mean no. of plants	37.0	% multi-stemmed	7.4			
	Forest	% of plants	40.8	Mean no. of plants	17.0	% multi-stemmed	1.0			
Crooks River										
Line 1	Vegetation	Fynbos	Ecotone (22)	Ecotone (23)	Forest (24)	Forest (25)	Forest (26)	Forest (27)	Forest (28)	Forest (29)
	No. of plants	0	17	34	29	18	11	3	9	14
	Mean corm length		72.4	108.1	196.9	120.9	260.5	121.3	167.4	151.5
	Mean corm diameter		15.2	16.4	18.2	15.8	20.1	16.3	18.3	17.7
	Slope		43	45	45	45	45	45	45	45
	Exposure		Part sun	Part sun	Part sun	Shade	Shade	Shade	Shade	Part sun
	Stone cover %		55	35	25	15	30	15	8	5
	Soil depth		33	38	23	41	27	17	25	32
Line 2	Vegetation	Fynbos	Ecotone (30)	Ecotone (31)	Forest (32)	Forest (33)	Forest (34)	Forest (35)	Forest (36)	
	No. of plants	0	31	31	22	4	1	6	3	
	Mean corm length		104.1	124.9	200.7	282.5	407.0	239.7	220.3	
	Mean corm diameter		16.2	16.1	16.5	16.3	16.0	18.3	19.0	
	Slope		45	45	45	42	45	45	45	
	Exposure		Part sun	Part sun	Shade	Shade	Shade	Shade	Shade	
	Stone cover %		35	15	5	10	3	1	1	
	Soil depth		33	58	59	78	45	31	48	
Total (plots along gradient)	**No. of plants**	0	48	65	51	22	12	9	12	14
	%	0.0	20.6	27.9	21.9	9.4	5.2	3.9	5.1	6.0
Total (vegetation groups)	**Ecotone**	% of plants	48.5	Mean no. of plants	28.3	% multi-stemmed	0.0			
	Forest	% of plants	51.5	Mean no. of plants	10.9	% multi-stemmed	0.8			

[1] The first two plots following the fynbos plot were regarded as ecotone, followed forest
[2] The number in brackets following the vegetation type, is the plot number used for the ordination analysis (Figure 6.7)