2008

THE CONSERVATION BIOLOGY OF BERBERIS HOLSTII ENGL. IN NYIKA NATIONAL PARK, MALAWI

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http://hdl.handle.net/10026.1/1625

http://dx.doi.org/10.24382/4699

University of Plymouth

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PhD 2008

Copyright Statement

THE CONSERVATION BIOLOGY OF BERBERIS HOLSTII ENGL. IN NYIKA NATIONAL PARK, MALAWI

by

CECILIA PROMISE MALIWICHI NYIRENDA

A thesis submitted to the University of Plymouth in partial fulfillment
for the degree of

DOCTOR OF PHILOSOPHY

School of Biological Sciences

Faculty of Science

2008

Abstract:

CECILIA PROMISE MALIWICHI NYIRENDA – THE CONSERVATION BIOLOGY OF *BERBERIS HOLSTII* ENGL. IN NYIKA NATIONAL PARK, MALAWI

Biological resources are particularly important in resource-limited countries where utilisation demands challenge conservation efforts. The study focussed on *Berberis holstii*, a plant resource on high demand in northern Malawi restricted to Nyika National Park. The uses, distribution, habitat characteristics, demography and seed germination requirements of this important species were investigated. Uses were investigated by means of ethnobotanical interviews. The species distribution in the park was mapped employing GIS. Habitats were characterised employing multivariate methods implemented in the programmes PC-ORD and PRIMER. Demographic studies employed matrix projections to characterise representative populations. Finally, laboratory germination trials allowed determination of light, cold stratification and temperature requirements for seed germination.

Forty-seven uses were documented. Of these, thirty were medicinal and the rest for income generation. The most common uses included infusion for coughs, malaria, stomachache, sexually transmitted infections and pneumonia. Because roots are employed, whole plants are dug out. This lead to the extinction of five of the recorded 94 sites. Fire periodically kills the aerial part of plants, which then tend to recover through resprouting. The species is restricted to high altitude, open areas on sandy/loamy soils. Despite harvesting and fire, demographic projections showed positive population growth. Population growth rate is more sensitive to mortality of late juvenile stages and early adult stages than it is to demographic transitions and contributions by other stage classes. Germination was higher when seeds were stored for one year, had a pre-chilling treatment (cold stratification) and were germinated under light at ~20°C. Seeds did not lose viability during two years of storage raising prospects for their artificial storage.

The study provides important information for the conservation and management of this important African endemic. It highlights some of the difficulties confronted in projecting the population dynamics of species with sporadic simultaneous recruitment and tests the ability of a recently proposed model to determine germination requirements. In a wider context, the study shows that a combination of methodological approaches (ethnobotany, biogeography, demography and germination) allows a more complete understanding of the evolutionary, ecological and social factors that must be taken into account in the conservation of individual species.

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List of Abbreviations

CBD	-	Convention on Biological Diversity
CCA	-	Canonical Correspondence Analysis
DNPW	-	Department of National Parks and Wildlife
EMA	-	Environmental Management Act
ESP	-	Environmental Support Programme
FA	-	Forestry Act
FD	-	Forestry Department
FGD	-	Focus group discussions
GPS	-	Global Positioning System
IDI	-	In-depth interviews
MK	-	Malawi Kwacha
NEAP	-	National Environmental Action Plan
NHBGM	-	National Herbarium and Botanic Gardens of Malawi
NPWA		National Parks and Wildlife Act
PRA	-	Participatory Rapid Appraisal
PVA	-	Population Viability Analysis
RUZ	-	Resource Use Zone
STI	-	Sexually Transmitted Infections
TMP	-	Traditional Medical Practitioner
TWINSPAN	-	Two Way Indicator Species Analysis
UNFCC	-	United Nations Framework Convention on Climate Change

Dedication

This thesis is dedicated to the following: my husband Dean and my son Maynard for enduring with me throughout the study period; my mum Honourable Justice Mrs Anastazia Msosa and my aunt Professor Lucy Maliwichi for their support which has made me sail through; my late grandparents Abambo Elias and Amayi Kamiya Maliwichi for the seeds which they sowed whose fruits I am reaping today.

Acknowledgements

First and foremost, I am very grateful to God the Almighty for being faithful and standing by my side throughout the road which otherwise seemed impassable. I am also very grateful to numerous people and organisations for contributing to the success of this study.

I would like to express my sincere gratitude to my Director of studies Dr. Miguel Franco for his untiring support and encouragement throughout the study period. Thanks so much for always being there and making my academic dream a reality. I am grateful to my second supervisor Dr Paul Ramsay for the support rendered. I am also indebted to Dr Mick Utley for the advice rendered as an internal assessor.

I am sincerely grateful to Norwegian government for the Norwegian Agency for Development Cooperation (NORAD) scholarship it offered me through Nyika Biodiversity Support Programme. I am also thankful to Newby Trust and an anonymous Trust for their financial contribution.

My heart goes out to my husband Dean and our son Maynard for their love and support. I am where I am today because of their understanding and perseverance. Thanks for being there when I needed you most. Thanks for providing your shoulders for me to lean on. What more can I ask for? I am very indebted to my family for the ceaseless support they gave me during my studies. Thanks to my parents-in-law (Mr MOSC and Mrs Frances Nyirenda), mum (Honourable Justice Anastazia Msosa, aunt (Professor Lucy Maliwichi), brothers (Alan, Yamiko and Lewis), sisters (Angela, Trinitas and Vanessa) and cousin (Dr Perks Ligoya) for providing light when there was complete darkness in the tunnel.

Thanks to my brothers and sisters for helping Dean in looking after Maynard while I was writing up. Thanks also to Yamiko for the support rendered while I was finishing up my studies. May the good Lord bless you all abundantly.

I owe great thanks to my late grandparents Abambo Elias and Amayi Kamiya Maliwichi. Thanks so much for your hard work, love and support. I have grown up to be what you wanted. I wish you were there to reap the fruits. I salute you and ask God the Almighty to rest your souls in eternal peace.

In Africa, I would like to thank all the respondents to ethnobotanical interviews for their time and willingness to provide the valuable information. I am thankful to National Herbarium and Botanic Gardens of Malawi for allowing me to do my studies and for the technical support provided. Specifically, I wish to thank Ms Beatrice Kubwalo, Messrs Donald Mpalika and Julius Bvutula for the tireless technical assistance. Thanks also to Messrs Ishmael Patel, Edwin Kathumba and Moffat Thera for helping with plant identification. Thanks to Department of National Parks and Wildlife (Thazima and Chilinda Camps) for the support they gave me during field work. I am grateful to Messrs Nhumaio and Katha (posthumous) for the support provided. I am sincerely grateful to Mr Paston and Mrs Lydia Simkoko for opening the doors of their house while I was doing fieldwork and also providing technical support throughout the study period. My gratitude also goes to University of Malawi's Centre for Social Research for advice on Participatory Rapid Appraisal. I am particularly thankful to Mr Bernie Zakeyo for helping with Focus Group Discussions and In-Depth Interviews and coding of the transcripts. I am grateful to Bvumbwe Agricultural Research Station, especially Mr Sonjela for assisting with soil analyses.

I also thank Malawi's National Statistical Office for providing population census data, University of Malawi's Chancellor College for guidance on sampling strategies, and Malawi Meteorological Services (Chileka) for providing climatic data. Thanks also to Peace Parks Foundation of South Africa, especially Craig Beech and Willem van Riet (Jr) for providing GIS base maps.

In United Kingdom, I am grateful to University of Plymouth's School of Biological Sciences for provision of laboratory facilities for the germination trials. My thanks to Angela Watson, Pete Smithers and Mike Whiffen for their technical assistance. I would like to thank my colleagues in Portland Square for the good working environment. I am especially thankful to Susan Morris for the immeasurable support provided. I am grateful to Sister Marion Gormley, Pat Morris, Dr Paul Robinson and Dr Mansel Davies for organising accommodation. I am thankful to Eden project particularly Ian Martin for the technical advice on germination. I am also grateful to Julian Harber for providing information on propagation of Berberis species.

Finally, I would like to thank everyone who contributed to this study.

Author's Declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

This study was financed with the aid of a scholarship from the Norwegian Agency for Development Cooperation (NORAD).

I declare that the work submitted in this thesis is the result of my own investigations except where reference is made to published literature and where assistance is acknowledged.

Presentations and conferences attended:

- Vice Chancellor's Research and innovation poster competition (April 2007), University of Plymouth

  Nyirenda, Cecilia & Franco, Miguel. Germination ecology of *Berberis holstii* Engl.

  Award received: 2nd best poster

- Terrestrial Ecology Research Group symposium (19th December 2005), University of Plymouth

  Nyirenda, Cecilia The conservation biology of *Berberis holstii* in Nyika National Park, Malawi. Findings and proposed future research

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- BIO 5113: Research Methods in Biology
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- BIOL 3105: Population Ecology and Conservation
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- Developing your research design
- EAR5102: Multivariate Analysis for Environmental Research
- Effective CV writing
- Endnote for beginners
- Excel 2002 scenarios
- Excel Pivot tables and Macros
- General Teaching Associates (GTA) course
- Getting started with quantitative research
- Intermediate Power point
- Introduction to career planning
- Introduction to electronic resources
- Introduction to Excel 2002
- Introduction to Microsoft Project (part 1)
- Introduction to qualitative research methods
- Introduction to qualitative research methods
- Introduction to SPSS – part 1 & 2
- Managing working relationships

- Negotiation skills
- Preparing for your viva
- Project management for researchers
- Rapid reading
- Research owning and using
- Risk management for research students
- Surviving interviews and assessment centres
- The Transfer Process
- Time management
- Updating your personal professional page
- Working with long documents

Word count of main body thesis: 26,310 words

Signed: ....[signature]..........

Date: ...27th JUNE 2008...

Chapter 1

General Introduction

1.1 Rationale for the chapter

This chapter provides a general overview of the importance of biological resources such as *Berberis holstii*. It first sets out a global perspective before focusing on the species of the genus *Berberis*. The relevant literature is reviewed in the process, and existing gaps identified. Finally, the chapter sets out the objectives of the study and the outline of the thesis.

1.2 Introduction and literature review

1.2.1 The role of biological resources in resource limited countries

A global perspective

The role of biological diversity in people's lives has been amply recognised (Busia, 2005, CBD, 2000). This role is particularly important in economically impaired countries where people depend on the biological resources for their immediate survival (UNDP, 1990). Therefore, depletion of biological resources has a more immediate effect on people. Most of the poor countries are in the tropics (Jepma, 1995) and this is where most threatened species exist (Plotkin, 1995).

The underlying factors of this depletion include: population increase, loss and fragmentation of natural habitats, land clearance for agriculture, pollution, overexploitation, climate change, biological invasion of introduced animal and plant species, and a wide gap in income distribution, social hardships, poverty, weak legislation, lack of institutional coordination in enforcement and policing of legislation, absence of comprehensive enforcement mechanism, and designation of nature reserves to meet national interests and not local needs (Spiteri and Nepal, 2006, Fiallo and Jacobson, 1995, Aumeeruddy-Thomas *et al.*, 2004, Malawi Government, 1998, Balick and Cox, 1996, Marinelli, 2004). Alongside depletion of the resources is loss of associated indigenous knowledge and practice (Slikkerveer, 2005, Marinelli, 2004), which are important elements in conservation (Schultes and Von Reis, 1995).

Recognising the challenges faced by the conservation of biological diversity, there is a global call outlined in the Global Biodiversity Strategy (CBD, 2000). The call aims at strengthening sustainable management and conservation of indigenous knowledge, perceptions and practices (Slikkerveer, 2005). Due to the multifaceted nature of the challenges to conserve biological diversity, multidisciplinary approaches are advocated for (Abbot, 1996).

The situation in Malawi

Like most countries in Africa, Malawi has an economy based on agriculture and many resources are obtained directly from the wild (Environmental Affairs Department, 2002, Malawi Government, 1998, Meadows, 1982).

Due to the vital role played by these resources, the government of Malawi recognised, as far back as 1925, the need of incorporating sustainable use and conservation of wildlife in the country's socio-economic development agenda (Abbot, 1996).

To manage the resources effectively, several strategies have been put in place at different levels. At the international level, Malawi is a signatory to conventions and frameworks such as the Convention on Biological Diversity (CBD), United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto protocol (Malawi Government, 1998). At local level, there is the National Environmental Action Plan (NEAP), the National Environmental Policy, the Environmental Management Act (EMA) and the Environmental Support Programme (ESP) (Malawi Government, 1998). With the exception of ESP, these schemes aim at establishing the overall policy and legislative framework that would ensure that sectoral policies are consistent with the principles of sustainable environmental management (Malawi Government, 1998). The ESP is aimed at inclusion of environmental concerns into the country's socio-economic development, hence empowering the local communities to manage their natural resources effectively (Malawi Government, 1998).

At institutional level, both *in-situ* and *ex-situ* conservation strategies have been put in place. These involve conserving the resources in protected areas. *In-situ* strategies mostly comprise national parks, game reserves and forest reserves, while *ex-situ* strategies include botanical gardens and nature sanctuaries.

The national parks and game reserves are controlled by government bodies and endeavour to preserve selected animal and plant communities (Bell, 1984).

Despite the political will of ensuring that the biological resources are sustainably utilised and conserved, some resources are being depleted at a very fast pace. For example, as of 1998, deforestation rate was about 2.8% per annum (Environmental Affairs Department, 1998). The fast depletion rate is of concern because of the associated economic losses and social impacts (Malawi Government, 1998). For instance, in 1994, depletion of resources amounted to ~10% of Malawi's GDP (Malawi Government, 1998, Environmental Affairs Department, 2002). Particularly worrisome is the fact that depletion is occurring not only in the wider countryside, but in protected areas as well.

Nyika National Park is one example of a protected area with continuous anthropogenic pressure (Dowsett-Lemaire, 1985). In an attempt to ensure sufficient conservation of biological resources within the park, in 1978, the government relocated the people living in it. Relocation to nearby areas and the growth of the human population surrounding the park means that the anthropogenic pressure is still present.

The Department of National Parks and Wildlife (DNPW) has attempted to regulate the exploitation of natural resources within the park while maintaining good public relations. Thus, local communities around the protected area are now integrated into the management initiatives (Dorward and Dorward, 1993, Dunn, 1995). The government allows people to collect resources from a 5-10km buffer zone in the periphery of the park, also known as resource use zone (RUZ), provided a permit is obtained.

The government also provides free seedlings to the communities to enable them to cultivate their own resources (Dorward and Dorward, 1993, Department of National Parks and Wildlife, 2004). In other instances, communities have been assisted financially and technically to raise, at household level, resources that are usually only found in protected areas, such as rabbits and guinea fowl (*Numida meleagris*) (Mphande and Jamusana, 1984).

To encourage people to understand the benefits of conserving biological diversity, they have been allowed to exploit resources in the protected areas on a commercial basis, e.g., bee-keeping, and the local communities have been given incentives to hand in weapons used to kill animals (e.g., guns and wire snares) (Dorward and Dorward, 1993, Mphande and Jamusana, 1984). Notwithstanding these efforts, it is necessary to monitor and guarantee the sustainable utilisation of plant and animal resources within the park. *Berberis holstii* is the most sought after plant species in the area and was therefore chosen as the subject of this study.

1.2.2 Study species

More broadly, the Berberidaceae contains 15 genera and ~650 species which are well represented in the North Temperate Zone (Whetstone *et al.*, 2000). The family has several remarkable biogeographic characteristics. For instance, *Achlys* has a disjunct distribution from western North America to East Asia (Fukuda, 1967, Whetstone *et al.*, 2000).

Diphylleia, *Jeffersonia*, and *Podophyllum* also show wide disjunctions from North America to East Asia (Whetstone *et al.*, 2000). Similarly, *Caulophyllum* has three species, one in east Asia and two in the Americas; *Vancouveria* is endemic to north-western United States; (Whetstone *et al.*, 2000).

Berberis species are medicinally important and are used for various purposes (Srivastava *et al.*, 2006). Although in Europe they are mostly used as ornamentals, they are used for medicinal purposes in many parts of the world. They are also used for jams and dyes in some cases (Heywood and Chant, 1982). Various plant parts are used (Table 1.1). *Berberis* species have therapeutic properties because of the alkaloids they contain (Facchini and St-Pierre, 2005). These alkaloids include berberine, oxyacanthine, berbamine and palmatine (Musumeci *et al.*, 2003, Hsieh *et al.*, 2007). For instance, berberine (from *Berberis aristata, B. repens, B. aquifolium and B. fremontii*) has anti diarrhoeal, febrifugal, hypotensive, immuno-stimulating, anti-inflammatory and antimicrobial properties (Musumeci *et al.*, 2003, Sack and Froehlich, 1982); it also aids in the raising of platelet count for primary and secondary thrombocytopenia patients and bile secretion stimulation (Birdsall, 1997).

There are about 500 species of Berberis worldwide (Whittemore, 1997). Two species are present in Africa; *B. vulgaris*, naturally present in north-west Africa, but with a wider natural distribution in central and southern Europe and western Asia, and *B. holstii*, endemic to the mountains of eastern and southern Africa. *B. holstii* is distributed in seven countries: Ethiopia, Somalia, Kenya, Uganda, Tanzania, Zambia and Malawi.

Table 1.1: Documented uses of some *Berberis* species.

Species name	**Use**	**Part used**	**Source**
B. aristata	Acute diarrhoeal treatment	Not specified	Sack and Froehlich (1982)
B. aristata	Different allergic disorders	Roots	Tripathi and Shukla (1996)
B. aristata	Tonic for liver and heart	Fruit	Gilani (1999)
B. buxifolia	Preservative	Not specified	Heywood and Chant (1982)
B. canadensis	Dye	Not specified	Heywood and Chant (1982)
B. crataegina	Anti-inflammatory, analgesic & febrifuge	Roots	Yesilada and Ku¨peli (2002)
B. haematocarpa	Chronic prostatitis & chronic pelvic pain syndromes	Not specified	Yarnell and Abascal (2005)
B. lycium	Pesticidal properties	Not specified	Tewary (2005)
B. ruscifolia	Dye	Not specified	Heywood and Chant (1982)
B. vulgaris	Dye	Not specified	Heywood and Chant (1982)
	Antiarrhythmatic & sedative	Berries	Fatehi (2005)
	Dissolution of cholesterol in gall bladder stone	leaves & fruits	Das (2005)
	Direct myotropic effect on cardiovascular system	Not specified	Peychev (2005)
B. vulgaris subsp. *seroi*	Enhanced aging of rural people	fruits, leaves & tender stems	Schaffer (2005)

The distribution coincides with the great chain of mountains and upland areas which run from the Ethiopian highlands to South Africa; these areas are of considerable phytogeographical and ecological interest (Chapman and White, 1970). Malawi is the southernmost locality of *B. holstii* (Wild, 1960) (Figure 1.1). Specifically, it has only been recorded on the Nyika Plateau within Nyika National Park. This is its only known locality in the Flora Zambesiaca region (Burrows and Willis, 2005).

Berberis holstii Engl., known as Holst's barberry, is regarded by some authors as a variety of the closely related Himalayan *B. aristata* DC. (White *et al.*, 2001, Cronquist, 1988). *B. holstii* is an evergreen perennial glabrous shrub (Bekele-Tesemma *et al.*, 1993). Locally known as Kayunga, it grows up to 1-3m tall, and has 1-4cm long tripartite spines, short axillary shoots and long oval berries (White *et al.*, 2001, Polhill, 1966, Bekele-Tesemma *et al.*, 1993) which turn from green to deep purple when ripe. The plant flowers in October/November and fruits ripe in May/June. By July, all fruits are dispersed (pers. obs.). An Afromontane endemic, it grows in open upland woodland, edges and glades of upland rain-forest, upland evergreen bushland and Juniperus-Hagenia-Olea forest (Polhill, 1966, Bekele-Tesemma *et al.*, 1993). Such habitats are favoured by many bird species which are agents of dispersal (Peterson Jr., 2003).

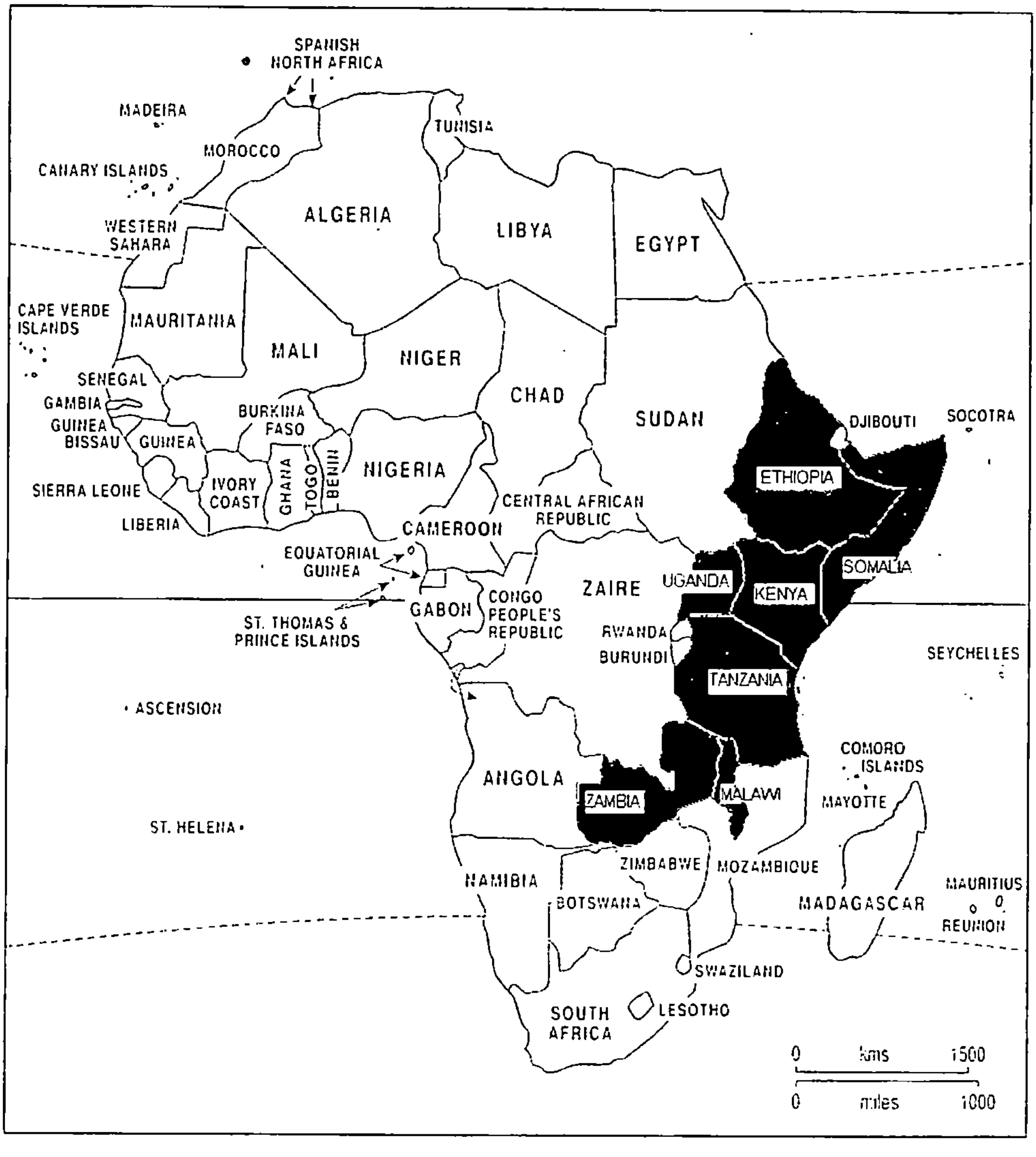


Figure 1.1: Map of Africa showing countries where *Berberis holstii* occurs (highlighted) (Source: Griffiths, 1994).

The only published works on the uses of *Berberis holstii* are those by Hedberg *et al.* (1982), Kokwaro (1993) and Bekele-Tesemma *et al.* (1993) which focus on Tanzania, East Africa (in general) and Ethiopia respectively. According to Hedberg *et al.* (1982), decoction of the roots is used in the treatment of jaundice while Kokwaro mentions the use of the same decoction for stomach pains and external application of powdered root bark to heal wounds. Bekele-Tesemma *et al.* (1993) state use of *B. holstii* for hedges and firewood. For Malawi, roots are also reported to be used medicinally (Burrows and Willis, 2005) but the exact uses have not been documented.

There is a general impression by people working in Nyika National Park that *B. holstii* is on high demand. The DNPW used to issue permits to collect *B. holstii*, but the practice was discontinued in 2001 due to the escalating demand. Nowadays, however, people collect *B. holstii* illegally. Efforts to propagate it by seed outside the park have been unsuccessful and there are concerns that the plant might be threatened.

Even though this is the case, the precise uses of *B. holstii* have not been documented. Its distribution within the park is not known. The characteristics of the habitats, which could explain the restricted distribution, have not been investigated. The structure and dynamics of the populations are not known. Finally, seed germination requirements have not been investigated.

1.2.3 Study area

The study took place in Nyika National Park, northern Malawi (10°15'-10°50'S and 33°35'-34°05'E). Malawi is a landlocked country situated at the southern end of the Great Rift valley and is part of the Zambezian Regional Centre of endemism (Dowsett-Lemaire *et al.*, 2002). What is now Nyika National Park started as a Juniper Forest Reserve in 1948 and was extended to its current size in 1978 (Johnson, 1994). Nyika, which means 'wilderness', was initially called Malawi National Park. The name changed in 1969 to Nyika National Park (Johnson, 1994, Southern Africa Botanical Network, 2000).

Nyika National Park covers an area of 3,200km^2 with 80km^2 being in Zambia (Dowsett-Lemaire *et al.*, 2002). The park comprises a mountain plateau, hills and escarpments (Department of National Parks and Wildlife, 2004), rolling grassland and montane evergreen forest patches (Brass, 1954, Dowsett-Lemaire, 1985, Johnson, 1994, Department of National Parks and Wildlife, 2004). Malawi's Nyika National Park is surrounded by Chitipa, Karonga and Rumphi districts (Department of National Parks and Wildlife, 2004). The present study focuses on Malawi's Nyika National Park (referred to as Nyika National Park in the rest of the thesis).

The park is located at an altitudinal range of 600m to 2607m (Department of National Parks and Wildlife, 2004). It experiences two main climatic seasons, namely wet (November to April) and dry (May to October), and receives 1500mm-1700mm of annual rainfall (Kaliba and Nhlane, 2003). The monthly minimum temperature ranges between 4°C and 11°C while monthly maximum temperatures range between 17°C and 20°C (Dowsett-Lemaire, 1985).

Extreme daily minimum temperature is -7°C for July (Dowsett-Lemaire, 1985, Burrows and Willis, 2005). However, a temperature of -12°C has been recorded at Chilinda (Burrows and Willis, 2005). Similarly, the temperature occasionally exceeds 26°C although 26°C is regarded as the extreme maxima (Johnson, 1994, Southern Africa Botanical Network, 2000).

The park comprises a plateau which accounts for 1320km^2. Located on the edge of the African Rift (Shroder, 1976), the plateau has distinct climate of mists and occasional frosts. The plateau is underlain with predominantly Precambrian to Lower Palaeozoic Basement Complex comprising metamorphic and Malawi Basement Complex igneous rocks (Thatcher 1974). The plateau's rolling uplands represent the Gondwana (Jurassic) surface (King 1963 cited by Thatcher 1974) divided by shallow valleys of the post-Gondwana erosion cycle (Thatcher, 1974).

Vegetation

The plateau is part of the Southern Rift Montane ecoregion, which is different from the other montane ecoregions of Africa because of the numerous northern plant taxa that it contains. These taxa reach their southernmost distributions in the Southern Rift Montane ecoregion (Williamson 1979, Chapman and White 1970, and Kerfoot 1964 cited by Estes 2001). Nyika provides the southernmost locality for montane forest trees such as *Euphorbia obovalifolia*, *Hagenia abyssinica* and *Juniperus procera* (Department of National Parks and Wildlife, 2004, Dowsett-Lemaire *et al.*, 2002).

Grasslands and relict patches of montane evergreen forests are characteristic of Nyika Plateau (Thatcher, 1974). Several authors consider that there was a continuous forest in the past which was transformed into forest patches and grasslands due to recurrent fire (Meadows, 1983, Shroder, 1976, Brass, 1954). Though geographically distant, Nyika plateau is similar to England's Dartmoor with respect to vegetation, rainfall, geology and drainage density (Meadows, 1982). The remaining parts of the national park are dominated by *Brachystegia* woodlands and other variations, such as *Acacia–Combretum* thorn thick and savanna (to the north), *Brachystegia–Julbernardia* (east), *Brachystegia* (south), *Brachystegia–Julbernardia* woodland (west) and *Brachystegia–Cryptosepalum* woodland (north-west) (Thatcher, 1974).

Value of Nyika National Park

Nyika National Park was the first and is the largest of the five Malawi national parks (Johnson, 1994). Although there is no information on the economic potential of most of its resources, the plateau has coal, nepheline syenites, limestone beds, manganese, bauxite, iron ore and construction materials like roadstone, gravel and sand (Thatcher, 1974). Biologically, Nyika National Park is important because it has a broad range of habitats (Johnson, 1994) and is one of Africa's Centres of Plant Diversity (Burrows and Willis, 2005, Southern Africa Botanical Network, 2000).

Apart from being an important water catchment area (Brass, 1954, Dowsett-Lemaire *et al.*, 2002), the plateau is home to south-central Africa's richest orchid flora (Kurzweil, 2000), over 400 bird species (Dowsett-Lemaire *et al.*, 2002) and game animals such as roan antelope (*Hippotragus equinus*), reedbuck (*Redunca arundinum*), zebra (*Equus burchelli*) and eland (*Tragelaphus oryx*) (Carter, 1987 cited by Estes 2001). It is also a breeding site for the declining wattled crane (*Bugeranus carunculatus*) (Stuart *et al.* 1990 cited by Estes 2001).

The plateau also has thirteen endemic plant species, seven plant sub-species (Willis *et al.*, 2001) and five endemic butterflies (*Charaxes dowsetti, Axiocerces nyika, Lepidochrysops handmani, L. chalceus* and *L.nyika*) (Dowsett-Lemaire *et al.*, 2002). Moreover, it has species whose only known locality in Malawi is in Nyika, e.g., *Acokanthera laevigata* and *Asplenium* sp.nov. in addition to *B. holstii*.

Legislation

Conservation of plant and animal species in protected areas is vested on DNPW and the Forestry Department (FD). DNPW is responsible for national parks and game reserves which are governed by the National Parks and Wildlife Act (NPWA). The FD's mandate is on the protection of animal and plant resources that are found in wooded areas (Malawi Government, 1997), and these are under the jurisdiction of the Forestry Act (FA).

The aim of the NPWA is to protect and conserve endemic, rare and endangered plant and animal species that are found in national parks and game reserves (Malawi Government, 1992). FA's purpose is to protect and manage forest reserves and promote involvement of communities in conservation of forests and trees in these areas.

Traditionally, FD is known to oversee forest resources while DNPW concentrates on animal resources. This distinction is reflected in the two Acts of Parliament. FA is silent on animal-related issues while NPWA emphasizes animal protection. NPWA stipulates that it is an offence to kill, wound or disturb game (Malawi Government, 1992).

The NPWA forbids the introduction of alien plants into protected areas and provides protection of endangered plants. Three plant species are listed: *Acokanthera laevigata* and *Asplenium* sp.nov. (which occur in Nyika only) and *Juniperus procera*.

1.3 Objectives of the study

The demand on *B. holstii* and associated illegal extraction from Nyika National Park has raised concern about its future. The study therefore attempted:

i. To document the uses of *Berberis holstii* and establish the reasons for its demand.

ii. To determine the distribution of *B. holstii* in Nyika as a way of facilitating its monitoring.

iii. To investigate the characteristics of the habitats where *B. holstii* grows as a means of understanding possible causes of its restricted distribution.

iv. To examine the properties of the populations in the wild in terms of structure and dynamics and possible linkages to anthropogenic pressure.

v. To investigate the germination requirements of *B. holstii* as a means to propagate it *ex-situ*.

vi. To use the results from these individual studies to draw recommendations on the sustainable utilisation and management of *B. holstii*.

1.4 Thesis outline

The thesis is divided into six chapters. The first chapter has given a general overview of the importance of biological resources with emphasis on Malawi and Nyika. Conservation challenges and current management strategies have been reviewed. Basic information on the study species and its genus, as well as on Nyika National Park has also been provided. Finally, the objectives of the study have been outlined.

Chapter 2 investigates the reasons for the demand of *Berberis holstii* in Nyika. This chapter presents an inventory of its uses, associated utilisation practices and beliefs, and people's awareness on legislation.

Chapter 3 maps the distribution of *B. holstii* in Nyika National park and investigates the floristic and environmental characteristics of the habitats in which it grows.

Chapter 4 looks at the demography of *B. holstii* in some of the sites identified in Chapter 3. The chapter assesses the link between anthropogenic pressure and the population structure and dynamics of *B. holstii.* Based on the results obtained, sustainable management practices are suggested.

Chapter 5 investigates the stratification, light and temperature requirements for seed germination.

Chapter 6 provides a general discussion of the findings of the previous chapters. It summarises their implications for the conservation and sustainable utilisation of *B. holstii.* Finally, the limitations of the study and recommendations for future research are delineated.

Chapter 2

Ethnobotany of *Berberis holstii*

2.1 Introduction

The relationship between people and plants has existed since mankind originated (Given and Harris, 1994, Schultes and Von Reis, 1995), but the scientific study of this relationship and the term to describe it, 'ethnobotany', emerged in 1895 (Cotton, 1996). Ethnobotany can be approached from different points of view, such as utilitarian (how people use plants), ecological (how local environment influences the management and utilisation of plants) or via ethno-systematics (traditional methods for identifying the plants) (Cotton, 1996, Schultes and Von Reis, 1995, Kokwaro, 1995). Ethnobotany encompasses documenting and understanding methods of cultivation, harvesting, processing and the sustainable use of plant species (Given and Harris, 1994, Prance, 1995). Due to the different aspects that the field touches, several disciplines are involved. These include agriculture, anthropology, biology, botany, ecology, history, literature, pharmacology and phytochemistry (Given and Harris, 1994, Cotton, 1996).

Ethnobotany is important because, firstly, traditional ethnobotanical knowledge is disappearing fast, before it can be documented (Given, 1993, Balick and Cox, 1996). Secondly, ethnobotanical studies have been the basis of many medicinal discoveries. Thus, 25-50% of the modern drugs derive, or did originally, from plants and owe their discovery to ethnobotanical studies (Davis, 1995). Well known examples are Aspirin (derived from *Filipendula ulmaria*), quinine (from *Cinchona officinalis*) and digitalis or digoxin (from *Digitaris purpurea*) (Cotton, 1996, Pei, 2001, Balick and Cox, 1996).

Ethnobotanical information is also important to policy makers because it highlights potentially valuable resources, their uses and traditional propagation and management methods (Balick and Cox, 1996, Alcorn, 1995). In the case of medicinal plants, the information also provides an overview of healthcare problems prevalent in an area (Cotton, 1996).

Importance of ethnobotanical studies in Malawi

The diverse and rich flora of Africa has sustained people for thousands of years (Kokwaro, 1995). In contrast to other parts of the world where ethnobotanical studies already have a long tradition, ethnobotanical studies in Africa only started in the 20th Century (Cotton, 1996). It is therefore important to bridge this gap in our knowledge.

Ethnobotanical knowledge is usually transmitted orally from one generation to the next, and thus involves memorizing (Kokwaro, 1995). This easily results in loss of information, some of which may have taken thousands of years to build up. Similarly, the information can easily be distorted (Balick and Cox, 1996, Prance, 1995, Kokwaro, 1995). Therefore, ethnobotanical studies ensure that knowledge is documented before it is lost and that the information, at least up to that point in time, is not distorted (Balick and Cox, 1996).

Southern Africa is endowed with rich plant and cultural diversity but ethnobotanical knowledge is still poorly documented (van Wyk, 2002) and few ethnobotanical studies have been undertaken in Malawi.

Most of ethnobotanical studies in Malawi have focussed on phytochemical screening (Décosterd et al., 1986, Bashir et al., 1993, Decosterd et al., 1988, Ferrari et al., 2000, Marston et al., 1995, Marston et al., 1984, Marston et al., 1986) or the listing of useful plants (Williamson, 1975, Morris, 1991, Malembo *et al.*, 1998). To date, there is no published ethnobotanical information on Nyika.

Ethnobotanical information is important in the context of Nyika because such information can be effective in solving conservation problems specific to an area (rather than applying information generated from elsewhere) (Alcorn (1995). In addition, an important aim of nature reserves is to preserve and disseminate information on traditional knowledge (Balick and Cox, 1996).

Given the social, economic and ecological importance of the study species, an ethnobotanical study was carried out to establish the uses of *Berberis holstii* among the people inhabiting the vicinity of Nyika National Park. The study also explored the knowledge that these people have of *B. holstii*, and how this knowledge is transmitted. Their familiarity with the existing legislation on the collection of *B. holstii* was also explored.

2.2 Objectives of the study

The objective of this part of the study was to investigate the reasons for the high demand of *Berberis holstii*. Specific objectives included:

i. Documenting the uses of *B. holstii*.

ii. Investigating the associated utilisation practices.

iii. Assessing the extent of the demand placed on *B. holstii*.

iv. Assessing the extent of knowledge of *B. holstii* among local communities and how this knowledge is transmitted between generations.

v. Documenting the possible existence of alternative species when *B. holstii* is not available.

vi. Investigating the level of awareness of policy regarding its collection.

2.3 Materials and Methods

Participatory Rapid Appraisal (PRA)

A qualitative study was conducted in July 2004 with the aim of assessing the views and perceptions of people on the importance and conservation status of *Berberis holstii*. A combination of two qualitative tools was used, namely Focus Group Discussions (FGDs) and In-Depth Interviews (IDIs). A total of 4 FGD sessions and 25 IDIs were conducted in three localities surrounding Nyika National Park. These localities were: Therere (in the district of Chitipa), Njalayankhunda (Karonga district) and Ntchenachena (Rumphi district). The districts were purposively selected because they surround the park and consequently, most people that were relocated from the park settled there.

A fourth locality, the Chilinda camp inside Nyika National Park, was also chosen (Figure 2.1). Chilinda camp is the only place in the park that is currently inhabited. Inhabitants are Department of National Parks and Wildlife and Nyika Safari Company employees, as well as the transient tourists.

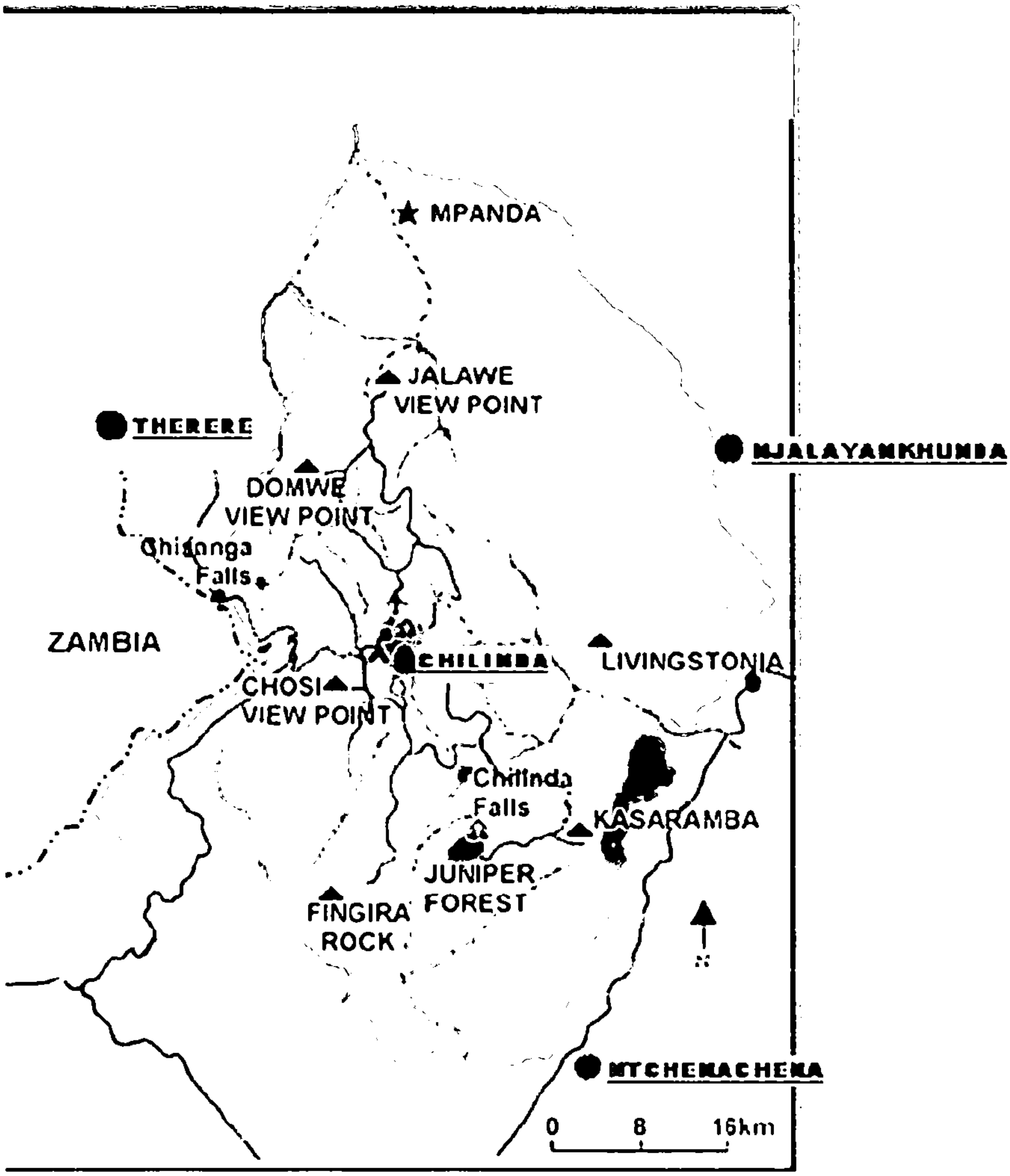


Figure 2.1: Sites where Participatory Rapid Appraisal sessions were undertaken in Nyika National Park (●).

The interviewees were those knowledgeable of *B. holstii*, hence all were adults. They were selected through a snowballing technique, which involves identifying an initial sample of respondents by the researcher. This sample, in turn, identifies another set of respondents and the process goes on until the required sample size is attained (Magnani *et al.*, 2005, Sullivan *et al.*, 2001).

One FGD was carried out in each of the study areas. The issues discussed during the FGDs included priority listing of plant species from Nyika National Park; documenting the collection, processing and uses of *B. holstii*; mapping of places where people collect *B. holstii*; techniques used in identifying *B. holstii* and knowledge of policies governing utilisation of *B. holstii*.

The IDIs employed guidelines stipulated in Appendix 2.1.Guided field walks were also conducted soon after each FGD. These involved going into the park under the guidance of one or two FGD participants. The walks were used to identify and verify the places where *B. holstii* were reportedly collected by FGD and IDI respondents. The FGDs and IDIs were recorded using a Sony micro-cassette recorder. The recorded information was transcribed afterwards. Themes emerging from the data were manually extracted and analyzed. Issues coming out of the themes were used to make inferences from the information that was obtained in questionnaire interviews.

Questionnaire interviews

The efficacy and accuracy of PRAs have been questioned (Narayanasamy *et al.*, 2001), and thus a quantitative method was also employed to ensure thorough documentation of the issues. This involved questionnaire interviews (Appendix 2.2). Prior to the interviews, the questionnaire was pre-tested to remove ambiguities (Drennan, 2003). Due to time and financial constraints, only areas that were within easy reach were visited during the main survey.

To maximise the number of interviewees, we interviewed any person we came across in each area. Tape recorders were used to record each interview. Because some interviews were conducted by research assistants, the recorded interviews allowed me to review the interviews daily and advise the assistants on forthcoming interviews. The data was analysed employing SPSS 15.0 for Windows. Frequencies were derived for all variables.

Data on socio-economic variables (age, sex, employment and education) was also cross-tabulated with knowledge and use of *B. holstii.* Pearson Chi-square statistics was used to assess the association between the variables (SPSS Inc., 2006).

2.4 Results

2.4.1 Demographic characteristics of respondents

Participatory Rapid Appraisal

A total of thirty-eight people participated in the focus group discussions. The participants were aged 30-65y-old. Chilinda and Njalayankhunda comprised men only (10 and 5 participants respectively). Therere comprised 13 participants (10 males and 3 females). Ntchenachena consisted of 10 participants, four of which were women. Because the discussions were carried out in a group, it was not possible to get personal demographic parameters of each participant.

The in-depth interviews were done with twenty-five respondents. Chilinda comprised eight respondents while Therere and Ntchenachena comprised six interviewees each. Njalayankhunda had five participants. All three areas, except Ntchenachena, had male participants. Ntchenachena comprised two women. The respondents in Chilinda were aged 26-42y-old whereas those in Therere were 28-65y-old. For Njalayankhunda and Ntchenachena, they were aged 39-55y-old and 46-65y-old respectively. In terms of tribe, all respondents in Chilinda and Therere were Tumbukas. In Njalayankhunda, there were three Tumbukas and two Phokas while in Ntchenachena there were four Tumbukas, one Mkhusa and one Tonga.

In terms of religion, all respondents were Christians except one person in Therere who did not belong to any denomination. All respondents were married except one person in Ntchenachena who was divorced. Most of the respondents had attained primary school education and were in salaried employment (Tables 2.1 and 2.2).

Table 2.1: Distribution of in-depth interview participants by educational qualification.

Site	Educational qualification (percent)		
	Secondary	Primary	Illiterate
Chilinda	62	38	0
Njalayankhunda	0	80	20
Ntchenachena	17	83	0
Therere	33	67	0

Table 2.2: Distribution of in-depth interview participants by occupation.

	Occupation (percent)			
Site	Business	Farmer	Salaried	TMP*
Chilinda	0	0	100	0
Njalayankhunda	40	20	0	40
Ntchenachena	33.3	33.3	0	33.3
Therere	0	66.7	16.7	16.7

*TMP = Traditional Medical Practitioner

Questionnaire interviews

A total of 198 people were interviewed (Table 2.3). These were distributed in the following age classes: 15% <20y-old, 33% 20-34y-old, 41% 35-50y, and 12% >50y. 36% of the respondents were females. The respondents belonged to 12 tribes with 49% of them belonging to the Tumbuka (Table 2.4).

Table 2.3: Distribution of questionnaire interviewees per site.

Site	Frequency	Percent
Chilinda camp	26	13.1
Chitipa Boma*	10	5.1
Chitipa village	31	15.7
Kaperekezi camp	31	15.7
Karonga boma	6	3.0
Karonga village	33	16.7
Rumphi boma	12	6.1
Rumphi village	37	18.7
Thazima camp	12	6.1

*A boma is a rural development centre.

Table 2.4: Distribution of questionnaire respondents by tribe.

Tribe	Frequency	Percent
Tumbuka	97	49.0
Lambya	29	14.6
Nkhonde	29	14.6
Henga	21	10.6
Ngoni	7	3.5
Lomwe	3	1.5
Phoka	3	1.5
Zambian	3	1.5
Chewa	2	1.0
Yao	2	1.0
Sena	1	0.5
Tonga	1	0.5

In terms of religious affinities, 97% of the respondents were Christian, 1% Islamic, and the rest did not disclose their denomination. About 70% were married (Figure 2.2). In terms of education, 54% had attained primary school education. 37% had secondary school education and only 2% had achieved tertiary education. 5% of the respondents were illiterate and 3% did not disclose their educational qualifications. Just over 50% of interviewees had steady income (own business = 26%, salaried staff = 25%; Figure 2.3).

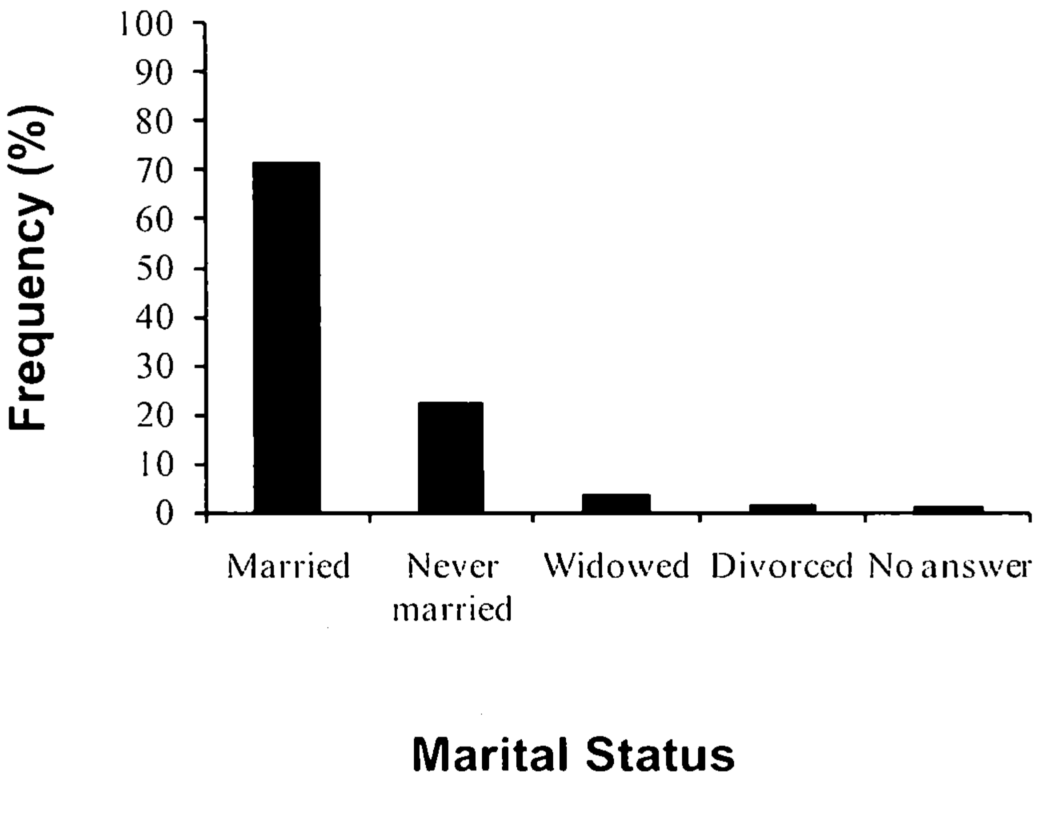


Figure 2.2: Marital status for questionnaire interviewees.

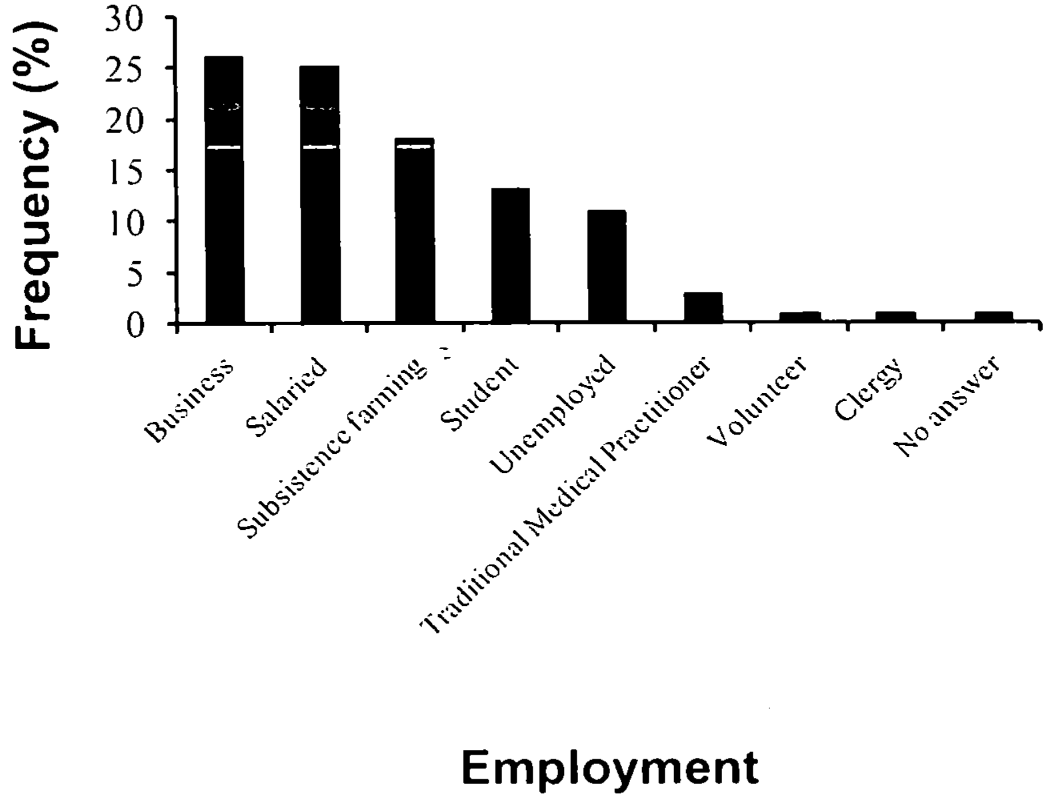


Figure 2.3: Employment status for questionnaire interviewees.

2.4.2 Knowledge surrounding utilisation of *Berberis holstii*

53% of respondents knew about *Berberis holstii*, with 43% of those knowledgeable having learnt about the plant from their parents, 28% from friends and 17% from other relatives (Figure 2.4). In contrast, the information gathered from PRA gave a different picture. Traditional Medical Practitioners (TMPs) mentioned that they knew about *B. holstii* from their ancestors, who told them about the plant through dreams.

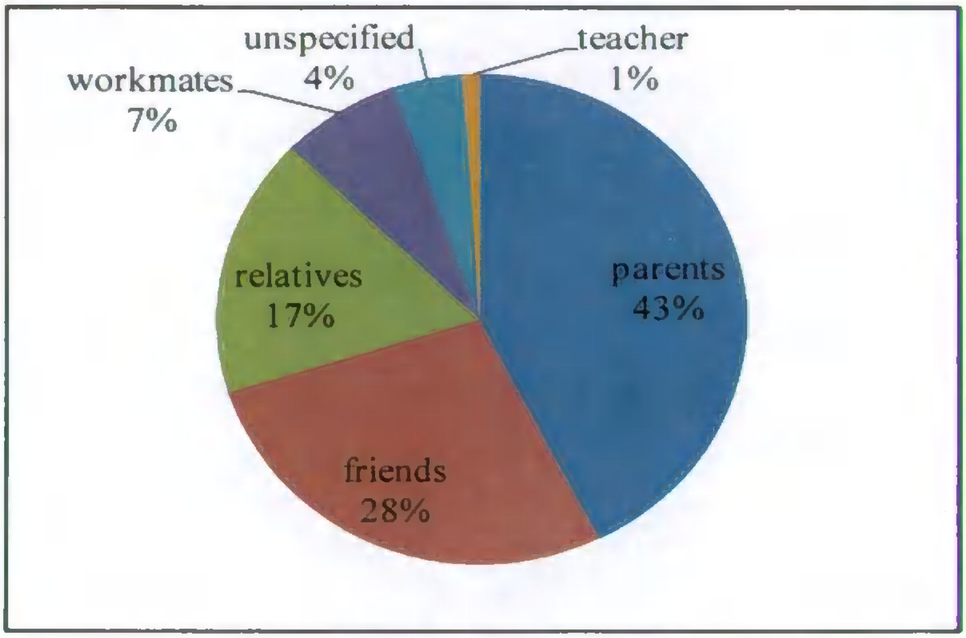


Figure 2.4: Sources of knowledge about the utilization of *Berberis holstii*.

The TMPs also said that the only knowledge they pass on to other people is that of common uses, such as treatment for coughs, but not about uses related to income generation. Irrespective of source, knowledge of *B. holstii* was not significantly associated with the respondents' age and sex, but was significantly associated with their level of education and employment status (2-tailed λ^2 = 6.215, 0.955, 9.268, 17.706; df = 9, 3, 9, 24; p = 0.102, 0.374, 0.055, 0.024, respectively).

2.4.3 People's perception of *Berberis holstii*

The PRA findings showed that *B. holstii* is considered an important plant species. It was ranked as number 1 priority species in all focus group discussions. This suggested that the species has been important for a long time. People ascribe this importance to its effectiveness when used in isolation. When mixed with other plants (e.g., *Cassia abbreviata* and *Rhamnus prinoides*), *B. holstii* is still the main component of the mixture.

The questionnaire interviews also revealed the high incidence of use of *B. holstii*. 74% of those who knew about it had used it. Of the 26% of respondents who had never used *B. holstii*, the most common reasons given were religious beliefs that ban the use of traditional medicine and difficulties in accessing the plant. In the case of those that had used *B. holstii*, there was no association between socio-economic status of the respondent (age, sex, education and employment) and usage (2-tailed λ^2=12.804, 5.415, 11.774, 33.776; df = 9, 3, 12, 24; p = 0.172, 0.144, 0.464, 0.089, respectively). Both PRA and questionnaire interviews showed that the plant is used more often by men than by women.

2.4.4 Uses of *Berberis holstii*

A total of 47 uses were recorded (Appendix 2.3). Thirty of the uses were medicinal. The remaining 17 non-medicinal uses were mostly associated with income generation and luck.

For the medicinal uses, cough ranked by far the highest (mentioned by over 40% of the respondents) followed by malaria, stomach ache and sexually transmitted infections (STIs) (Figure 2.5). Other conditions mentioned (excluded from Figure 2.5) were asthma, backache, hematuria, menorrhagia, body pains and sore throat (0.8% each).

Thirty-seven uses were recorded during PRA. Thirteen were similar to those mentioned during the questionnaire interviews. The twenty-four that were unique to PRA are as listed in Appendix 2.3. The respondents of questionnaire interviews also mentioned fifteen uses which they had heard from other people. Topping the list were also cough, malaria, stomach ache and STIs (30%, 12%, 10% and 8% respectively) (Figure 2.6). The rest of the uses were similar to those reported in Figure 2.5 except for the use as a charm for winning court cases.

2.4.5 Commercialisation of *Berberis holstii*

The sale of *B. holstii* was confirmed by 23 respondents. On the other hand, 28 respondents mentioned that it is not sold, while 18 were not aware of whether it was sold or not. Of those who said it was not sold, 12 indicated that this was due to the conviction that, as a medicinal plant, it should be provided freely to people needing it. Two people said *B. holstii* is not sold because possession of it alone is illegal.

One person mentioned that the plant is not sold because its collection is done under supervision of DNPW staff; hence people only collect enough material for their patients. One respondent said *B. holstii* is not sold because it is readily accessible in his area, which is near the park.

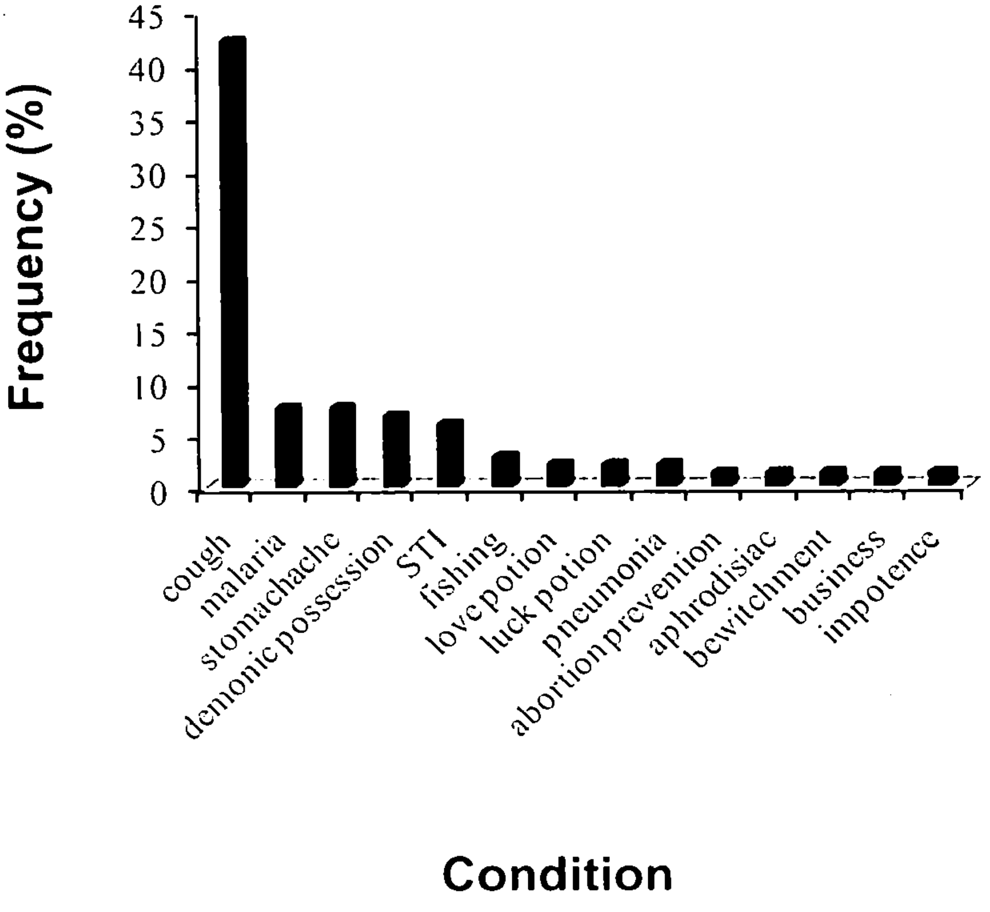


Figure 2.5: Most commonly reported uses of *Berberis holstii* that respondents had personally used (n = 115).

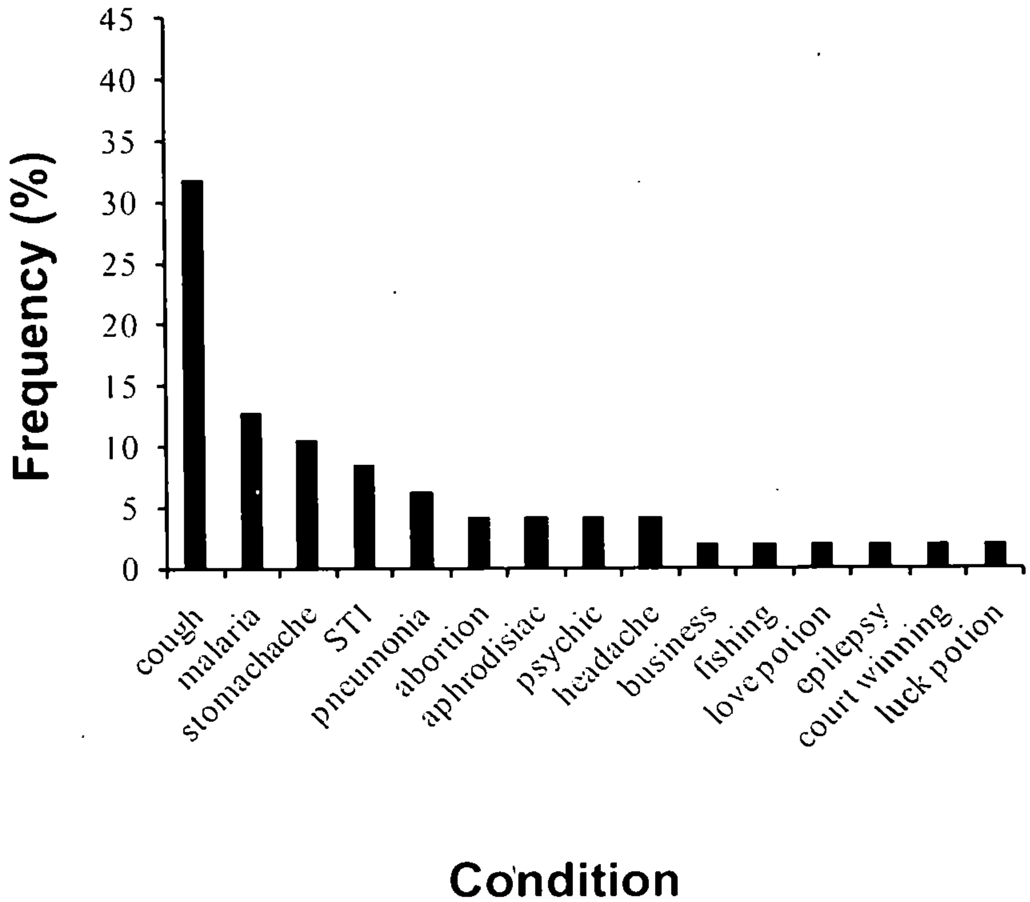


Figure 2.6: Most commonly heard uses of *Berberis holstii* (n = 48).

Of the people who said that *B. holstii* is sold, fourteen attributed it to the fact that it is scarce but useful. One respondent ascribed its sale to the expensiveness of conventional drugs. One respondent said the reason for the commercialisation of *B. holstii* was that people did not know it well enough to identify and collect it on their own.

With respect to buyers of *B. holstii*, fifteen respondents said these were ordinary villagers, while three respondents mentioned TMPs. With regard to sellers, nine refused to disclose their identities. The rest (three each) mentioned DNPW staff, TMPs and market-based vendors.

Respondents mentioned seeing *B. holstii* being sold in Rumphi and Mzuzu markets (50 and 100km, "as the crow flies", from Chilinda Camp, respectively). Some mentioned orders being placed by customers from as far away as Lilongwe and Blantyre (380km and 590km, "as the crow flies", from Chilinda Camp respectively). Roots were the most commonly sold part (mentioned by 21 respondents)–in the surveys, discarded stems and branches of uprooted plants were occasionally found next to the holes produced when dug out. Two respondents also mentioned seeing the stem's bark being sold, and one respondent each mentioned leaves and already prepared root infusion.

The only price information gathered in this study was for roots and prepared infusion. Depending on the amount, the prices ranged from 0.2 GBP to 7.2 GBP (Table 2.5). PRA discussions suggested that the prices increase with distance from Nyika. In areas near the park (e.g. Nthalire) people give the plant for free, but as the distance increases (e.g. in Ntchenachena and Njalayankhunda), the prices can become exorbitant.

Table 2.5: Price ranges for raw roots and root infusion of *Berberis holstii.*

Product sold	Quantity	Price range per quantity (MK)	Price range per quantity (GBP equivalent)	Number of responses
Root	5cm long	<50-100	<0.2–0.4	4
	30-45cm long	50-2000	0.2–7.2	3
	>45cm long	50-100	0.2–0.4	1
Infusion	300ml	50-100	0.2–0.4	1

1.00 British pound sterling (GBP) = 278.00 Malawi kwacha (MK) - as of 22nd May 2008 (NBS Bank, 2008).

2.4.6 Collection: associated beliefs, frequency and mode of transport

PRA participants, but not individual respondents, stated that collection of *B. holstii* was associated to ceremonial beliefs, and that rituals needed to be observed for the plant to be effective. The most widespread belief was that the soil should not be put back after the roots are dug out. Other beliefs included harvesting it while naked, excavating it from the eastern and western sides and using the plant a day after collection.

For those that collect it, they travelled distances ranging from 10km to 150km (The maximum straight distance across Nyika is 85km, but walking distances are obviously longer) (Table 2.6). Chilinda and Kaulimi were the sites most collected by respondents. Many respondents also mentioned being aware of other people collecting at Chilinda (Figure 2.7). Although the respondents mentioned that they did not collect *B. holstii* frequently, most were reluctant to disclose how often they collected it.

Of the ten people who disclosed information on collection, five mentioned that they collected it depending on demand, two collected it fewer than six times a year and two collected it 6-12 times a year. The quantities collected per trip were generally small (<1kg) (Figure. 2.8). However, people from more distant communities (e.g., Njalayankhunda) disclosed that they collected as much as 28kg per trip.

54% of the respondents accessed the places mentioned in Figure 2.7 by car while 38% walked and 8% used bicycles. Out of those that travelled by car, 69% used DNPW vehicles and 31% used public transport. The latter was costing between 1.00GBP and 4.00 GBP (i.e. MK300.00–MK1, 000.00). The public transport, however, did not reach the exact locations where *B. holstii* exists. People therefore had to walk further to find *B. holstii.*

Table 2.6: Distance travelled by questionnaire respondents to collect *Berberis holstii*.

Site	Maximum distance	Frequency (no.)
North Rumphi	150	2
Nganda	150	1
Nthakati	150	1
North Rukuru bridge	150	1
Mpopoti	120	1
Vitumbi junction	120	1
Balilo valley	100	1
Domwe junction	100	1
Juniper forest	100	1
Mpata	100	1
Kasaramba junction	90	1
Chosi	80	1
Chilinda	60	5
Airstrip	60	1
Police Transmitter	60	2
Lake Kaulimi	55	5
Juniper road	10	1

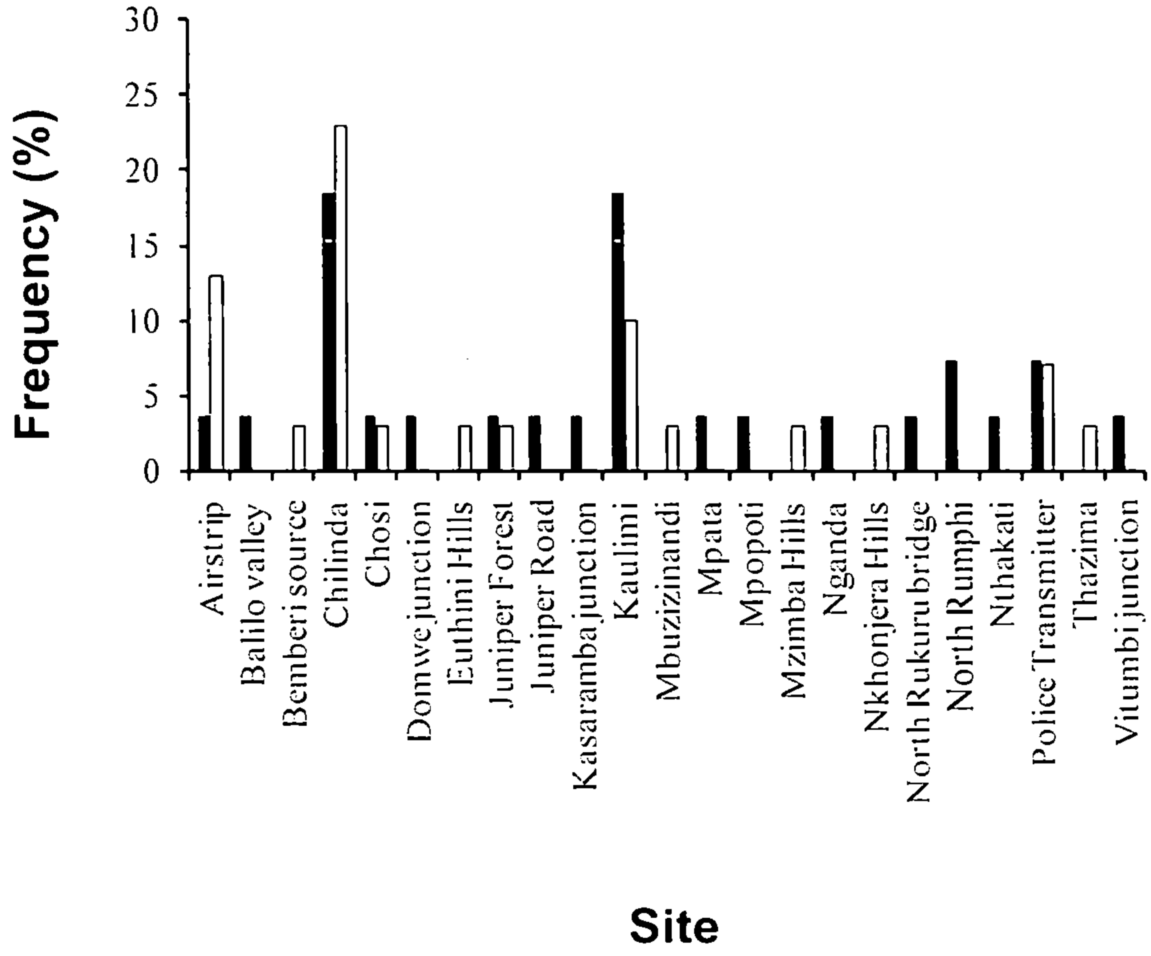


Figure 2.7: Areas of collection of *Berberis holstii* by respondents (dark bars) and people they know of (clear bars).

The PRAs indicated that it took at least 3 hours to walk from Therere to the nearest place where *B. holstii* is found. In Ntchenachena, the nearest place was only one hour walk but the farthest that people reported travelling was 10 hours. In Njalayankhunda, the minimum travelling time was 14 hours and the maximum was three days. In Chilinda, people walked for a maximum of one hour to collect *B. holstii*. Most often they collect *B. holstii* while on duty, hence use official vehicles.

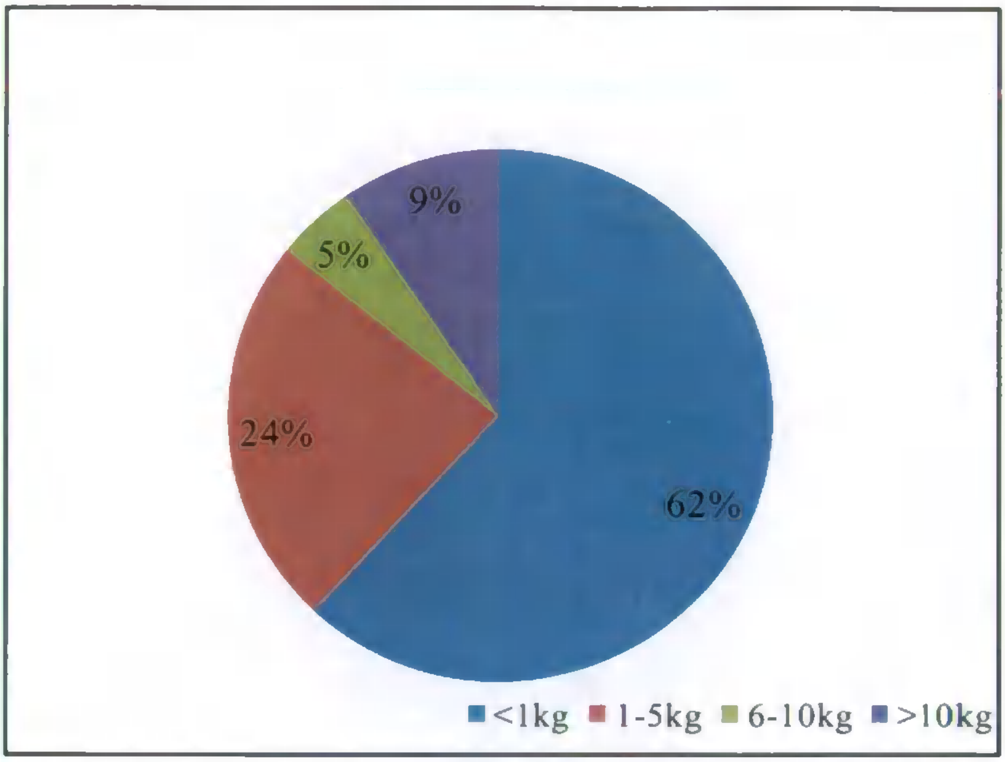


Figure 2.8: Amount of *Berberis holstii* collected per incursion into the park.

2.4.7 Preparation and application methods

The root was the most commonly used part of the plant (reported by about 90% of the respondents). About 80% of the respondents said other people used roots too (Figure 2.9). 84% of respondents said *B. holstii* was prepared as a root infusion and the rest said it is consumed raw.

The infusion was prepared by either soaking or boiling the roots. The infusion was either drunk, poured/rubbed over the body or added to porridge. With the exception of one respondent, all the others (29) said there were no associated side effects. The side effect mentioned was possible miscarriage and even death as a consequence.

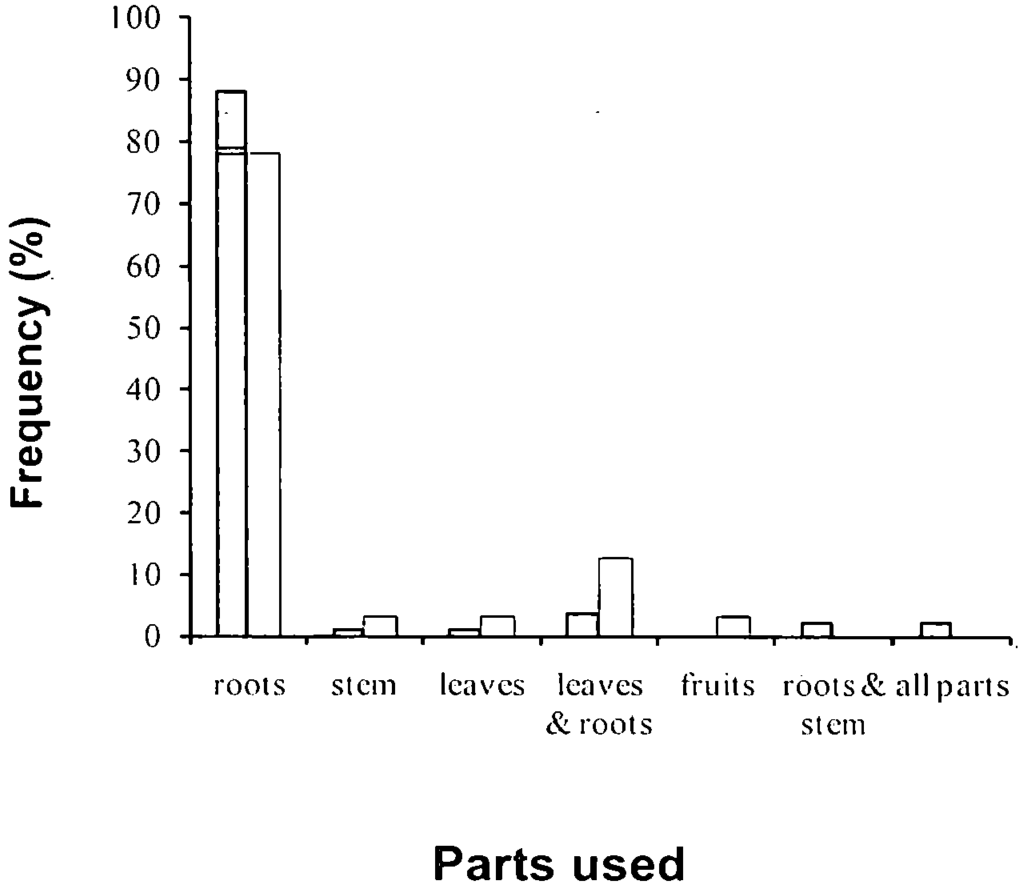


Figure 2.9: Parts used in preparation of *Berberis holstii*. Filled bars represent parts used by respondents. White bars are parts that respondents have heard are used by other people.

2.4.8 Storage techniques

67.5% of interviewed people mentioned that *B. holstii* cannot be kept for more than 2 years. 17.5% said it can be stored and remain effective for up to 5 years, and 15% stated that it can be kept for >5 years. The most common storage method was keeping it in a dry place (63%) (Table 2.7). When kept in a dry place, the plant was either in unprocessed or in powder form.

If the latter, the plant was either ground while raw, or after being boiled or roasted. One person said, however, that boiling accelerates decomposition.

Table 2.7: Methods used to store *Berberis holstii*.

Storage technique	**Frequency (%)**
Kept in dry place	63.63
Stored under the roof	14.55
Wrapped in paper	12.72
Stored in the shade	7.27
Kept in bottle	1.82

2.4.9 Availability

There was a general feeling that the plant was abundant before people were relocated from the park in 1978, but that it became scarce during the period following relocation until the end of the one party era in 1994. People believe that *B. holstii* became abundant again during the multiparty era, i.e., post-1994, and that it will continue to be abundant in the future (Figure 2.10). There were striking differences in the way PRA respondents perceived the level of abundance of *B. holstii*. Those people that were relocated from the park had a feeling that the plant is abundant, whereas those that reside and work in the park believe it to be scarce.

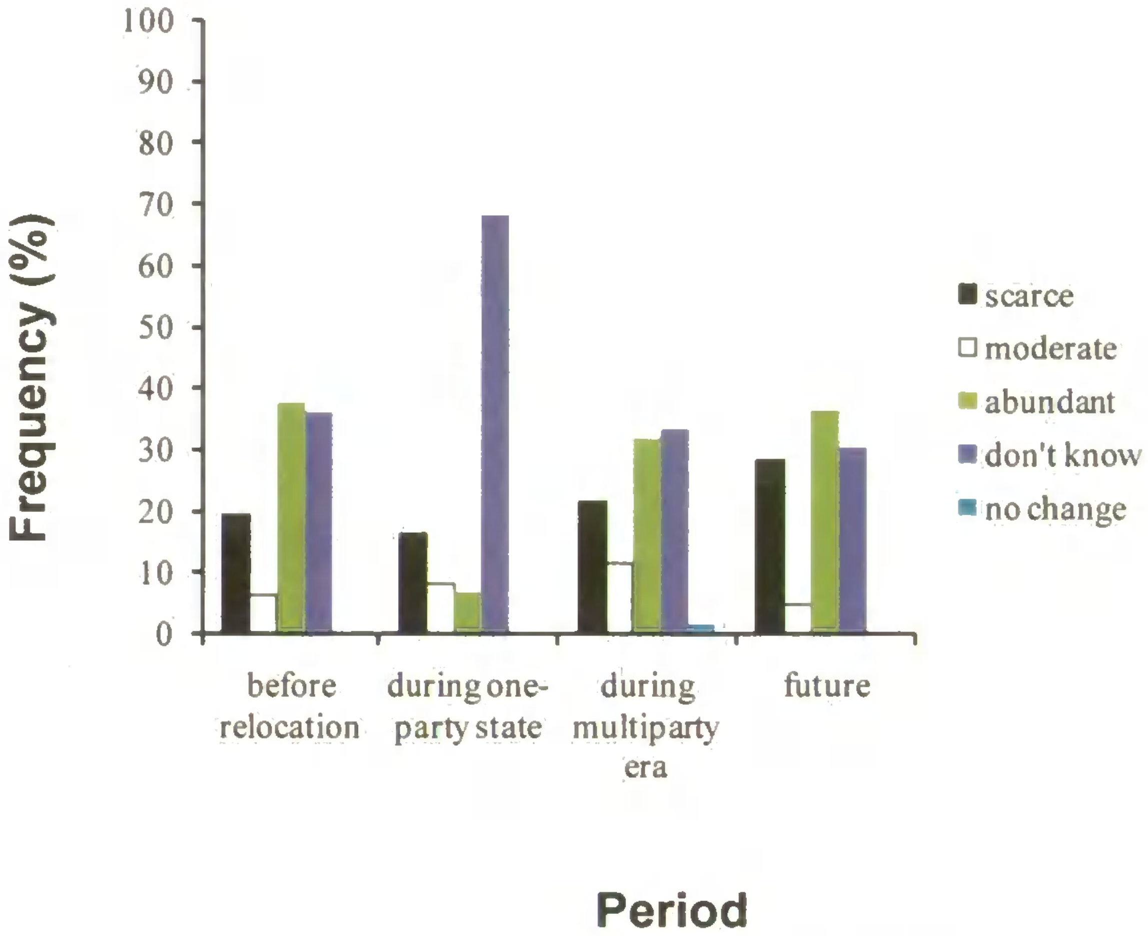


Figure 2.10: The perception of respondents on the availability of *Berberis holstii* over time.

2.4.10 Use of alternative plant species

Due to the restricted distribution of *B. holstii*, people reported that they use alternative species when *B. holstii* is not available. 57 plant species were reported as alternatives (Appendix 2.4). Of these, the most commonly mentioned were: *Cassia abbreviata* (common name: Muwawani), *Rhamnus prinoides* (Lupindura) and *Zanthoxylum chalybeum* (Zobara).

PRA participants mentioned that yellow colour and bitter taste were the guiding factors for determining whether or not a plant should be used as an alternative. Out of the five ailments for which *B. holstii* is commonly used, four (cough, malaria, stomach ache and pneumonia) had alternative plants. Cough had the highest number of alternative species (28) and no alternative species were mentioned for STIs.

2.4.11 Awareness of existing sustainable utilisation and conservation initiatives

Propagation initiatives

Thirty-nine out of 65 respondents had not heard of the *B. holstii* propagation programme conducted by DNPW a few years ago, in which seedlings were distributed freely. Eleven people however said that they would like to propagate *B. holstii* if they knew how. Six people felt that attempting to propagate *B. holstii* was pointless because it cannot survive outside the plateau. They also thought that seedlings that DNPW distributed did not survive because people did not get enough information on how to cultivate the plants. Three people believed there was no need to cultivate *B. holstii* because it is readily accessible from their villages. Finally, two people said that obtaining the propagating material (i.e., seeds) was difficult.

Policy instruments

Forty-five people expressed knowledge of policies related to conservation of park resources. Two of these mentioned that none of the existing policies was specific to *B. holstii*. The people who claimed to have knowledge on policies specific to *B. holstii* mentioned the following:

i. A collection permit is required (mentioned by 28 respondents)

ii. Collection must be supervised by DNPW staff (7 respondents)

iii. *B. holstii* should not be harvested in excess (5 respondents)

iv. Collection of *B. holstii* is forbidden because it is endemic/indigenous to the park (2 respondents)

v. Collection is allowed in medical emergencies (1 respondent)

All of the respondents that said were knowledgeable of policies said that DNPW is the body that instituted the policy. However, according to PRA's participants, DNPW's concern is animals, not plants.

Twenty respondents said there were harvest quotas for *B. holstii* and 25 said there were none. For the former, there were disparities in the quantities mentioned. Seven stated 1-5kg and three said the amount is decided on-site by DNPW staff. One respondent each mentioned 6-10kg and >10kg. Two respondents said there is no harvest quota specific to *B. holstii*.

2.5 Discussion

2.5.1 Demographic particulars of respondents

It was not possible to pre-select a sample comprising equal number of males and females or to sample in proportion to the sex ratio in the districts. Thus, the sample was biased towards males because more men than women are employed by the park, more men than women are found in bomas (rural development growth centres) and traditional healers are also usually men.

The distribution of interviewees by tribe, religion and education reflected the composition of the population in this part of Malawi.

2.5.2 Knowledge, attitude and practice surrounding utilisation of *Berberis holstii*

The study found that *Berberis holstii* is in demand. The study also found that, despite the plant being restricted to Nyika, its demand extends as far away as Lilongwe and Blantyre (380km and 580km, respectively).

Awareness of the existence and uses of *B. holstii* has remained reasonably constant during the one party regime and the multiparty era (46% and 42% respectively). Despite the broad concern that the introduction of democracy would lead to unsustainable utilisation of biological resources in Malawi (Malawi Government, 1998), this link was not confirmed in the case of *B. holstii*. It seems that relocation of people in 1978 did not affect the appreciation that people have of the plant. It appears that, faced with lack of alternative resources, people's awareness of the importance of park resources increased.

As in most indigenous knowledge, the tradition of collecting and using *B. holstii* is passed on orally from generation to generation (Kokwaro, 1995, van der Geest, 1997). Traditional healers, on the other hand, guard this information more jealously.

Over 70% of those aware of the existence of *B. holstii* have used it. Most likely, this popularity is due to its many reputed uses and properties. In a country like Malawi, where healthcare facilities are not only insufficient but also inaccessible (McCoy *et al.*, 2005), use of traditional remedies for primary healthcare is widespread.

Other uses, such as treatment for demonic spiritual possession (vimbuza) must be regarded in the context of the prevailing beliefs and culture in the northern region of Malawi. Vimbuza is a common phenomenon in this region especially among Tumbukas and it is treated by dancing and drumming (Friedson, 1996). Considered as a spirit disorder, vimbuza is associated with acute delusional state, dissociation disorder and depressive neurosis (Peltzer, 1989).

2.5.3 Commercialisation of *Berberis holstii*

Economic benefits accruing from *B. holstii* are difficult to establish. Whatever its magnitude, the economic incentive encourages its exploitation. It is a sign of benevolence among the local people that *B. holstii* is often provided free of charge, even by some TMPs who are then paid in kind.

2.5.4 Collection

The collection method employed, uprooting of the entire plant, is highly destructive and prevents the plant from resprouting. Also, because bigger plants are preferred (see Chapter 4), the potential reproductive contribution of these plants to population growth is suddenly eliminated. Finally, the practice of not putting back the soil after collection also eliminates the chances of small portions of the root to take hold and resprout.

Although it is difficult to test the veracity of the responses regarding the amount and frequency of collection, observations over three years of study of sample populations suggest the intensity of harvest is relatively small and sporadic. Nonetheless, there is also evidence that occasionally a large proportion of the plants in a locality are excavated, leading to local extinction (see Chapter 3). How long it may take for these populations to recover is a question that is analysed in Chapter 4.

2.5.5 Storage

It is encouraging that the roots can last, and presumably remain active, for a period of at least two years. Damaschin (2006) states that roots of *Berberis* species have a maximum shelf life of two years.

2.5.6 Utilisation of alternative plant species

Although numerous plant species are used as alternatives to *B. holstii,* demand for the latter is still high, possibly due to the belief that *B. holstii* is more effective.

2.5.7 Awareness of existing policy and its implications on conservation of *Berberis holstii*

The fact that *B. holstii* is not protected by law was evident in the people's responses. Many people were aware of policies related to conservation of park resources in general and not specifically for *B. holstii.* The disparities in the responses given by the respondents who claimed to know about policies specific to *B. holstii* suggest the spread of misinformation.

2.6 Summary

This chapter documented the uses of *Berberis holstii,* as well as people's perception of its availability. In addition, collection, application, management and associated beliefs were explored. The chapter also assessed the extent of the demand placed on *B. holstii* and the misinformation on conservation-related policies. The following findings were significant:

i. A total of 47 uses were documented, thirty of which were medicinal. Cough, malaria, stomach ache, sexually transmitted infections and pneumonia were the topmost reasons for its use.

ii. Roots were the main product sought (mentioned by >90% of the respondents). Their collection was associated with uprooting and widespread belief of not putting back the soil after excavation.

iii. 57 plant species were used as alternatives. *Cassia abbreviata, Rhamnus prinoides* and *Zanthoxylum chalybeum* being the most common ones. Despite availability of alternative species, there is a preference for *B. holstii.*

iv. *B. holstii* is popular and on demand. The demand extends beyond the areas immediately adjacent to the park reaching the southern and central regions of Malawi. Despite the high demand, there is no policy to safeguard the species.

Chapter 3

Floristic and environmental characteristics of the habitats

3.1 Introduction

As indicated in Chapter 1, *Berberis holstii* has a restricted distribution in Malawi. Within the region where it is found, the precise places where the plant grows are not known and the characteristics of the habitats have not been assessed. Thus, this chapter investigates the distribution of *B. holstii* within Nyika National Park and the characteristics of the habitats where it is found.

In order to understand this distribution, historical, biogeographical and ecological requirements need to be investigated. This is particularly important in the conservation of rare species (e.g., Dinsdale *et al.* 1997). *Berberis holstii* is a rare plant species not only in Malawi, but throughout its distribution range (Bekele-Tesemma *et al.*, 1993). Its montane distribution in East Africa is further limited to the edges of forest patches. In the context of Nyika, information on the exact locations in which particular plant species grow is important (Burrows and Willis, 2005) as well as the floristic composition and environmental characteristics of the habitats (Dowsett-Lemaire (1985), and White (1983) as cited by Brass (1954)). Such information is also important to understand the factors contributing to the diversity of Nyika (Department of National Parks and Wildlife, 2004).

In addition to understanding the factors that determine the distribution of *B. holstii* in Nyika, the present study generated information on the characteristics of the soils which is sorely needed in Nyika (Meadows (1983). Furthermore, by mapping the known distribution of an important species in Nyika, the study sets the base for monitoring the populations.

This should also aid in their future management (Bell, 1987, Supernaugh, 1984, Bell and McShane-Caluzi, 1984). Maps not only serve a communication and analysis purpose, but assist in planning and policy-making in natural resource and environmental management (Millington and Alexander 2000, Chinzinga, 1984).

3.2 Objectives of the study

The overall objective of this study was to investigate the distribution of *Berberis holstii* in Nyika and the underlying factors that might explain the causes of the restricted distribution. Specific objectives included:

i. Locating and mapping the places where *B. holstii* is found.
ii. Documenting the plant species that grow in association with *B. holstii.*
iii. Assessing the environmental factors that characterise the habitats where *B. holstii* grows.

3.3 Materials and Methods

3.3.1 Mapping the distribution of *Berberis holstii*

The Peace Parks Foundation of South Africa has developed a GIS map for Malawi which includes Nyika National Park. Using ArcGIS 9, this map was used as the base for locating the *B. holstii* sites identified in this study.

Additional localities were obtained from the literature and herbarium specimens from National Herbarium and Botanic Gardens of Malawi (NHBGM).

3.3.2 Site identification

Based on herbarium records, information generated through ethnobotanical interviews and consultations with the Department of National Parks and Wildlife (DNPW) staff and local communities, places reported to have *Berberis holstii* were visited to verify its presence. Additional places which were encountered during the field visits were also included. These visits took place in July 2004, October 2004, April-June 2005, and May-June 2006.

3.3.3 Sampling

Because *Berberis holstii* generally grows in small areas, 10m × 10m quadrats were used to sample the areas where it was found. When the area was $\leq 100m^2$, one quadrat was laid down. When the area was $>100m^2$, ~25% of the total area was sampled through random sampling employing 10m × 10m quadrats. A total of 65 sites were visited and sampled.

3.3.4 Collection of plant species data

All flowering plant species present in the plots were recorded. These records were of presence/absence, not abundance.

Identification was done on-site and the only plant specimens that were collected were those that could not be identified in the field (Dowsett-Lemaire, 1985). The on-site identification was done by experienced technicians from NHBGM. The plant species that were difficult to identify in the field were collected, pressed in plant presses, dried and taken to NHBGM for identification. The list of plant species names that was generated was verified using Binns & Logah (1972), W^3TROPICOS database (http://mobot.mobot.org/W3T/search/vast.html), Burrows & Willis (2005) and Southern Africa Botanical Network (2000). Plants were classified into family, genus, three higher taxa (dicotyledons/monocotyledon/seedless), habit (herb/shrub/tree), life-cycle (annual/biennial/perennial) and growth form (acaulescent/ erect/prostrate/scandent/straggling) using Marinelli (2004) and Heywood & Chant (1982). *B. holstii*'s cover (at each site) was coded employing Braun-Blanquet scale as follows: 1 = <1% cover, 2 = 1-5%, 3 = 6-25%, 4 = 26-50%, 5 = 51-75%, 6 = 76-100% (Kent and Coker, 1992).

3.3.5 Collection of environmental data

Geographical position of each site (altitude, latitude and longitude) was recorded using a Meridian Gold Magellan Geographical Positioning System (GPS). Based on Dowsett-Lemaire's (1985) classification, the zone between 2200m and 2500m above sea level comprise the central plateau. Therefore, altitude was subdivided into lower (<2200m), central (2200m-2500m) and upper plateau (>2500m).

Due to concerns that *B. holstii* might be threatened (Department of National Parks and Wildlife staff pers. comm.), the sites were also classified in terms of disturbance by visual inspection into animal browsing, fire, infrastructural development (e.g., road maintenance) and uprooting. An index of impact of disturbance was also recorded for each site: none (negligible impact - <25% individuals affected), minimal (25-50% individuals affected), substantial (50-75% individuals affected) and severe (>75% individuals affected). The sites were also classified by habitat type (roadside, forest patch edge, grassland and rocky), and state, relative age, and cover of *B holstii.* Since aspect is an important factor in vegetation studies (Kent and Coker, 1992, Longley, 2005), orientation was recorded for each site. The orientation, determined by a SILVA clinomaster compass, was linearised into aspect employing the following formula:

cosine($180^{\circ} - x$) +1.1; where x = orientation in degrees from north (Wang *et al.*, 2007).

Information on soil was collected from selected sites (40). Soil was collected from two profiles (15cm and 30cm depths) and analysed at Bvumbwe Agricultural Research Station in Malawi in accordance with the Mehlich 3 soil analysis protocol (Chilimba, 2000). The following variables were determined: % silt, % clay, soil class, % Organic matter, % Organic Carbon, % Nitrogen, as well as pH, Phosphorus, Potassium, Calcium and Magnesium concentration.

3.3.6 Community classification

The list of plant species associated with *B. holstii* was sorted into a species by site matrix while the environmental data was organised into an environmental factor by site matrix. Multivariate methods were used to analyse the data (Abbot, 1996, Kent and Coker, 1992). Specifically, PC-ORD 5 (McCune and Mefford, 1999) and PRIMER 5 (Clarke and Warwick, 1994) were employed. PC-ORD was used in community classification through Two-Way Indicator Species Analysis (TWINSPAN), and the analysis of the relationship between environmental variables and vegetation was performed through Canonical Correspondence Analysis (CCA) biplots (Kent, 2005).

For PC-ORD, the environmental data was standardised to ensure that it was recorded in the same measurement units as species data (Kent, 2005). Because soil was not sampled in all sites, two separate analyses were conducted to investigate the correlation between communities and environmental variables. One analysis excluded soil-related variables (65 sites) while the other included them (40 sites only). The number of variables in each dataset was 11 and 22, respectively. In the latter, 14 variables with the lowest correlation were excluded from the analysis. PRIMER was used to investigate differences in plant species composition between sites through Analysis of Similarity (ANOSIM), Non-metric Multi-Dimensional Scaling (MDS) and Similarity Percentages (SIMPER).

3.4 Results

3.4.1 Distribution of *Berberis holstii*

Berberis holstii was reported to exist in ninety-four sites. Of these, thirty-six were mentioned during the Participatory Rural Appraisal and forty-seven were mentioned during questionnaire interviews. Three sites were reported in herbarium records and literature and the remaining eight were located during field surveys. Four of the sites were outside Nyika National Park, three of them in nearby hills (i.e. Phwezi, Euthini and Kalembo in Rumphi, Mzimba and Chitipa districts, respectively). The remaining site was in the Southern Region of Malawi in Neno, Mwanza district. Out of the 71 sites that were visited (inside the national park), five sites no longer have *B. holstii* and one could not be traced. All the 65 sites that were confirmed to have *B. holstii* were within the plateau (Figure 3.1 and Appendix 3.1). More than 80% of these sites were within the central plateau (i.e. between 2200–2500m above sea level) and only 1% were above 2500m altitude.

3.4.2 General characteristics of the sites

B. holstii was found growing in different types of habitats (Appendix 3.2). In terms of habitat type, 32% of the sites were forest edges, 20% were inside the forest, and 17% each on roadside and rocky substrate. Only 14% were in grassland (Figure 3.2).

There was no indication of preference with respect to aspect, 23 sites had a north-easterly aspect, 20 a south-westerly aspect, 12 north-westerly and 10 south-easterly aspect.

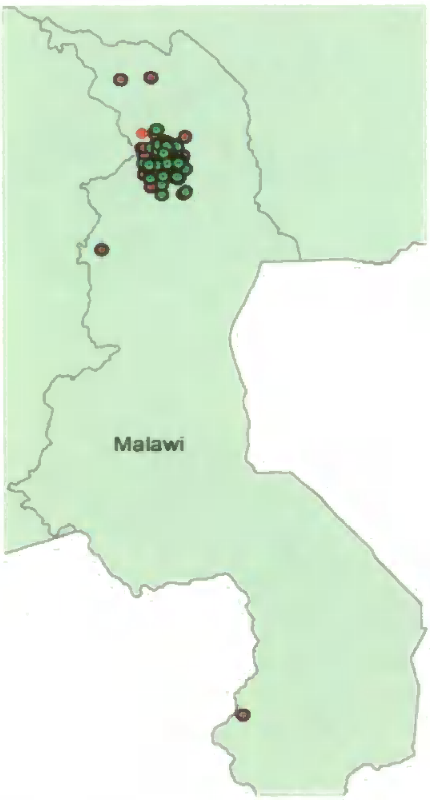


Figure 3.1: The distribution of *Berberis holstii* in Malawi. Green circles= sites visited and confirmed to have *B. holstii;* purple circles = sites reported but not visited; Red circle = site visited but *Berberis holstii* not traced.

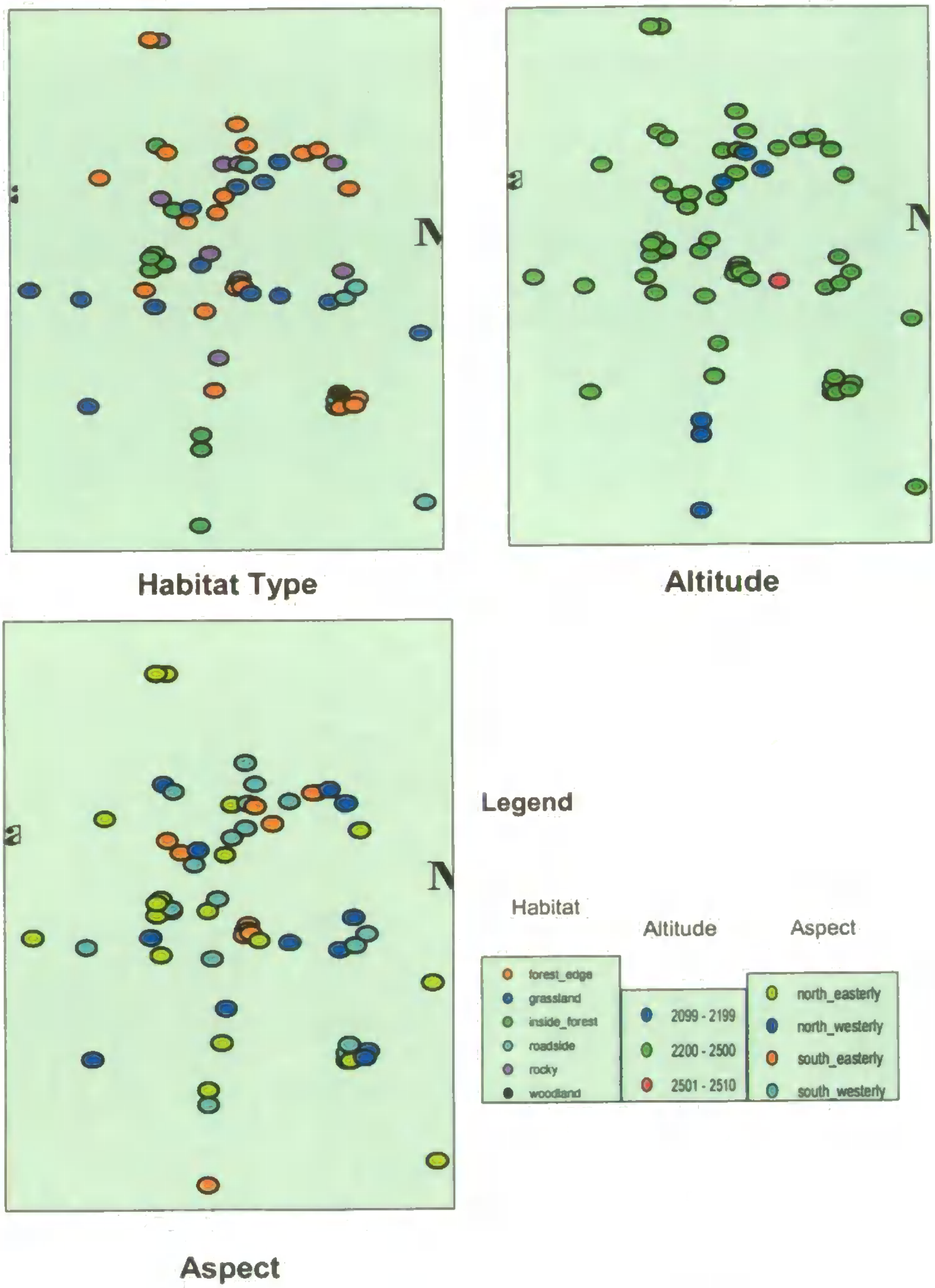


Figure 3.2: General characteristics of the sixty-five sites in Nyika National Park.

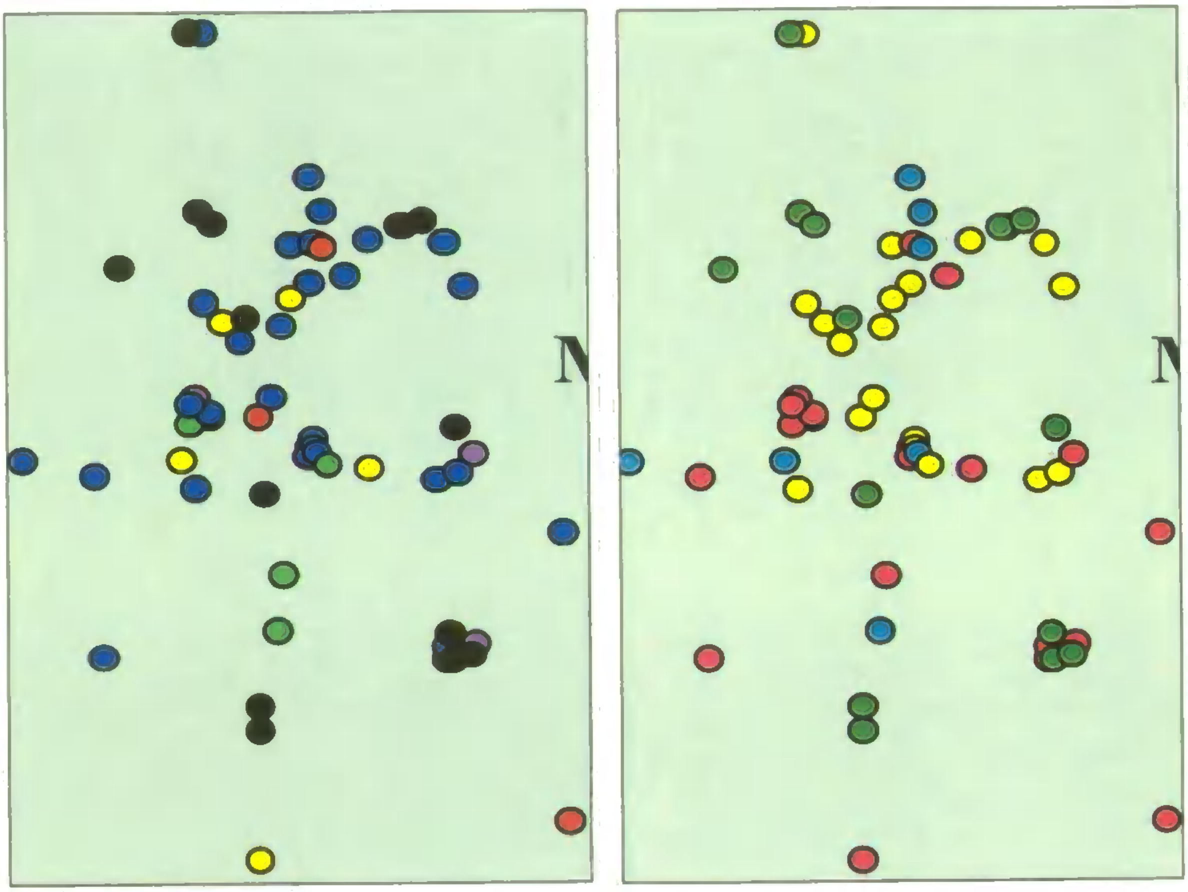
3.4.3 Disturbances affecting the sites where *Berberis holstii* grows

Different types of disturbance affected *B. holstii* (Appendix 3.2). The main sources were anthropogenic and comprised fire, harvesting and infrastructural development (road construction and building work). Some of the populations were also affected by animal browsing. Fire and uprooting were the most frequent. Fire affected >60% of the sites while uprooting was evident in ~13% of the sites (Figure 3.3). All these disturbances had different impacts. In most cases, fire had an impact on >50% of *B. holstii* individuals. The disturbances also had an effect on the structure of *B. holstii* populations in terms of relative age, cover and state. 45% of the sites had young populations of *B. holstii* (sexually immature plants ≤1m tall), 31% had older (height>1m) but still immature populations and the remaining sites had adult, flowering/fruiting populations.

In terms of *B. holstii*'s cover, 36 sites had 1-5%, 14 sites had 6–25%, five sites had 26–50%, six sites had 51–75% and four sites had 76–100%. 60% of the sites had their *B. holstii* population regenerating after fire (Figure 3.4).

3.4.4 Floristic composition of the sites

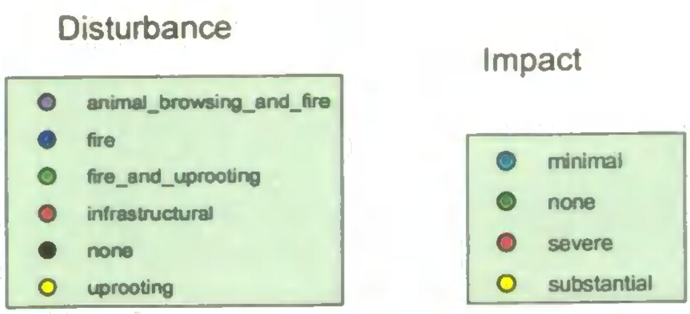
456 plant species were found growing in the *Berberis holstii* study sites (Appendix 3.3). 326 of these were dicotyledons; 103 monocotyledons, 25 seedless plants (Bryophytes and Pteridophytes) and 2 gymnosperms.



Type of disturbance **Impact of disturbance**

Figure 3.3: Incidence of disturbance in sixty-five sampled populations.

Legend:



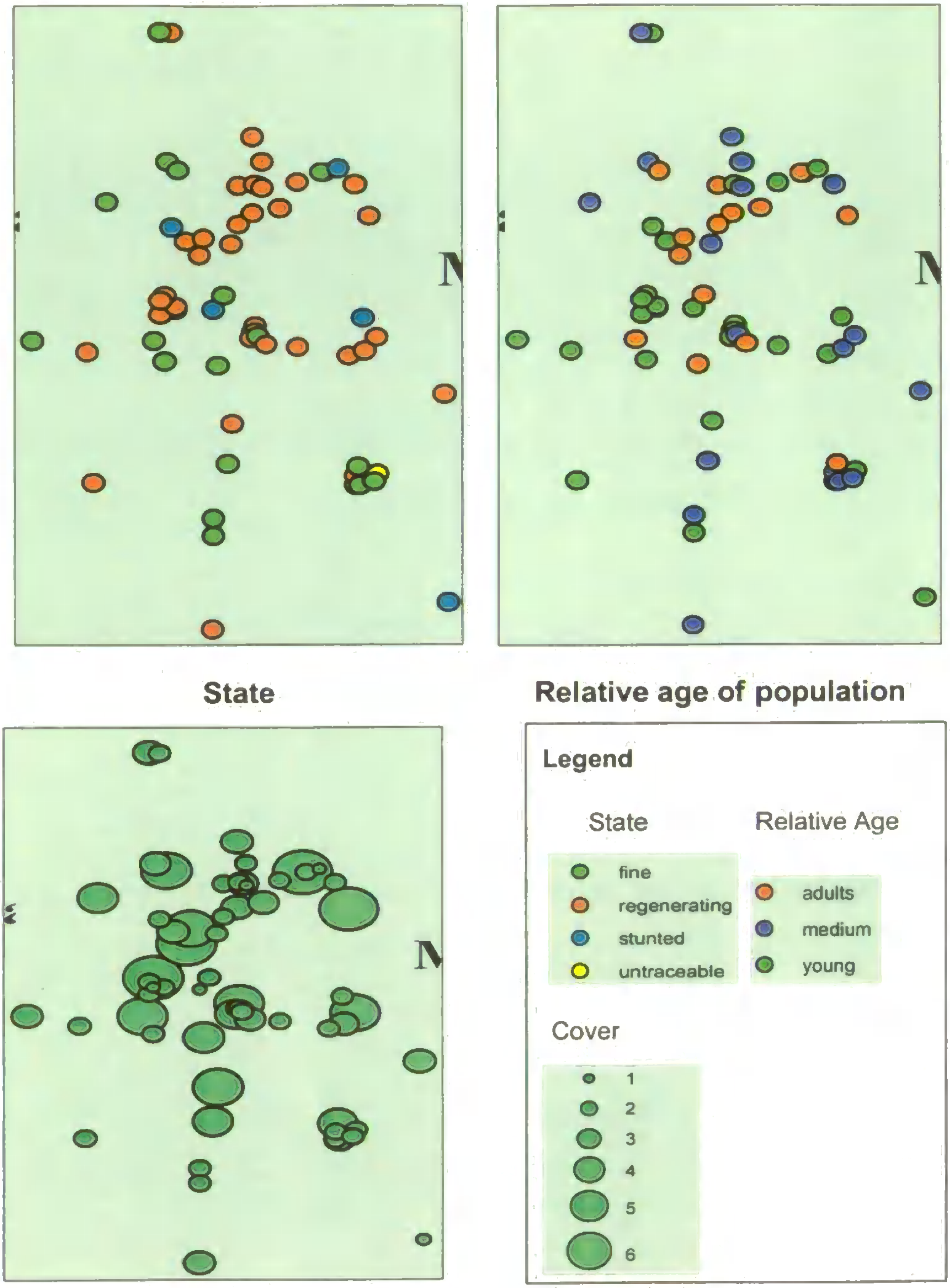


Figure 3.4: Characteristics of *Berberis holstii* in the sixty-five study sites.

The plant species belonged to 80 families with Asteraceae, Poaceae, Fabaceae and Lamiaceae being the most frequent (61, 60, 42 and 38 plant species, respectively). The plant species belonged to 228 genera of which *Helichrysum*, *Panicum*, *Cyperus*, *Plectranthus* and *Eragrostis* contained the highest number of species (16, 12, 12, 11 and 8 species respectively). At species level, *Pteridium aquilinum, Brachythrix sonchoides, Artemisia afra, Helichrysum odoratissimum* and *Setaria sphacelata* were the most frequent. They occurred in 50, 47, 38, 32 and 32 sites, respectively.

3.4.5 Soil properties

All 40 sites analysed had slightly acidic soils (pH ~6). With the exception of one site with low N (0.08%-0.12%), all the sites had intermediate proportions of N (0.13%–0.20%). Thirty-two of the sites had high (>2.35%) Organic Carbon (OC) and the rest had medium levels of OC (0.88% – 2.35%). Magnesium was high (0.6–3cmol/kg) in 38 sites and low in two (0.2–0.5cmol/kg). Silt content was <10% in nine sites, 10–20% in 30 sites and >20% in one site. For clay, 24 sites had <10%, 13 sites 10-20% and 3 sites >20%. All the sites had low K and P (0.06–0.1cmol/kg and 9-18µg/g, respectively). Calcium had intermediate levels (5–10 µg/g) in 39 sites and low levels (2.5–5 µg/g) in one. In terms of texture, ten sites had loamy sand soil, nine sites sandy loam, six sandy/loamy sand, four loamy sand/sandy loam, three sites each sandy clay loam, sandy loam/sandy clay loam and sandy respectively, and one site each sandy/sandy loam and sandy loam/loamy sand respectively (see Figure 3.5 on classification used).

Thirty-three sites had high Organic Matter content (OM>4%) and the rest had medium levels (1.5–4%) (Appendix 3.4 and Figure 3.6).

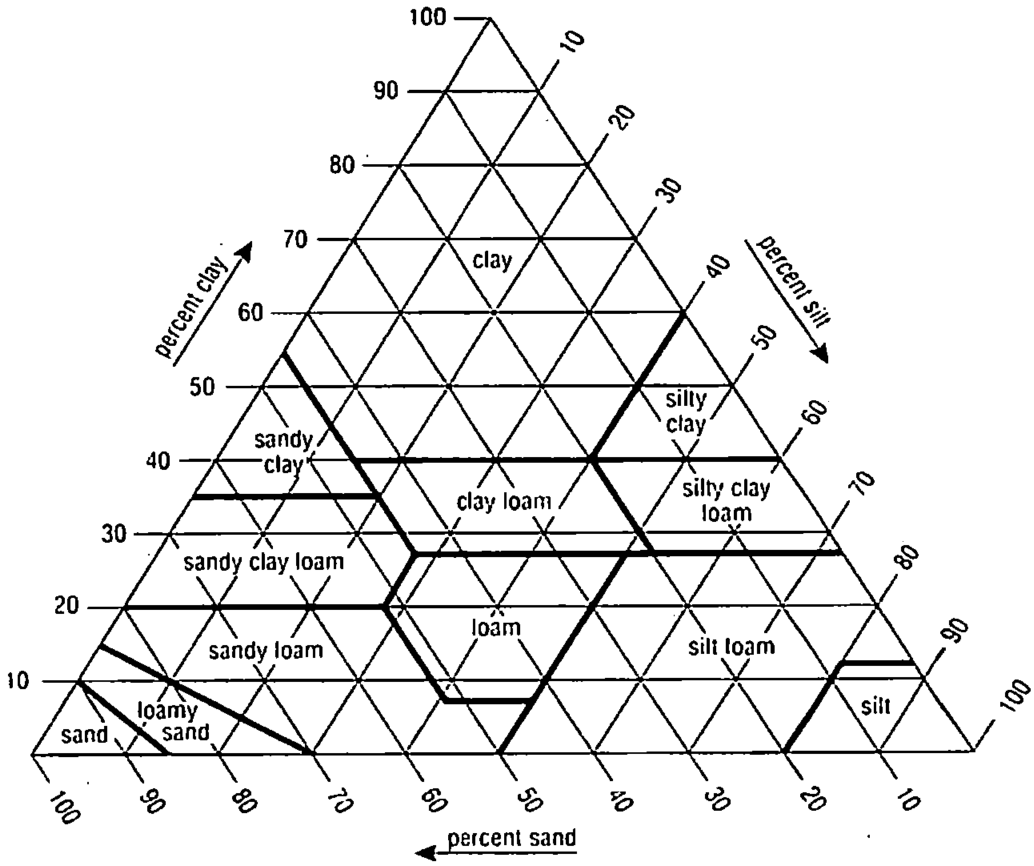


Figure 3.5: Ternary classification of soil textures (Source: Brady and Weil (2008).

3.4.6 Community classification

Based on Two Way Indicator Species Analysis (TWINSPAN) and ecological knowledge on Nyika, three site groupings were obtained. The first group comprised sites affected by fire. The second group contained sites affected by fire and infrastructural development. The third group consisted of sites affected by harvesting/up-rooting.

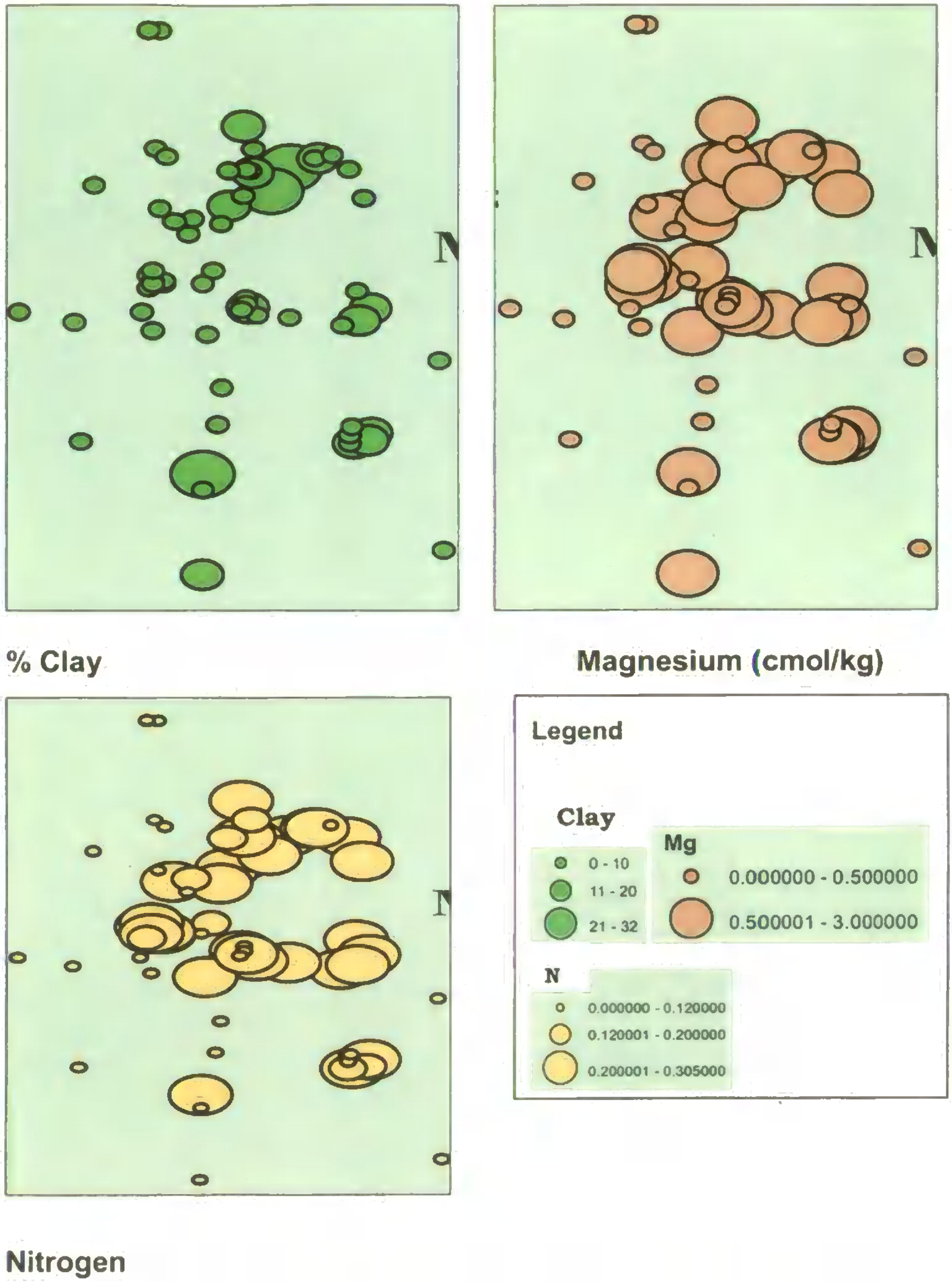


Figure 3.6: Soil properties of the forty sites sampled in Nyika National Park.

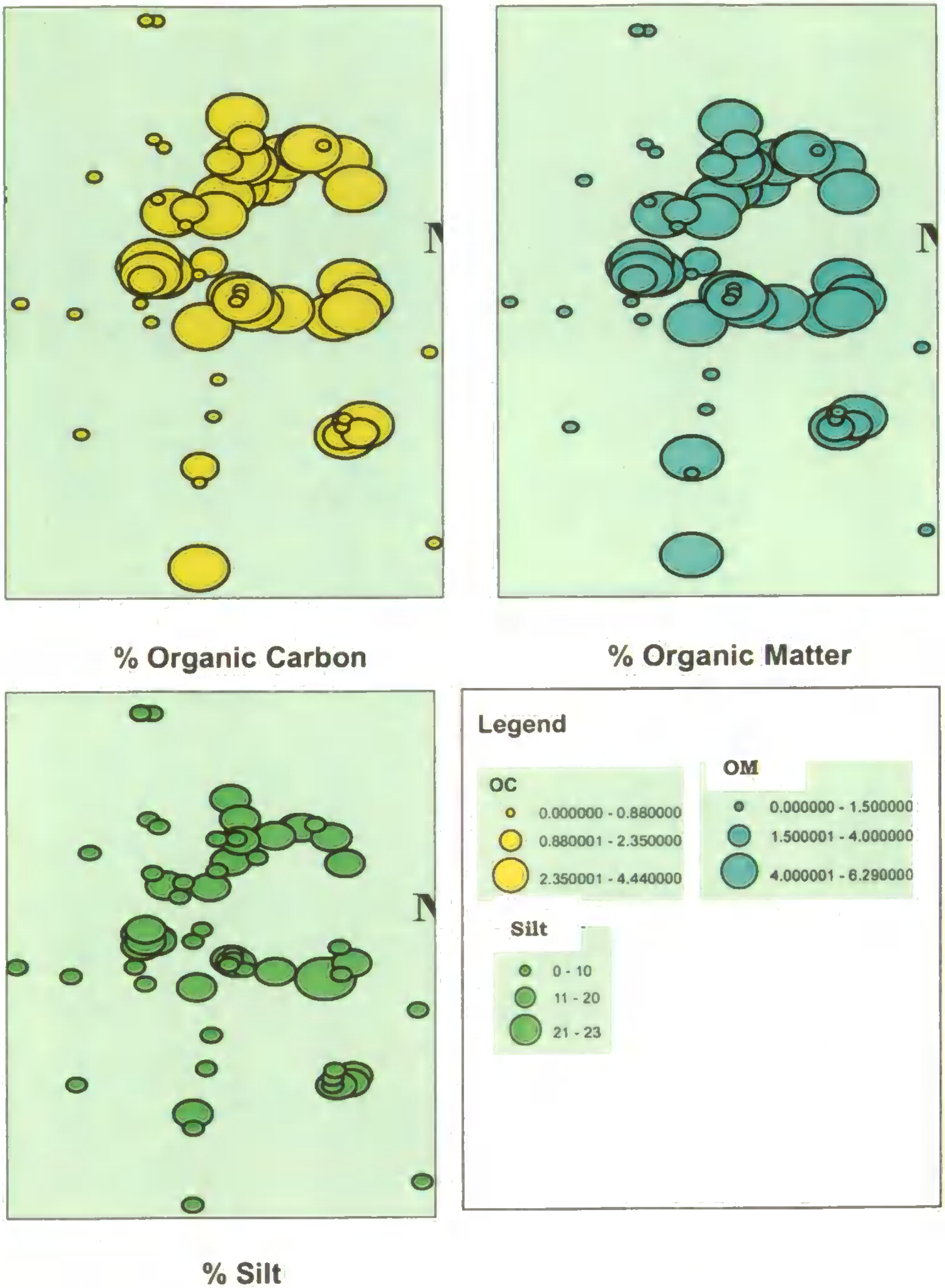
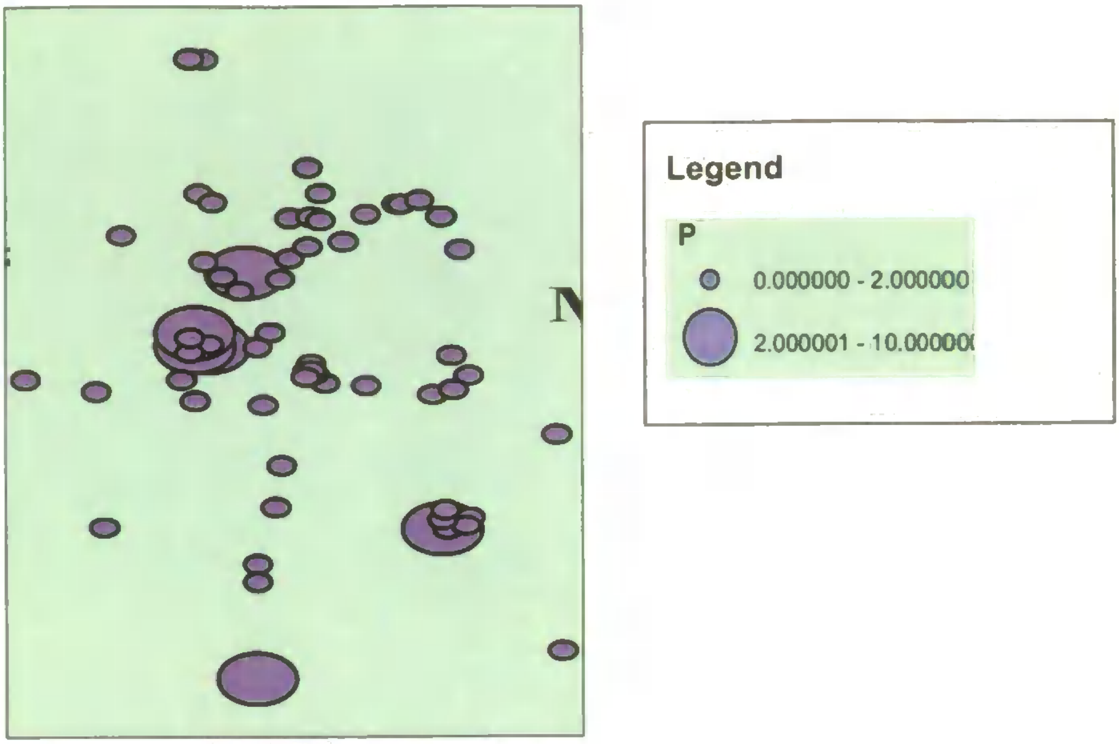


Figure: 3.6: Continued.



Phosphorus (µg/g)

Figure: 3.6: Continued.

In terms of vegetation, two main communities were identified: those dominated by members of the Asteraceae and those dominated by trees. Both groupings contained a high diversity of grasses and these allowed identification of sub-communities. In the Asteraceae community, the dominant grass genera were:

Sub-community 1: Agrostis, Andropogon and *Coelachne*

Sub-community 2: Eragrostis and *Hyparrhenia*

Sub-community 3: Digitaria, Panicum and *Setaria*

Sub-community 4: Eulalia

On the other hand, the tree-dominated community had three sub-communities dominated by the grass/sedge genera:

Sub-community 1: Eucomus, Setaria, Hyparrhenia and *Exotheca*

Sub-community 2: Carex and *Sporobolus*

Sub-community 3: Themeda

Grouping species in "guilds" (genus, family, major taxa, growth-form, habit and life-cycle), an Analysis of Similarity (ANOSIM) showed that, rather consistently, the sites were significantly different with respect to family, genus and major taxa guilds (Figure 3.7). In family, genus and major taxa guilds, the observed value of the test statistic R was >95% of the *R*s obtained by permutation of data matrix values. This lead to rejection of H_0, i.e., there are significant differences in species composition between the sites, as specified by the levels of these guilds (Figure 3.7). However, Similarity percentages (SIMPER) analysis revealed that, in order of importance, *Pteridium aquilinum, Helichrysum odoratissimum* and *Setaria sphacelata* made the greatest contribution to the similarity of the groupings of study sites.

For the different "guild" schemes, the level of similarity ranged from ~15% to ~80%. The guilds' similarity increased in the order: species < genera < family < growth form < habit < life-cycle <major taxa (Figure 3.8).

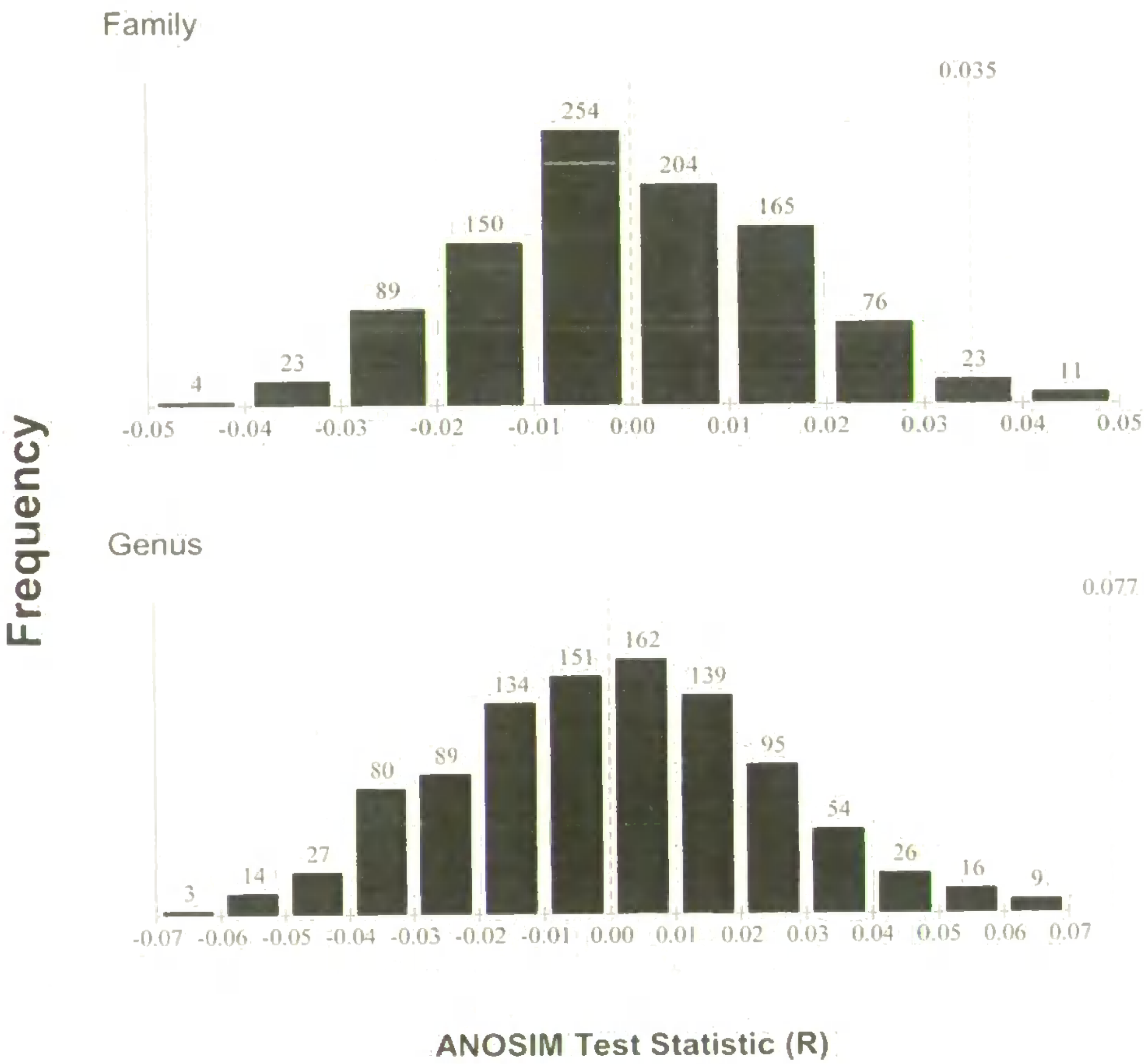


Figure 3.7a: Analysis of Similarity (ANOSIM) between the sixty-five study sites. The guilds are: family ($R = 0.034$, $p<0.196$) and genus ($R = 0.077$; $p<0.001$).

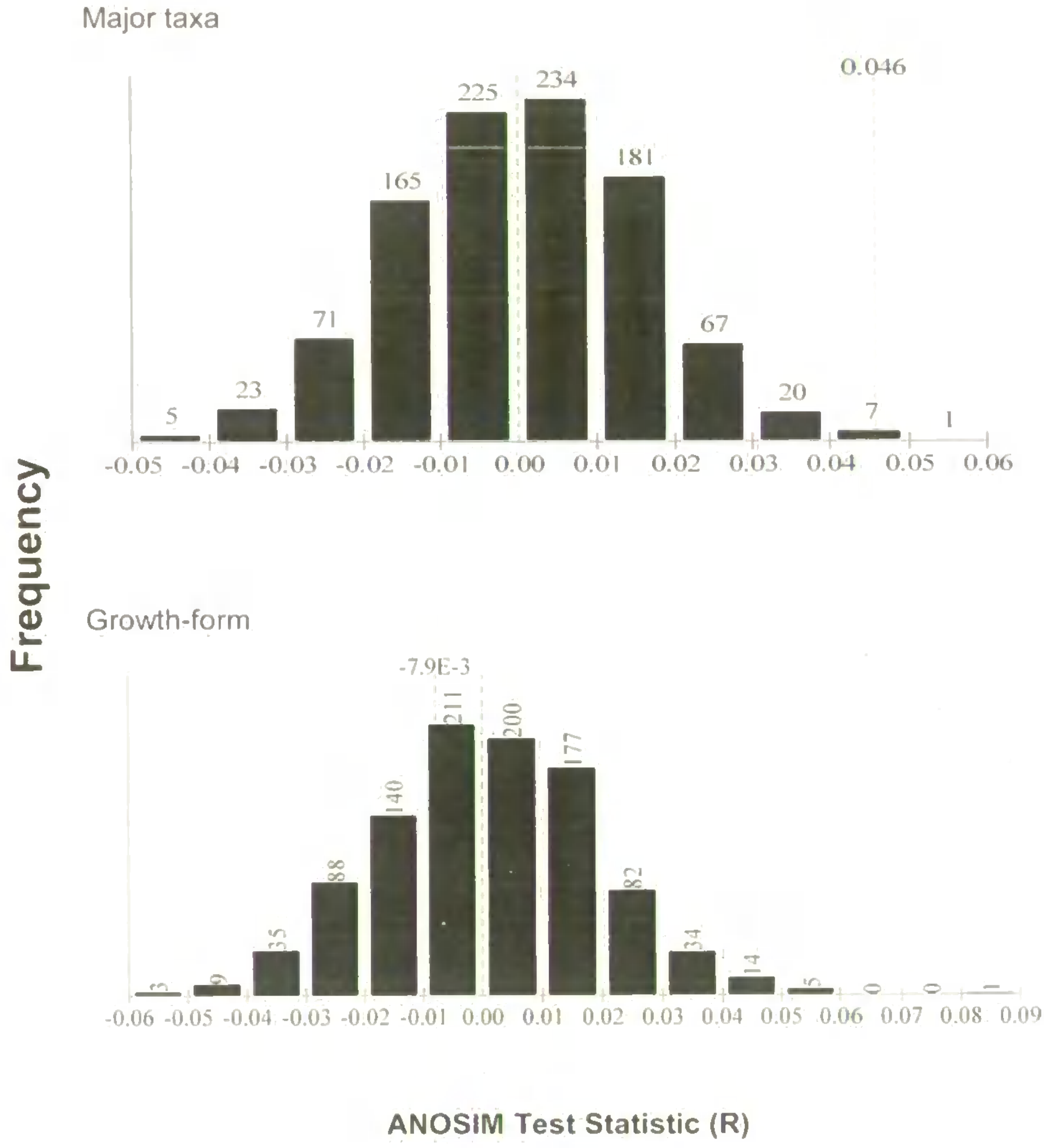


Figure 3.7b: Analysis of Similarity (ANOSIM) between the 65 habitats. The guilds are: growth-form (R = -0.008, p<0.686) and major taxonomic group (R = 0.046, p<0.002%).

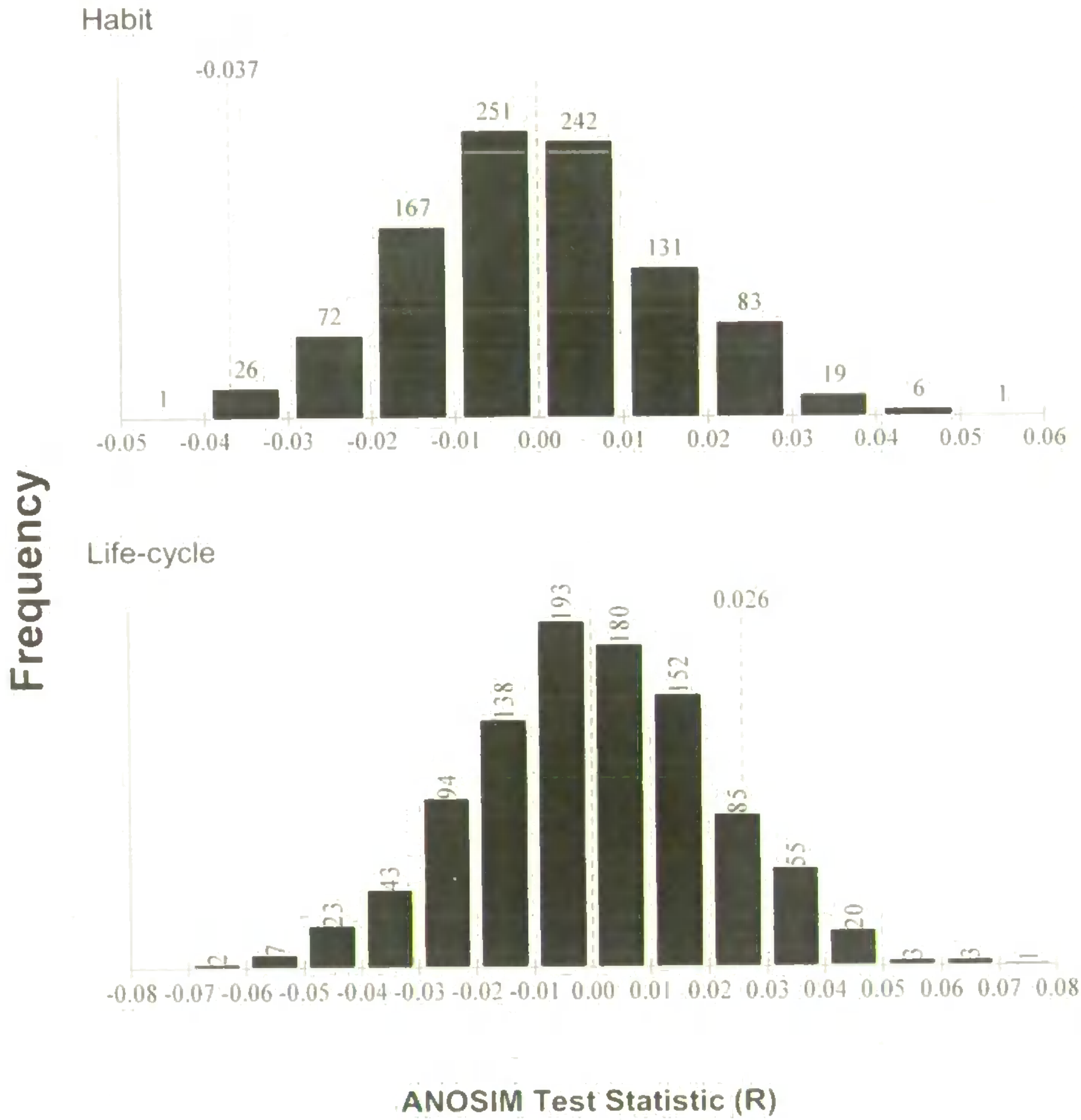


Figure 3.7c: Analysis of Similarity (ANOSIM) between the 65 habitats. The guilds are: habit ($R = -0.037$, $p<0.993$) and life-cycle ($R = 0.026$, $p<0.113$).

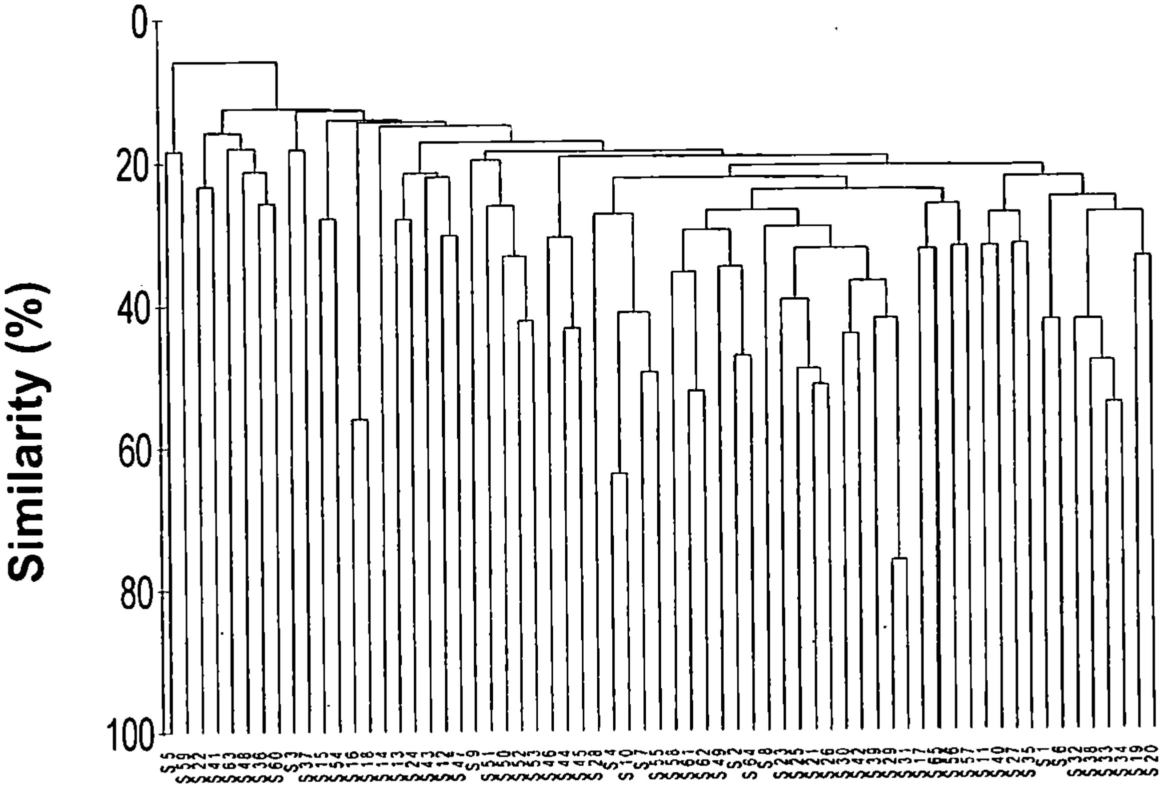


Figure 3.8a. Similarity dendrograms between sites when these are grouped according to species guild.

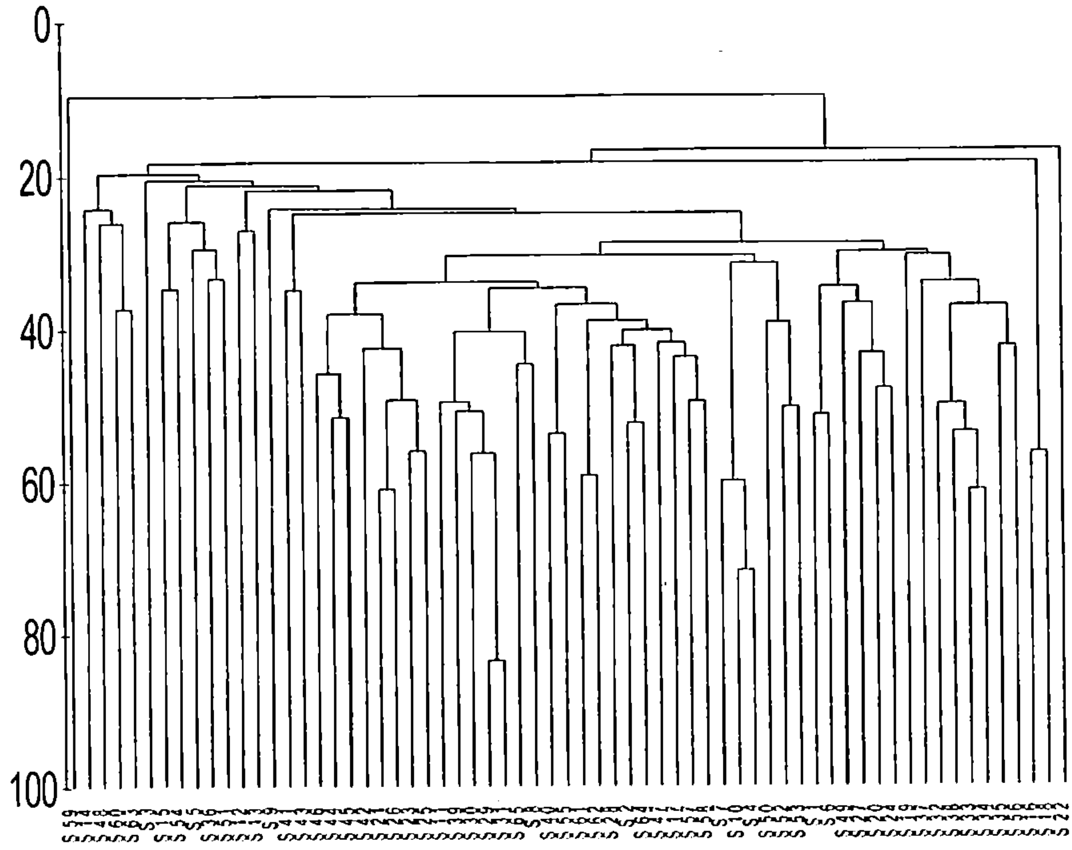


Figure 3.8b. Similarity dendrograms between sites when these are grouped according to genera guild.

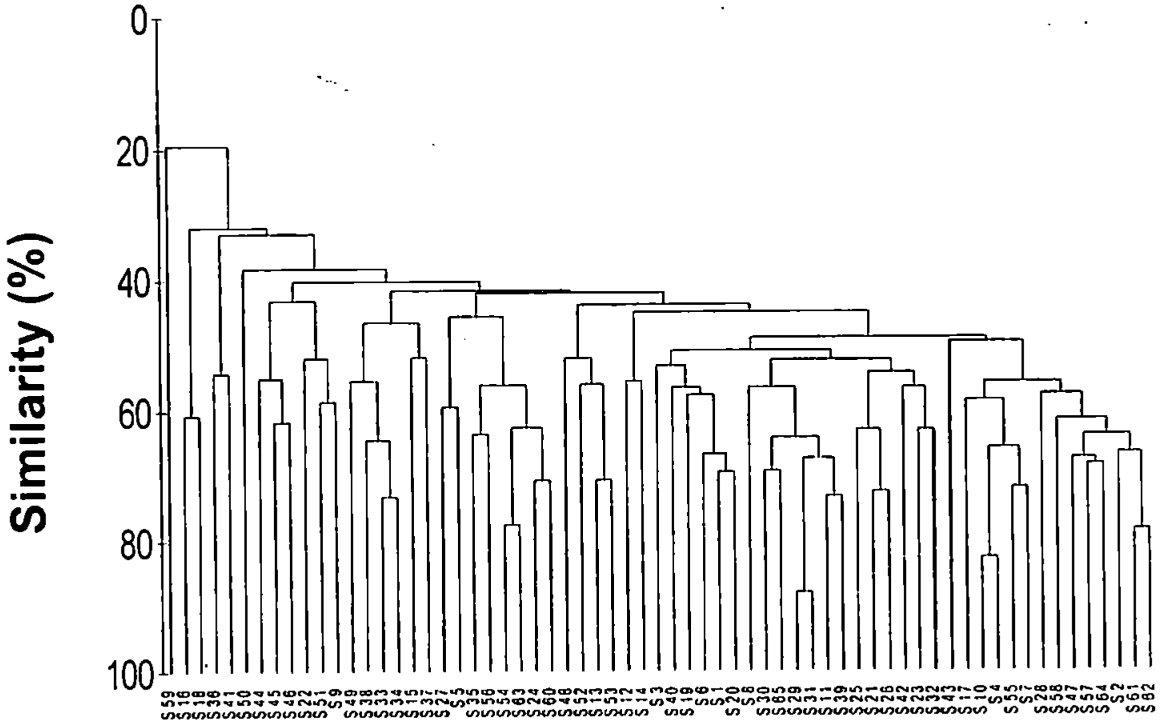


Figure 3.8c. Similarity dendrograms between sites when these are grouped according to family guild.

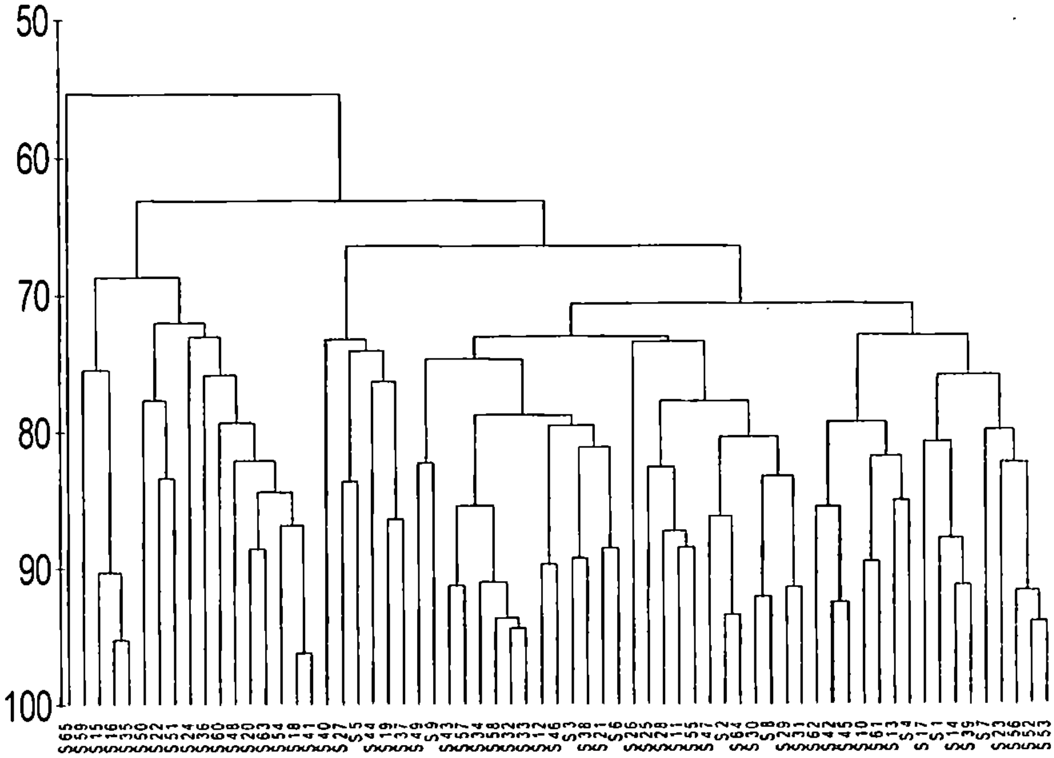


Figure 3.8d. Similarity dendrograms between sites when these are grouped according to growth form guild.

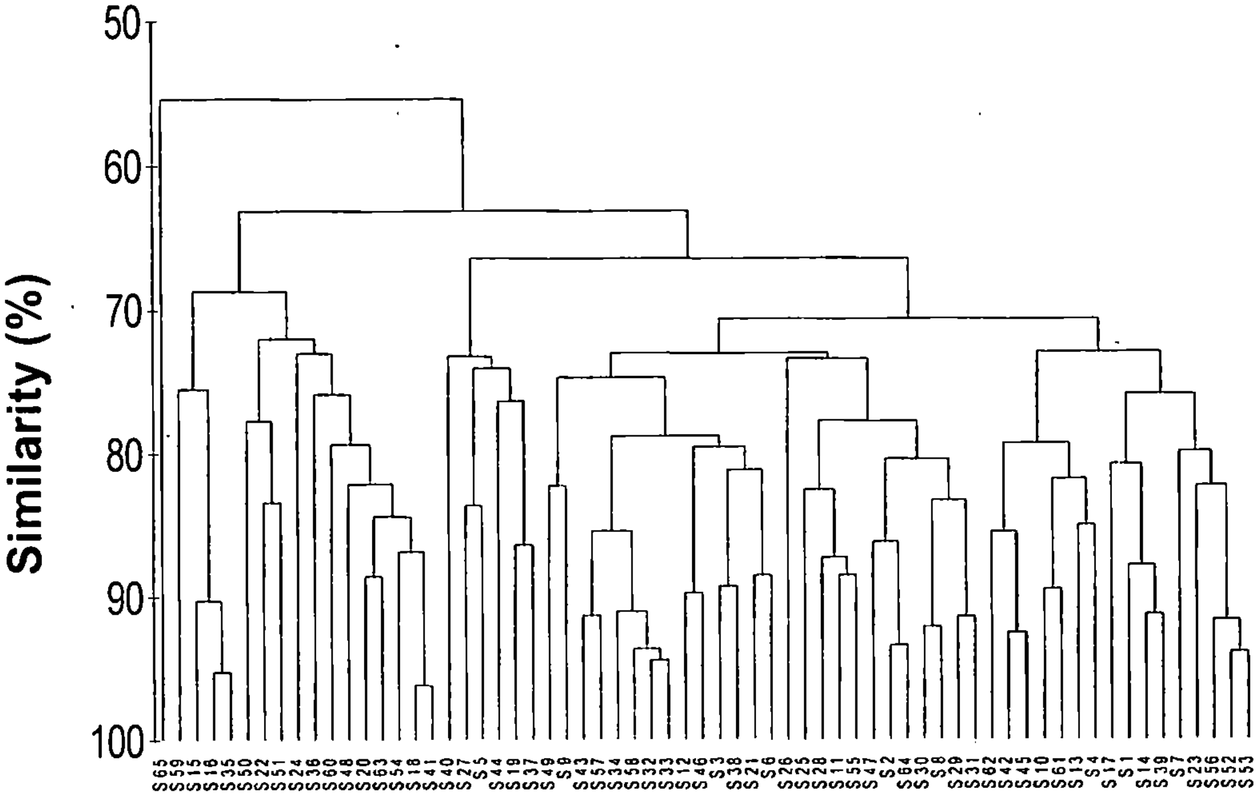


Figure 3.8e. Similarity dendrograms between sites when these are grouped according to habit guild.

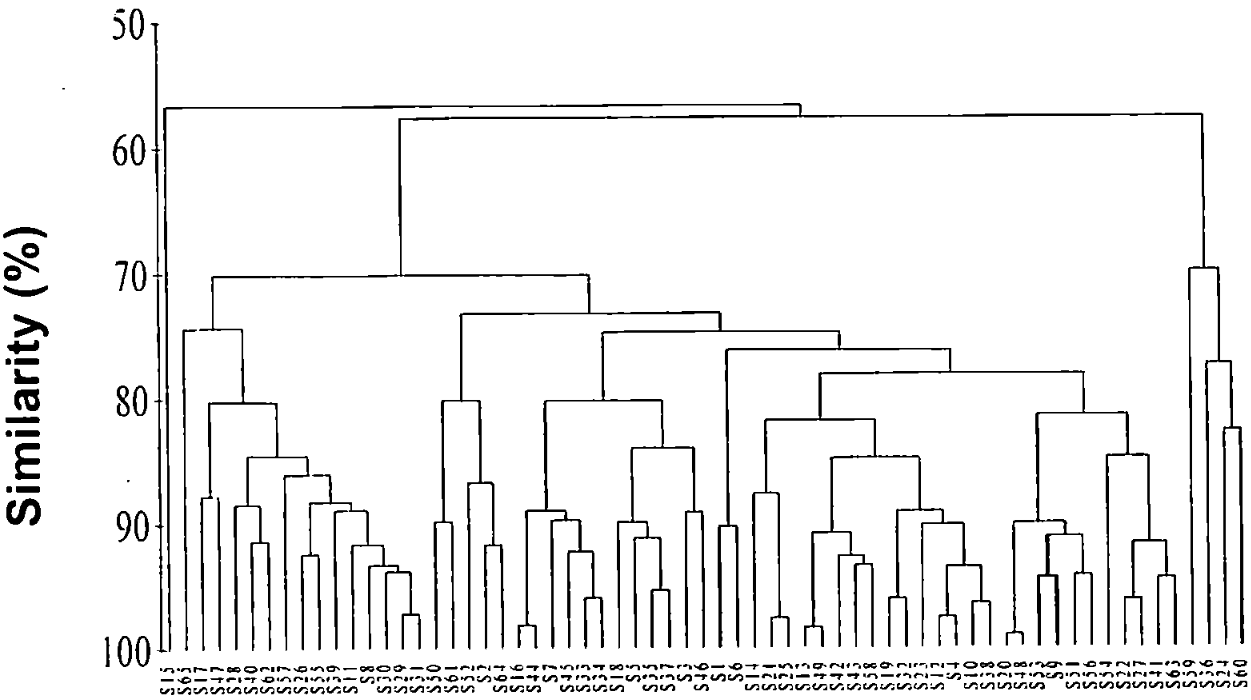


Figure 3.8f. Similarity dendrograms between sites when these are grouped according to life cycle guild.

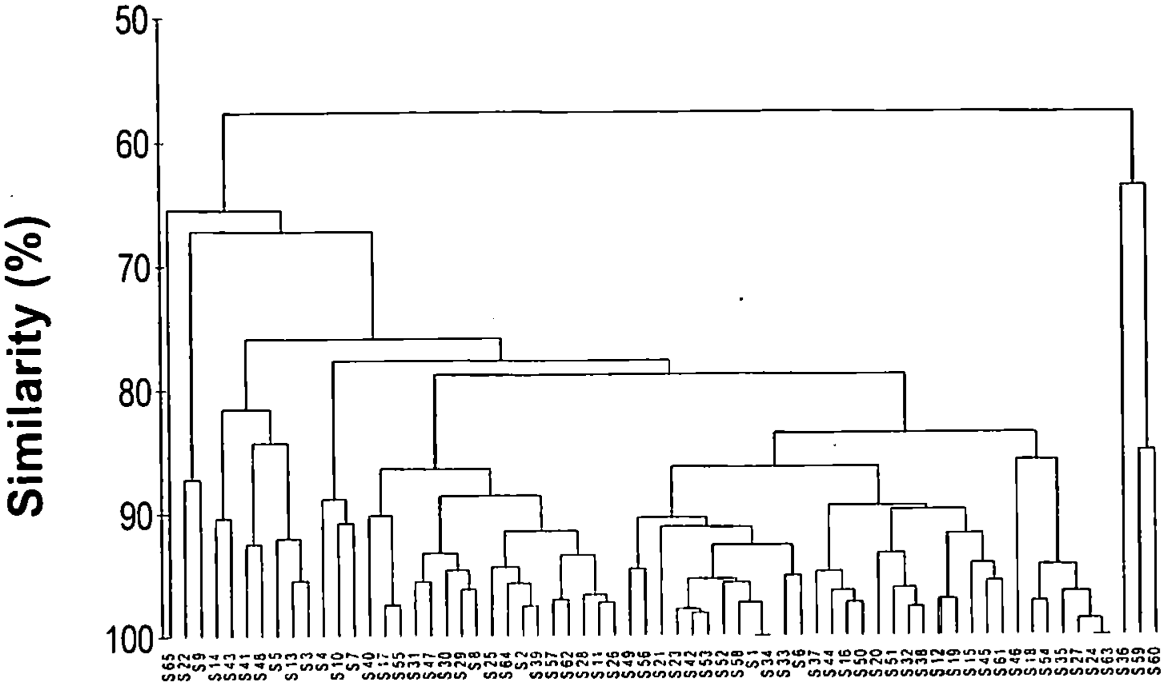


Figure 3.8g. Similarity dendrogram between sites when these are grouped according to major taxa guild.

3.4.7 Correlation between communities and environmental variables

When soil was not taken into account, an ordination employing Canonical Correspondence Analysis (CCA) revealed that altitude and longitude were the most important, uncorrelated variables (Figure 3.9). The rest of the significant variables in descending order were: aspect, *B. holstii*'s cover and volume (same level of importance), and latitude. Altitude was the most highly correlated with Axis 1 while aspect and *B. holstii* cover were highly correlated with Axis 2.

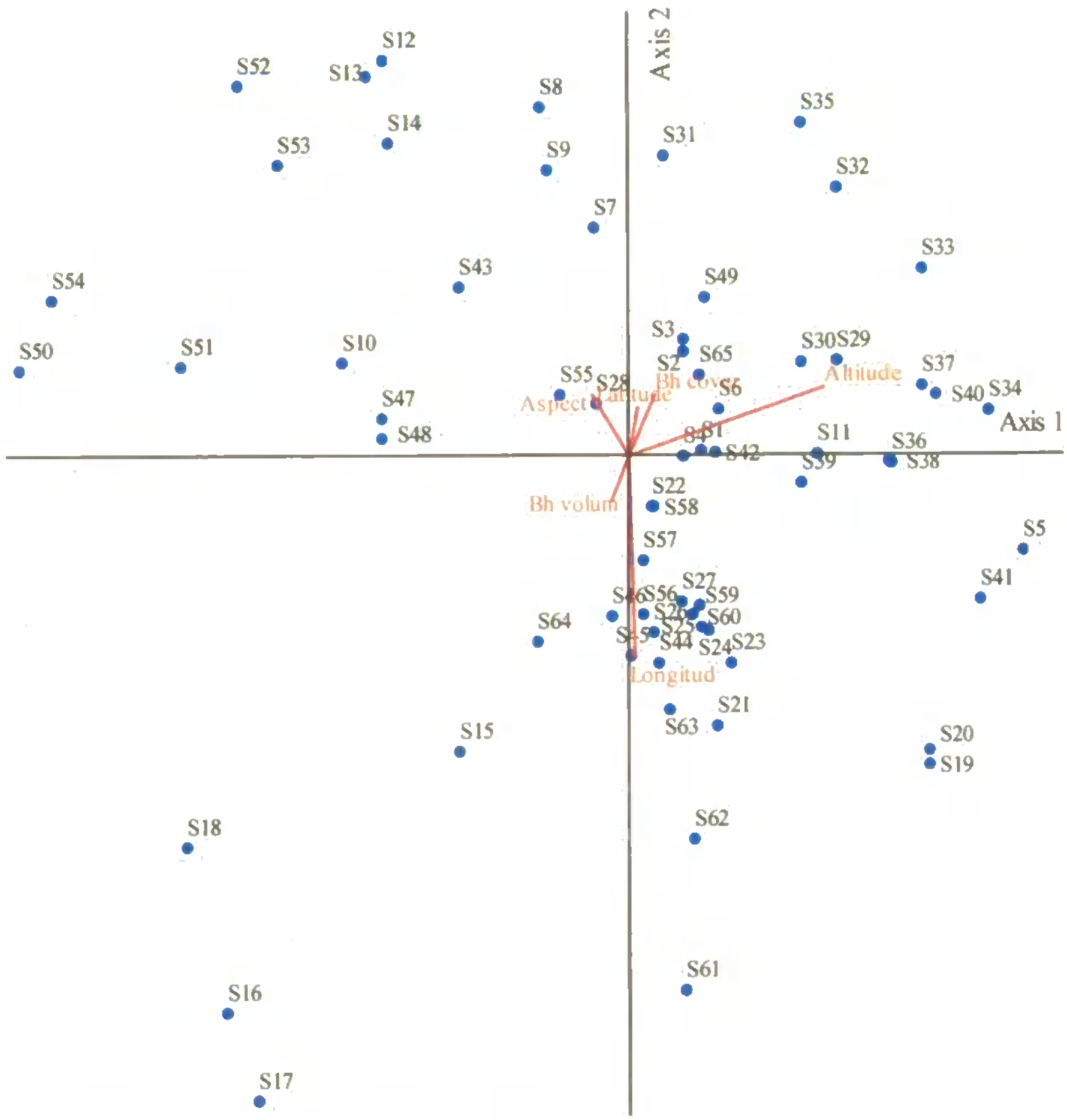


Figure 3.9: Canonical Correspondence Analysis ordination biplot of 65 sites employing 11 soil-unrelated environmental variables.

No variable was negatively correlated with Axis 1 but longitude showed negative correlation with Axis 2. Taking into account soil-related variables, the ordination revealed that the most important variables were, in decreasing order, magnesium, *B. holstii* volume, %clay, latitude and altitude, and %silt. Magnesium showed the highest correlation with Axis 1 followed by %Silt and Phosphorus, while pH showed the highest correlation with Axis 2. %Clay, and latitude showed negative correlation with Axis 1 while *B. holstii* volume was negatively correlated with Axis 2 (Figure 3.10). Although Figures 3.9 and 3.10 show different rankings in terms of importance of the environmental variables, altitude was the only factor that was correlated with Axis 1 in both scenarios.

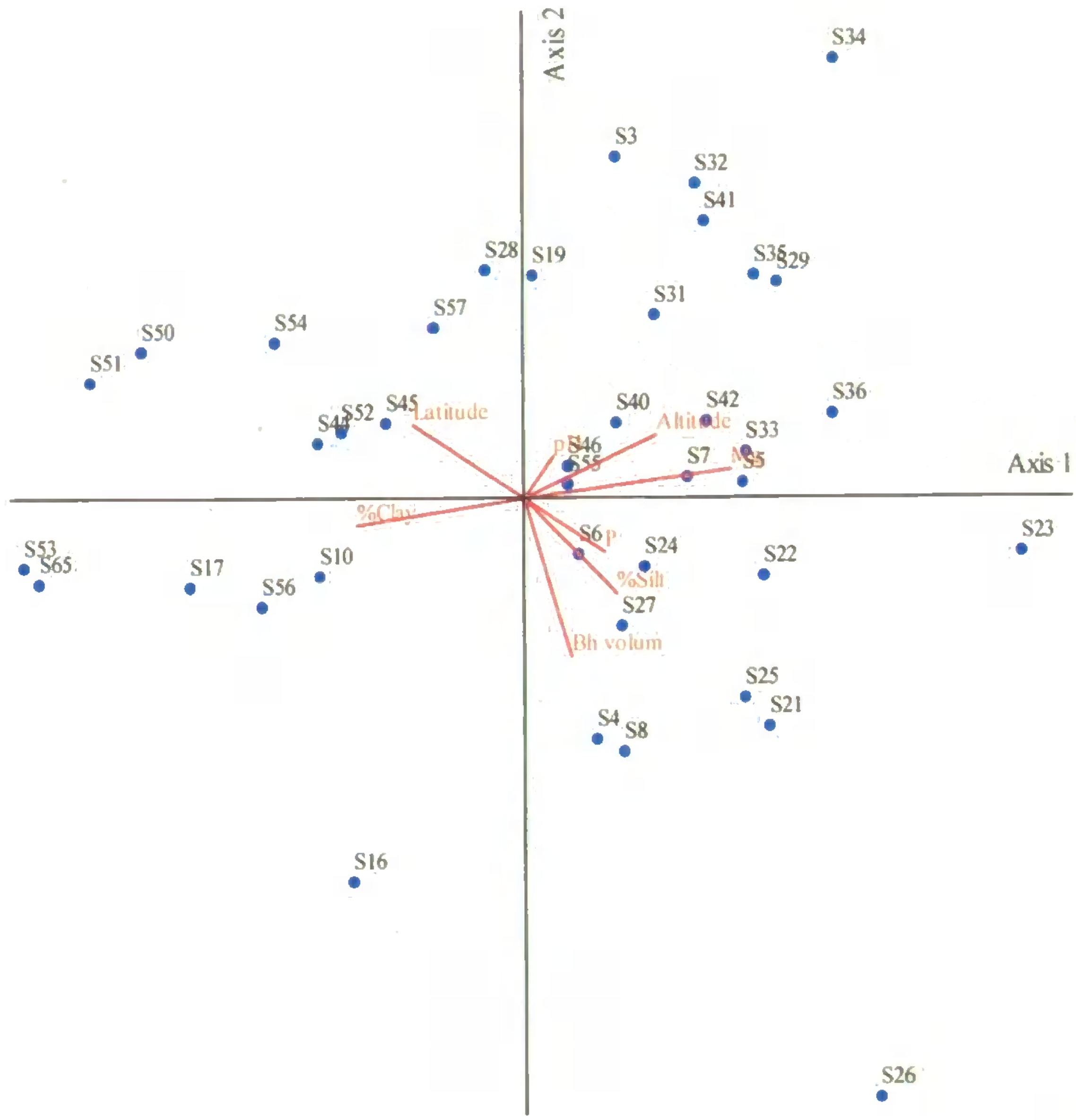


Figure 3.10: Canonical Correspondence Analysis biplot of the eight soil-related environmental variables with the highest correlation.

3.5 DISCUSSION

3.5.1 Distribution of *Berberis holstii*

Location of the sites

Berberis holstii was reported to exist in 94 sites. Of these, 96% were within Nyika National Park, confirming that *B. holstii* is mostly restricted to Nyika (Wild, 1960). All the 71 sites that were visited were on the plateau, above 2000m altitude. For the localities outside Nyika, it is difficult to confirm the information without visiting them. It is possible that the plant species that people referred to is not *B. holstii*, but a plant with morphological similarities such as bitter taste, spines and yellow root/stem colour. It is also possible that the information provided was simply wrong, but this is unlikely because all reported localities visited contained the plant.

The fact that eight sites that had not been reported before were found, suggests more sites may be found in the future. For instance, DNPW scouts reported seeing *B. holstii* near the Wovwe river source; a site that was never reported in this study (Anonymous DNPW staff, pers. comm. 2005). The fact that numerous sites were documented diminishes the concern for the demise of the species in the near future (see also chapter on population dynamics). More critical, however, may be changes in climate that may occur in the plateau.

Recent projections predict an increase in both average temperature (~3°C by 2075) and rainfall (~33%) and that the increase in precipitation may not be sufficient to compensate for the increase in temperature, resulting in more evapotranspiration and, therefore, drought effects across the whole ecosystem (Environmental Affairs Department, 2002). This report also cites the likely increase in browsing resulting from drought. Which plant species will be affected the most depends on their palatability to herbivores. *B. holstii* is likely to be affected because it is browsed by large herbivores such as bushbuck (*Tragelaphus scriptus*), eland (*Taurotragus oryx*) and zebra (*Equus burchelli*).

Availability of Berberis holstii

Although the preceding section suggests that *Berberis holstii* is not under imminent danger, the situation is different at the population level. *B. holstii* no longer exists in five of the sites: Lake Kaulimi (car park), Chilinda (Chalet 3), Dembo (descent to bridge), Domwe and Chowo. Coincidentally, these sites are readily accessible to people. For instance, Lake Kaulimi is popular with tourists and is visited frequently. The same occurred at Chilinda Chalet 3 which is situated at Chilinda camp. Dembo and Chowo were on roadsides disturbed during road maintenance. Domwe is the nearest point to Nthalire villages in the Chitipa district.

Although few sites have been depleted of *B. holstii*, the fact that most of the sites are exposed and some are on roadsides makes them easily accessible. Proximity to villages also contributes to the risk of exploitation and localised extinction. For example, the Juniper Forest site is currently the closest to the nearby villages. It is also currently the most exploited of all the populations that were studied.

3.5.2 General characteristics of the habitats

Bekele-Tesemma *et al.* (1993) report that *B. holstii* grows in forest edges in Ethiopia. In Nyika, it grows in a wide range of habitats including forest interior, roadsides, grasslands and forest edges. The most-preferred habitat was forest edges. Although *B. holstii* is less often found in the open grassland, most of the sites contain grasses, as these dominate Nyika Plateau (Meadows, 1984), and all sites are relatively open.

In terms of altitude, *B. holstii* is found between 2099m and 2510 m. Considering that the entire national park is located between 600m and 2607m, this provides evidence that *B. holstii* is restricted to higher, but exposed altitudes (Bekele-Tesemma *et al.*, 1993). These areas are characterised by cool habitats, with occasional frosts and rainfall of 1,000mm–1,200mm per annum (Dowsett-Lemaire, 1985, Thatcher, 1974, Burrows and Willis, 2005, Donovan *et al.*, 2002, Shroder, 1976).

Judging by the characteristics of the soils where it is found, *B. holstii* prefers slightly acidic (pH~6) soils with medium % Nitrogen (0.13–0.20), high % Organic Matter (>4), high % Organic Carbon (2.35), high concentration of Magnesium (0.6–3 cmol/kg), 10-20% silt, low Potassium and Phosphorus (0.06–0.1 cmol/kg and 9 – 18 μg/g respectively), and medium Calcium (5 – 10 μg/g). The soils are predominantly sandy (they are within the left hand side of the soil texture triangle (Figure 3.5). The Organic Matter content is characteristic of grasslands and areas which are burnt periodically, while the acidic pH is typical of high-altitude tropical environments (Meadows, 1985). Sandy soils have poor nutrient content and have high drainage (Brady and Weil, 2008).

3.5.3 Floristic and environmental characteristics of the sites

B. holstii grows in proximity to over 450 plant species. It is difficult to clearly determine the requirements of *B. holstii* based on a diverse number of plant species because they are all likely to differ in their specific optimal requirements due to micro-spatial and temporal variations (Meadows, 1985). The fact that the sites are different is also evident based on the ANOSIM and similarity dendrograms. Despite this, the sites reveal floristic similarities. All the sites contain grasses. This is not unusual because grasslands are typical of Nyika and are maintained by induced periodic burning (Lemon, 1968).

The sites are also similar because they contain *Pteridium aquilinum* (Dennstaedtiaceae), *Brachythrix sonchoides* (Asteraceae), *Artemisia afra* (Asteraceae), *Helichrysum odoratissimum* (Asteraceae) and *Setaria sphacelata* (Poaceae) which are the most frequent species. *Pteridium aquilinum* is a temperate species that inhabits montane grasslands and forest margins (Burrows and Willis, 2005), and degraded forest–grassland ecotones (Mills, 1979 as cited by Department of National Parks and Wildlife (2004)). It is an invasive plant species which is colonising grasslands rapidly and excluding other plant species in Nyika, and is resistant to fire (Department of National Parks and Wildlife, 2004).

Brachythrix sonchoides is an inhabitant of evergreen forest margins and stream banks (Burrows and Willis, 2005). *Helichrysum odoratissimum* is an indicator of grassy and rocky slopes and exists in bare places such as roadsides and forest margins (Burrows and Willis, 2005). *Artemisia afra* grows in high montane grassland areas and secondary vegetation, and is a pioneer after fire (Burrows and Willis, 2005). *Setaria sphacelata*, together with *P. aquilinum*, are indicators of moist areas (Lemon, 1968, Burrows and Willis, 2005), whereas *P. aquilinum* and *H. odoratissimum* are indicators of "final phase of forest degeneration and primary stage recovery" (Dowsett-Lemaire, 1985). Based on the characteristics of these species, there is an indication that *B. holstii* favours transition zones between grassland and forest margins, and that these areas are periodically subject to fire. Fire, which is prescribed and initiated by DNPW staff, is used to maintain the grassland ecosystem essential for the ungulates which are the main attraction to visitors of the park.

Fire is also a unifying environmental variable that shows similarity of the sites. All the sites are affected by fire. The sites are also similar with respect to soil properties. At least 90% of the sites had similar soil properties especially in terms of Calcium, Magnesium, Nitrogen, pH, Phosphorus, Potassium and sand.

3.5.4 Correlation between floristic variation and environmental variables

Excluding soil-related characteristics, the most important variables in the distribution of *B. holstii* are relief-based, i.e., altitude, aspect and longitude. Altitude and aspect show the highest correlation with Axes 1 and 2 of the CCA. If soil-related variables are incorporated, Mg becomes the most important of all followed by altitude, *B. holstii* volume, %Clay, latitude, %Silt, Phosphorus and pH. Correlation with main axes shows that Magnesium and altitude have the highest correlation.

The replacement of longitude in the first CCA by *B. holstii*'s volume and (with opposite sign) pH in the second CCA suggests that there is an E-W gradient in productivity and soil characteristics. In descending order of importance, the main soil characteristics were Magnesium, %Clay, %Silt, Phosphorus and pH. The high correlation for variable altitude in both CCAs emphasises the restricted altitudinal band in which *B. holstii* is found.

3.5.5 Anthropogenic pressures impacting on *Berberis holstii*

One of the fundamental reasons for undertaking this study was to establish the threats which *B. holstii* is exposed to. According to DNPW, there are fears that *B. holstii* is threatened by illegal harvesting (Anonymous staff, pers. comm. 2004). This study found that, *B. holstii* is exposed to fire, harvesting and infrastructural development. Although common, the harvesting of *B. holstii* is not as widespread as first thought; fire is the main pressure. Infrastructural development is the least of all pressures. Nonetheless, *B. holstii* has experienced localised extinction primarily due to harvesting. Also, based on the indicator species that *B. holstii* grows in association with, and visual observation of the sites, it is evident that fire is prevalent in the area.

It is difficult to establish to what extent fire is a natural phenomenon (e.g., by lightening) in Nyika. According to Roques *et al.* (2001) and Sankaran *et al.* (2005), 1500-1700mm of rain is not conducive to natural fires. Burning is certainly carried out periodically as part of the management of the park (by DNPW) to maintain the grassland cover. Poachers also contribute with additional intentional and accidental fires (Lemon, 1968, Dowsett-Lemaire, 1985, Department of National Parks and Wildlife, 2004). Burning by DNPW staff is part of the fire protection policy which has been in place for over 50 years (Dowsett-Lemaire, 1985) (Department of National Parks and Wildlife, 2004).

The study found that ~40 sites were affected by fire. 31 of the sites were affected by DNPW's fire while the rest were apparently caused by poachers.

Considering that DNPW's burning is done in alternate one-hectare blocks every three years (Burrows and Willis, 2005) it is likely for *B. holstii* populations to be cut back by fire periodically. The plant, however, is able to re-sprout (see next chapter).

3.5.6 Implications of habitat characteristics on survival of *Berberis holstii*

Because fire kills all the aerial parts of the plant, it has the effect of initiating a new cohort of ramets (stems). By delaying reproduction, this even-age structure simplifies the dynamics of the population and keeps it away from a stable stage distribution (see next chapter).

Since burning is normally done every three years, *B. holstii* needs to have the capacity to grow and reproduce within the three years. *B. holstii* must therefore have efficient dispersal mechanisms to enable seeds to colonise recently burnt areas. As in other species of *Berberis*, their fleshy, brightly red/purple fruits are likely dispersed by birds (Allen and Wilson, 1992, Baskin and Baskin, 1998). This would explain their wide distribution in what are isolated scrub and woodland pockets or islands in a sea of grass in Nyika.

3.6 Summary

The study investigated and mapped the distribution of *Berberis holstii*. In order to understand the possible underlying factors contributing to their distribution, floristic and environmental characteristics of the sites where *B. holstii* grows were assessed. These were the main findings:

i. 94 sites were recorded in which *Berberis holstii* is reported to exist. Four of the sites were located outside Nyika National Park. >80% of the 71 sites that were visited were located within the Nyika plateau, between 2099-2510m above sea level, confirming that *B. holstii* is mostly restricted to the plateau.

ii. The recording of numerous sites in which *B. holstii* exists diminishes concerns that the plant is under imminent danger of demise. At population level, however, *B. holstii* has experienced localised extinction. It is depleted in five sites mainly due to harvesting.

iii. *B. holstii* grew in a wide range of habitats: forest edges, forest interior and roadsides. These habitats were open and contained grasses.

iv. *B. holstii* grew in association with 456 plant species. The most common were: *Pteridium aquilinum, Brachythrix sonchoides, Artemisia afra, Helichrysum odoratissimum* and *Setaria sphacelata.*

v. Altitude was the main factor determining *B. holstii*'s distribution. However, *B. holstii* showed preference to: open transition zones between grassland and forest edges; and predominantly sandy soils slightly acidic, with intermediate Nitrogen, high Magnesium, and low Potassium and Phosphorus contents.

Chapter 4

Population dynamics

4.1 Introduction

Economically and culturally important species tend to be on high demand (Cunningham, 2001). This impacts on the species' probability of extinction and raises the issue of sustainable utilisation (Hemerik and Klok, 2006). In order to determine the impact of the demand and make appropriate recommendations on sustainable management, the species' population dynamics, the extent of the demand placed on it and the available management options need to be assessed through the species' vital statistics (Pianka, 1974). The vital statistics describe demographic processes that individuals undergo. These include birth, survival, growth, maturation and reproduction (Morris and Doak, 2002) (Caswell, 2001). Demographic methods are effective techniques that are ideally suited to quantify the numerical response of both natural and exploited populations (Norris and McCulloch, 2003). These methods focus on the potential of the populations to grow and the underlying factors that allow this to happen.

The history of demographic studies traces as far back as 1874 (Harper, 1977). To date, the studies are popular and have proved useful in conservation biology (Degreef and Baudoin, 1996, Silvertown et al., 1996, Colas et al., 1997, Augustine, 1998, Efford, 1999, Mills et al., 1999, Smith et al., 1999, Akçakaya, 2000, Lennartsson, 2000, Wisdom et al., 2000, Heppell et al., 2000, Kammesheidt et al., 2001, Lennartsson and Oostermeijer, 2001).

Population Viability Analysis (PVA) is a subset of demography specifically concerned with the evaluation of threats faced by populations of species (Akçakaya and Sjögren-Gulve, 2000). Based on demographic data, PVA acts as a bridge between science and policy; it is a flagship technology of conservation biology and a foundational tool of ecosystem conservation (Morris and Doak, 2002). PVA provides a quantitative way in which trends in population growth rate (a crucial factor in conservation management) can be linked to specific parts of the life cycle or particular demographic processes (Silvertown *et al.*, 1993). Because of PVA's ability to consider several classes of threats (environmental, demographic and genetic stochasticity, systematic trends, and episodic catastrophes), it is important in conservation and management (Menges, 2000).

In addition, PVAs have the potential of guiding effective and scientifically justifiable decisions (Dixon et al., 1997, McCarthy et al., 2001) as well as quantifying and identifying potential management targets, e.g., through sensitivity and elasticity analyses (Caswell, 2000, de Kroon et al., 2000, Brook et al., 2002, Baguette and Schtickzelle, 2003). The sensitivity and elasticity analyses can be derived from matrix models, a tool of choice in PVAs of perennial species. Matrix models link the individual to the population through the changes that occur in their vital rates through their life cycle (Caswell, 2001).

Due to the concerns that *Berberis holstii* might be threatened, this chapter investigated the population structure and dynamics of *B. holstii* populations in Nyika National Park.

The study also investigated the impact of anthropogenic disturbance on the demography of the populations. Based on the findings, the study makes recommendations on sustainable management practices.

4.2 Objectives of the study

The objective of this part of the study was to assess the current status of *B. holstii* populations and to project their demographic behaviour assuming the observed conditions persisted in the near future (Coulson *et al.*, 2001). The specific objectives were:

i. To determine the structure of five selected populations of *B. holstii*.

ii. To project their growth.

iii. To determine the life-cycle stages critical to population growth.

iv. To infer the impact of human interventions (fire and whole plant extraction) on population growth and suggest sustainable management practices.

4.3 Materials and Methods

Site selection

Five permanent rectangular plots, which were followed up annually for three years, were established in May 2005. Sites that had visually healthy adult plants were selected.

Although initially it was intended to cover the variety of conditions present in the park, including human disturbance (particularly fire and illegal harvesting) it was soon realised that this would require an effort beyond the scope of a PhD thesis. A pragmatic approach was taken, in which subjectively-judged representative sites were chosen to gain as much understanding of the system as possible in the three years available for the investigation. The plots selected had the following characteristics:

Mpopoti (Population 1): A site that had been burnt within the past year, comprising only young, pre-reproductive *B. holstii* plants.

TT Base (Population 2): A site that had been burnt in the recent past that contained older plants than those in Mpopoti, some of which were reproductive.

Dembo (Population 3): A site that had not been burnt in the recent past with older, larger individuals than those at Mpopoti and TT Base.

Juniper (Population 4): A site that had not been burnt for, apparently, at least fifty years. As evidenced by the discarded aerial parts of *B. holstii* plants and the soil disturbance where plants had been dug out, this site had undergone recent harvesting.

Kaulimi (Population 5): A site that had not been burnt for at least fifty years and did not have signs of harvesting.

Although the field situation is obviously more complicated, these sites can be thought of as arranged in a successional sequence from population 1 to population 5.

Plot size was dependent on the area covered by *B. holstii* in each site (Table 4.1). Incidentally, this shows that patches of *B. holstii* are small. These patches are, however, numerous and scattered all over the plateau (Chapter 3).

Table 4.1: Dimensions of permanent plots.

Plot	**Length (*m*)**	**Width (*m*)**	**Area (m^2)**
Mpopoti	7	5	35
TT Base	50	40	2000
Dembo	20	15	300
Juniper	20	10	200
Kaulimi	20	15	300

Data collection

All *B. holstii* ramets (stems) found in the plot were tagged. An initial careful excavation around some ramets indicated that those belonging to a genet tended to be clumped. Subsequently, and in order not to disturb the plants' root system, ramets were grouped into individual genets based on their perceived clumpiness. Thus, for each apparent genet, the number of ramets (stems) was recorded (Table 4.2). Height (*H*) and diameter 10cm above the ground (*d*) were recorded for each ramet. These measures were used to compute stem volume (V) employing the formula of a cylinder: $V = \pi\left(\frac{d}{2}\right)^2 H$

Seedling and ramet recruitment were recorded every year and tagged for future monitoring. Their height and width was also recorded and monitored. Fruit production was counted for each individual. For one individual that was too tall to reach at Kaulimi, fruit production was estimated by multiplying the number of fruits of easy to reach branches of the same individual by the number of times these branches fitted, by visual estimation, into the total canopy volume.

Table 4.2: Total number of ramets and estimated genets at the study sites from 2005 to 2007.

Plot	**2005**		**2006**		**2007**	
	Genets	**Ramets**	**Genets**	**Ramets**	**Genets**	**Ramets**
Mpopoti	100	172	82	120	69	94
TT Base	512	1406	521	1940	462	1631
Dembo	167	209	199	250	188	263
Juniper	93	127	85	124	84	148
Kaulimi	153	201	229	637	196	603

Matrix construction and modelling

Yearly records of survival, growth, fecundity and recruitment were used to parameterise stage-structured population matrix models.

Six stage classes were determined based on developmental stage and size (stem volume) (Caswell, 2001). *S* comprised seedlings (bearing cotyledon leaves and with stem diameter <1mm). J_1 were immature individuals with stem volume<10 cm^3 and purple stems. This category also comprised vegetative recruits. J_2 were bigger than J_1 (10-100 cm^3). Though predominantly immature, J_2 also contained some reproductive individuals. A_1 consisted of, presumably young, adults 101-500 cm^3 volume, A_2 contained adults with 501-2000 cm^3 volume, and A_3 were the largest adults with >2000 cm^3 volume. The seed stage was not included because laboratory germination experiments showed that the seeds were unlikely to form a seed bank (see Chapter 5). Their duration would therefore be <1y, the interval over which parameters were calculated and the matrix model operates.

To facilitate the task of building the matrix models, a life cycle graph, also known as Coates-graph (Caswell, 2001), was constructed (Figure 4.1). Two annual transition matrices were developed for each population, representing the periods 2005-2006 and 2006-2007. However, due to a fire destroying the aerial parts of plants at Kaulimi in 2005, only the 2006-2007 transition matrix was constructed for this site. The results from this matrix, however, are not presented here because the structure and dynamics of this site correspond to the earliest stage of succession after fire, not to the advanced seral stage it was meant to represent (Appendix 4.1)

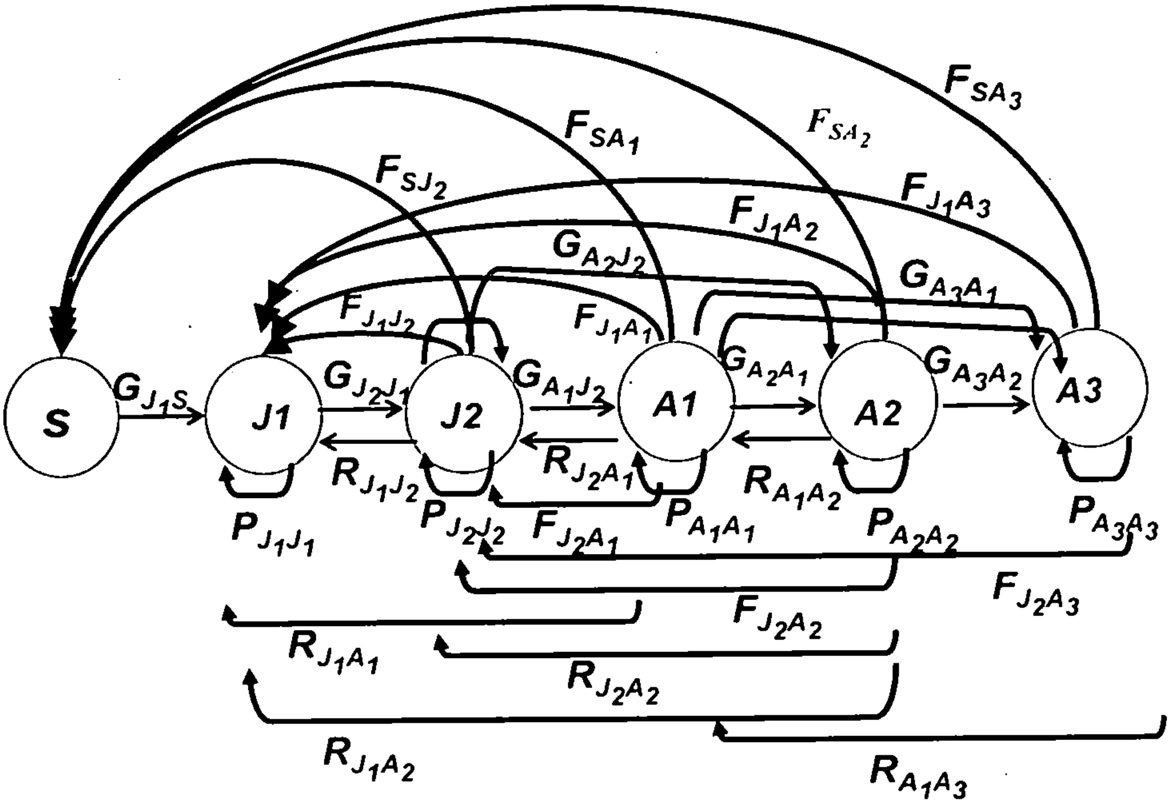


Figure 4.1: Lifecycle graph for *Berberis holstii*. Stages are: S = seedling; J_1 and J_2 = juveniles; A_1, A_2 and A_3 = adults. F_{ij} represents fecundity and includes either seedling (F_{Si}) or clonal (F_{J_i}) recruits, G_{ij} = growth, P_{ij} = stasis, R_{ij} = retrogression (between stages i and j).

Given this life cycle graph, the projection matrix (**A**) had the general form:

$$A = \begin{bmatrix} 0 & 0 & F_{SJ_2} & F_{SA_1} & F_{SA_2} & F_{SA_3} \\ G_{J_1S} & P_{J_1J_1} & F_{J_1J_2} + R_{J_1J_2} & F_{J_1A_1} + R_{J_1A_1} & F_{J_1A_2} + R_{J_1A_2} & F_{J_1A_3} \\ 0 & G_{J_2J_1} & F_{J_2J_2} + P_{J_2J_2} & F_{J_2A_1} + R_{J_2A_1} & F_{J_2A_2} + R_{J_2A_2} & F_{J_2A_3} \\ 0 & 0 & G_{A_1J_2} & P_{A_1A_1} & R_{A_1A_2} & R_{A_1A_3} \\ 0 & 0 & G_{A_2J_2} & G_{A_2A_1} & P_{A_2A_2} & 0 \\ 0 & 0 & 0 & G_{A_3A_1} & G_{A_3A_2} & P_{A_3A_3} \end{bmatrix}$$

with no stasis observed at the seedling stage, no retrogression observed between categories A_3 and A_2, and no growth observed between J_2 and A_3, J_1 and A_1, J_1 and A_2, J_1 and A_3, S and J_2, S and A_1, S and A_2, and S and A_3 categories. The projection model is $N_{t+1} = AN_t$ where N is a vector of population size (number of plants in each category of the life cycle) at two successive time intervals, t and t+1 (Caswell, 2001).

Two years of demographic data for a perennial species with a complex life cycle in a periodically disturbed environment is not enough to gauge the interannual variability that would allow the use of time-varying (e.g. stochastic) models. Instead, the two annual transition matrices for each population were used to calibrate a mean deterministic matrix model per site. These mean matrices allowed broad comparisons to be made between populations. Also, given the complexity and uncertainty of the genet-population structure, the unit of study was the ramet. The projections were carried out with the programme STAGECOACH 2.3 (Cochran and Ellner, 1992).

The matrix elements of stasis (P_{ij}), growth (G_{ij}) and retrogression (R_{ij}) were calculated as the proportion of survivors from one census (year) to the next that stayed in the same class (stasis), moved to further classes (growth), or moved to previous classes due to biomass loss (retrogression), respectively (see equations 1-3 in Franco & Silvertown 2004). Since it was not possible to trace the parents of sexual (S) and clonal (J_1 and J_2) recruits, anonymous reproduction was assumed (Caswell, 2001). Thus, fecundity of the average individual in age class i, F_i, was calculated as (Caswell, 2001):

$$F_i = \left(\frac{n_r(t+1)}{\sum f_i n_i(t)} \right) f_i$$

Where

F_i = Average anonymous reproduction by the average individual in stage class i in the interval t to t+1.

n_x = Number of recruits in category x (at time t+1); $x = S$, J_1, J_2.

f_i = For sexual reproduction this is the average proportion of fruits in stage class i (at time t); for asexual propagation, and because of the impossibility of quantifying the contribution of individual ramets in a genet, it was assumed that classes J_2-A_3 contribute the same proportion, i.e., $f_i = 0.25$.

n_i = Average number of individuals in stage class i (at time t)

The parameters obtained included the finite rate of population growth (λ, the dominant eigenvalue of the matrix), its associated right and left eigenvectors (**w** and **v**, respectively), the corresponding sensitivity and elasticity matrices ($S=\{s_{ij}\}$ and $E=\{e_{ij}\}$, respectively), the damping ratio (ρ) and the period of oscillation (P_i). The right eigenvector represents the stable stage distribution; the left eigenvector, the reproductive value, the relative contribution of the average individual to future population growth as it moves through the life cycle (Caswell, 2001). ρ is a measure of the rate of convergence to the stable stage distribution. It is the ratio of the two largest eigenvalues in the eigenvalue spectrum of each matrix. P_i is the oscillation period, the duration of an oscillation as the population converges toward its stable stage distribution.

Sensitivity measures the absolute effect that a change in each matrix element (keeping all other elements constant) would have on λ, while elasticity measures their relative effect (Caswell, 1978, de Kroon *et al.*, 1986). Sensitivity and elasticity analyses feed back into the decision-making process by targeting those vital rates that maximise changes in population growth (Norris and McCulloch, 2003).

Because the matrices could not converge, parameters related to stable stage distribution (e.g. $\bar{A}$ - mean age of parents of a cohort at stable stage distribution; R_0 – net reproductive rate, the average number of offspring an individual produces throughout its entire life span; μ - mean age at which members of a cohort reproduce; and T - time required for the population at stable stage to grow by the depicted R_0) could not be determined. Matrix elements are made up of the more basic parameters, called vital rates, survival (σ_{ij}), positive and negative growth (γ_{ij} and $|\rho_{ij}|$) and fecundity (ϕ_{ij}) (Franco and Silvertown, 2004). Employing the method described by these authors, the summed elasticity of these vital rates over the whole matrix was calculated for each population and plotted in a ternary graph, the demographic triangle, using STATISTICA version 6.1 (StatSoft Inc., 1984-2003). The observed population distribution and the stable stage distribution were compared using G-test (http://udel.edu/~mcdonald/statgtestgof.html).

4.4 Results

4.4.1 Population structure

All five populations of *Berberis holstii* were young. Except for Dembo, all were dominated by juvenile stages J_1 and J_2. Dembo was dominated by J_2 and A_1. Population density decreased with time since disturbance (fire) (Figure 4.2). This was clearer for ramets than it was for genets. Kaulimi is the "exception that confirms the rule" because, starting with a small population of large individuals in 2005, its numbers increased substantially after it was burnt. Most of the new recruits were of vegetative origin (J_1 and J_2), but there was also a substantial amount of sexual recruitment (S). With the exception of Kaulimi (and for the reasons already mentioned), the number of plants decreased, and their size increased, with the hypothesised successional sequence (Figure 4.3).

Proportion of reproductive plants was generally higher than non-reproductive plants, suggesting rapid growth and recovery of individual plants to fire. Fruit production was high. Most of the fruits were produced by individuals whose stems were between $10cm^3$ and $1000cm^3$.

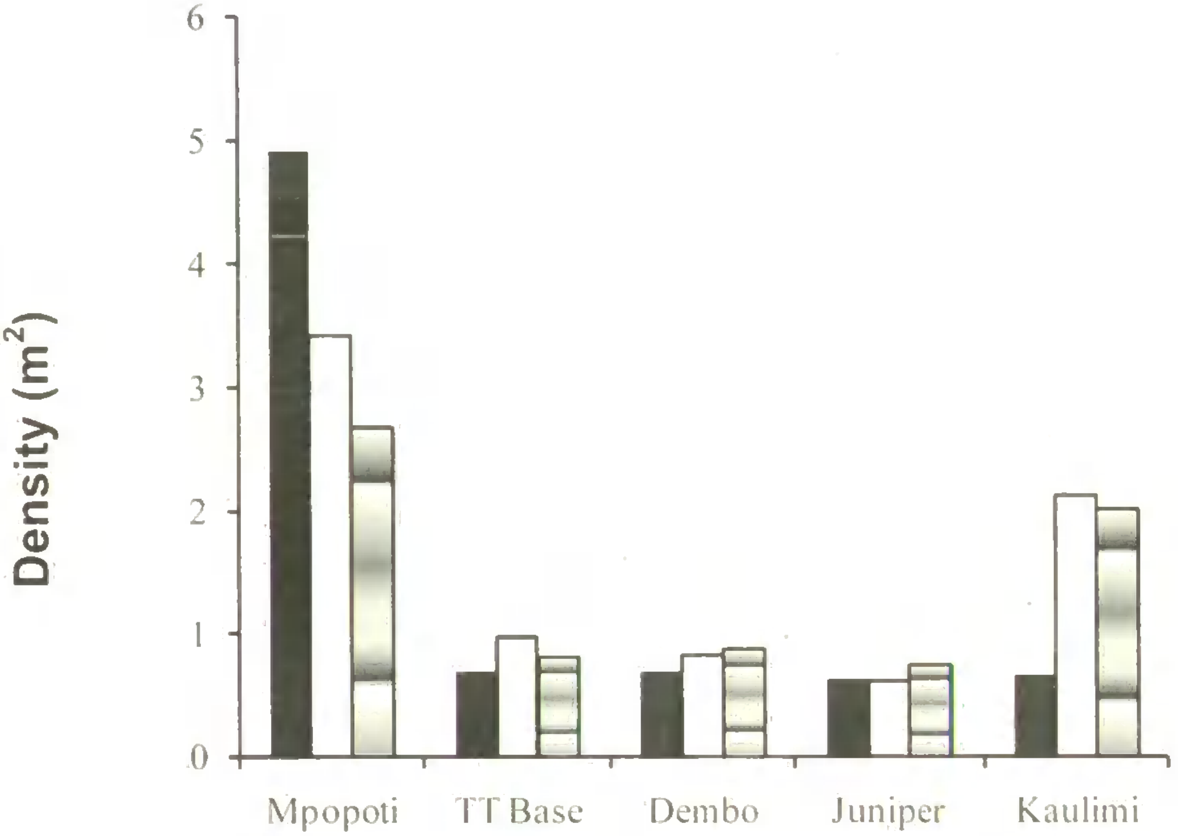


Figure 4.2: Density of ramets of *Berberis holstii* in five permanent plots over three years of study: 2005 (black filled columns), 2006 (clear) and 2007 (striped).

Although infrequent, some small-stemmed ramets were able to bear fruits (Figure 4.4). Despite high fruit production, the number of seedlings produced was lower than the number of clonal recruits. Fire had a clear impact on the latter in that production of clonal recruits increased whenever there was fire. The fruiting behaviour varied with succession (Figure 4.5). For Dembo, Juniper and Kaulimi, individuals in the A_1 class contributed the highest proportion of fruits while for Mpopoti and TT Base it was J_2. Once again, the pattern was broken by Kaulimi after it was burnt.

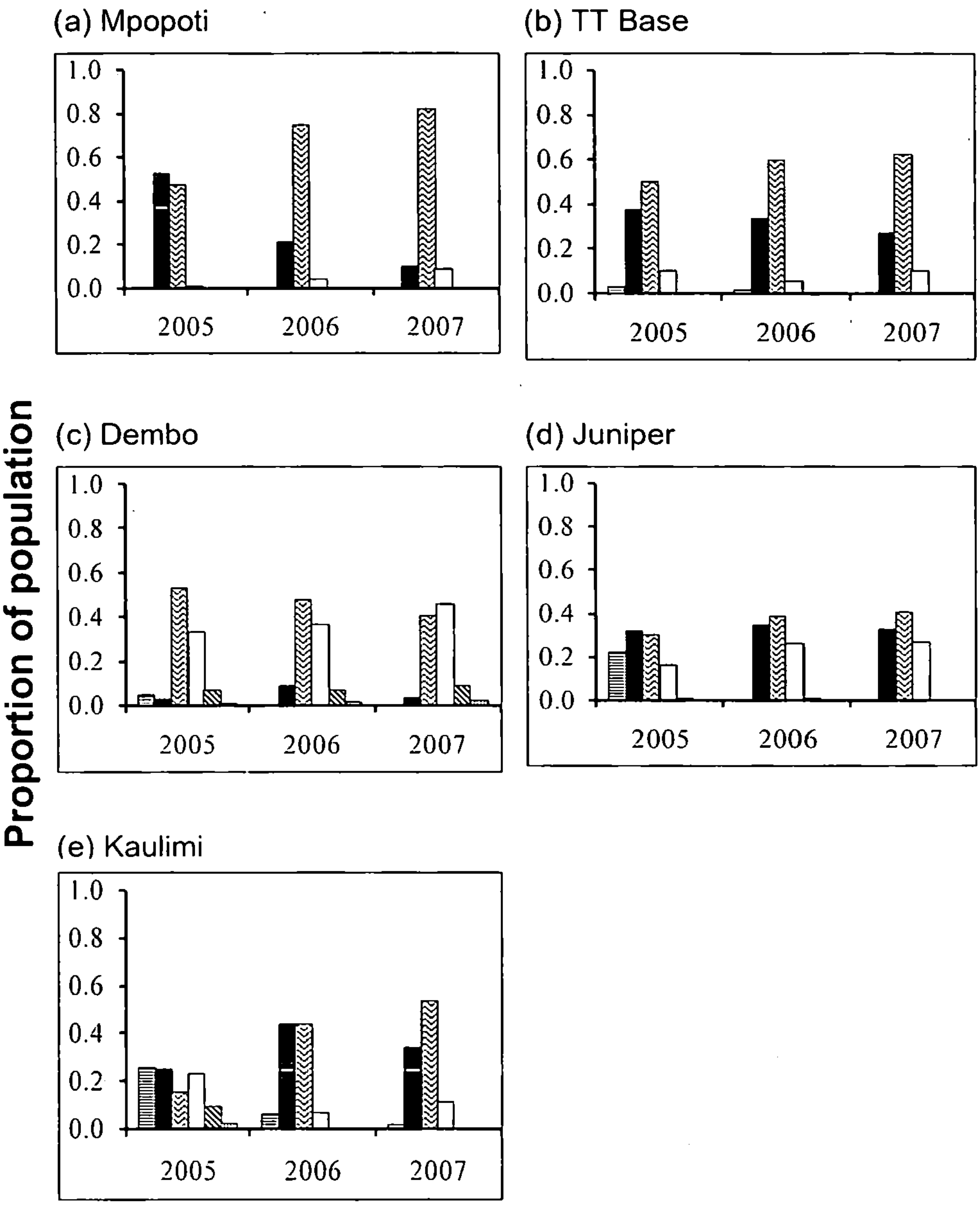


Figure 4.3: Population structure of *Berberis holstii* ramets in the five permanent plots during the three years of study. Stages are: Horizontal stripes = *S*, black = J_1, zigzag = J_2, clear = A_1, left diagonal = A_2, vertical stripes = A_3. For definition of stages see text.

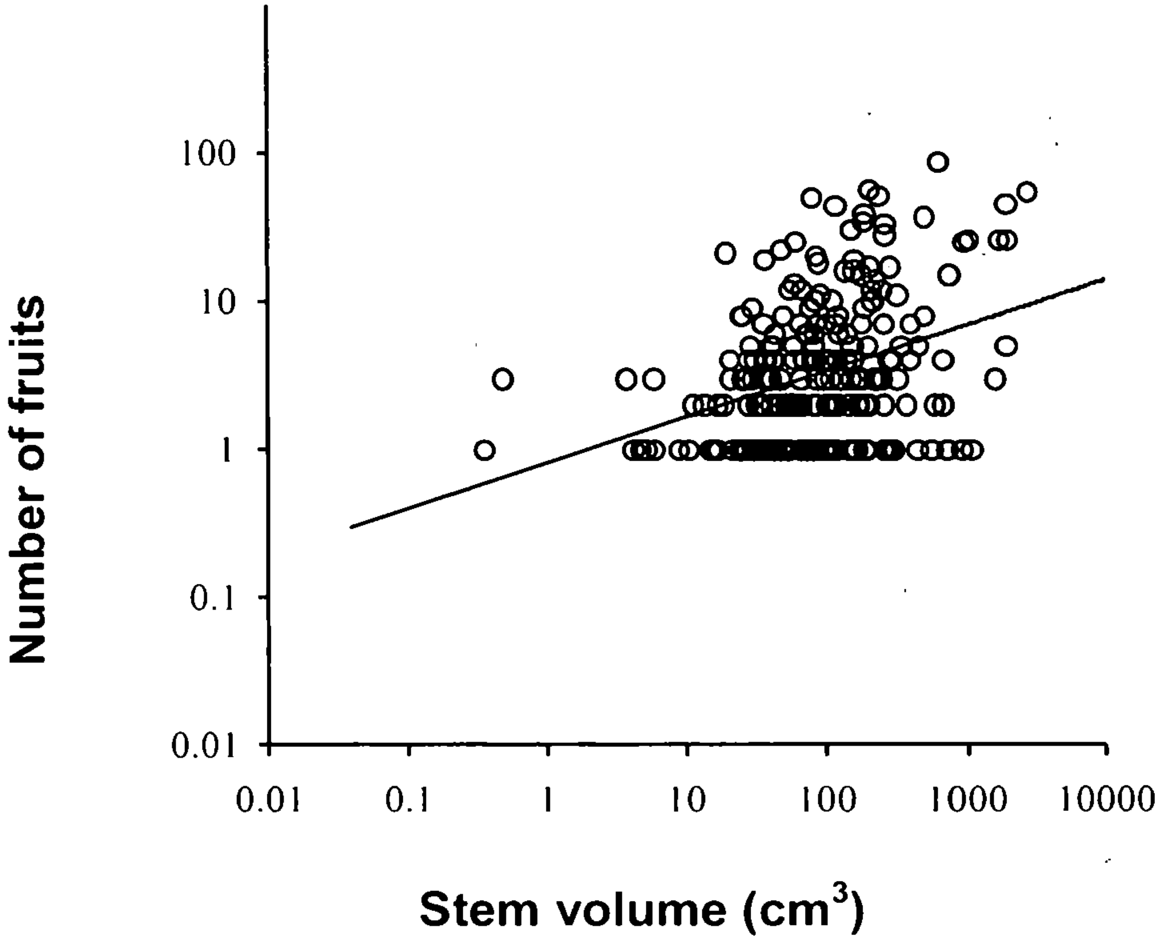


Figure 4.4: Relationship between fruit production and stem volume in *Berberis holstii*. The line represents the fitted least-squares power function ($y = 0.4559x^{0.4364}$, $R^2 = 0.24$).

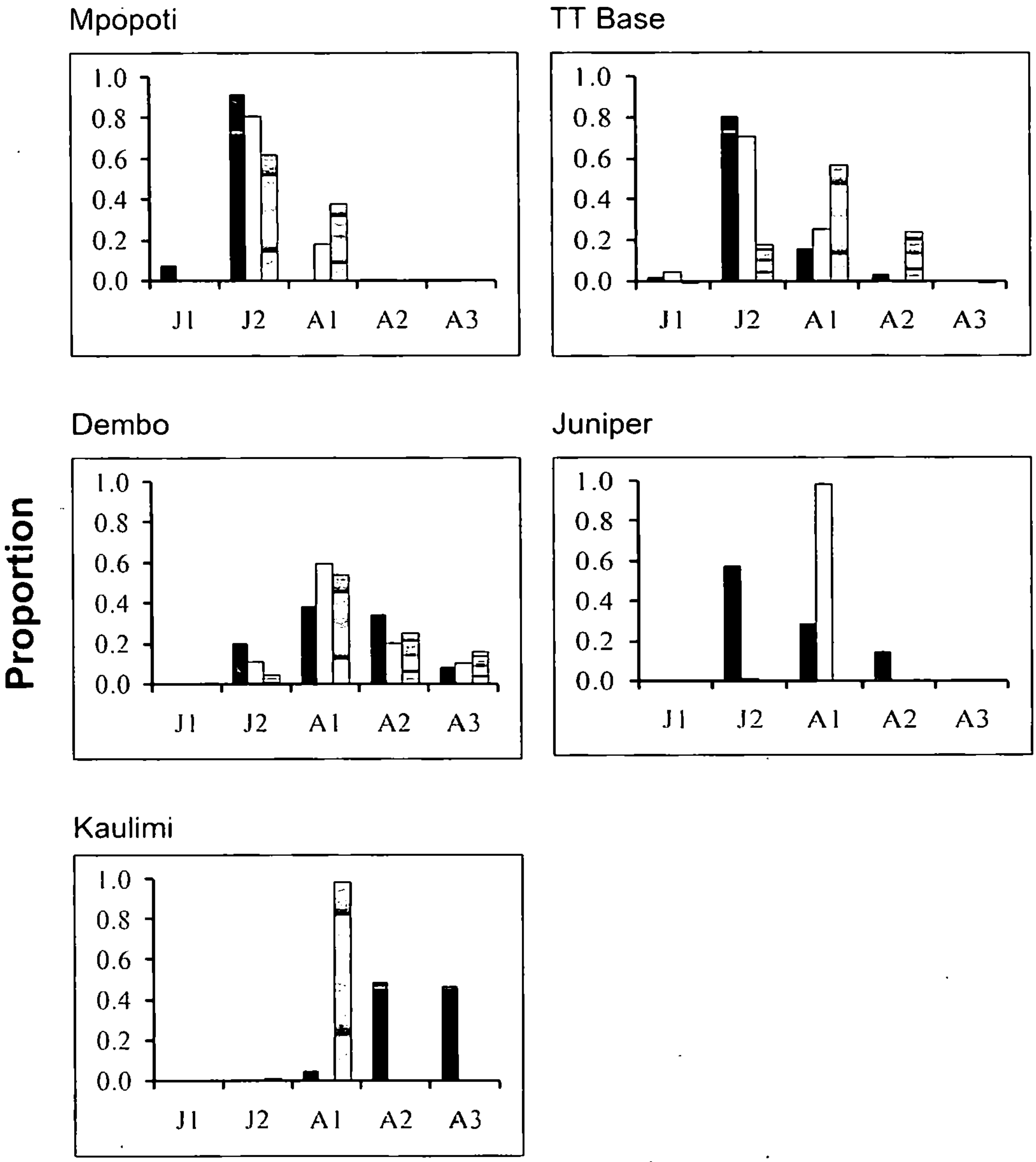


Figure 4.5: The contribution of different stage classes to fruiting in the years 2005 (black columns), 2006 (clear columns) and 2007 (striped columns).

The proportion of individuals in the seedling stage increased with population age. Mpopoti had no seedlings, TT Base had 2%, Dembo had 4%, Juniper had 20% and Kaulimi had 25% (Figure 4.3). Mpopoti had no seedlings in the three years of sampling. Dembo and Juniper only produced seedlings in 2005. TT Base produced seedlings in 2005 and 2006. Although Kaulimi was burnt in 2005, it produced seedlings in all the three years. Seedling survival was low.

4.4.2 Population growth

There were significant differences between the observed population distribution and the stable stage distribution projected from the average matrices in Mpopoti, TT Base and Dembo populations (G=422.3, df=5, $p<0.01$; G=290, df=5, $p<0.01$; G=52.6, df=5, $p<0.01$, for Mpopoti, TT Base, Dembo, respectively). There were no significant differences with regard to Juniper population (G=8.3, df=5, $p>0.07$).

The projections showed that populations are expected to have a bell-shaped stable-stage distribution. This was particularly in the case of TT Base, Dembo and Juniper. For Mpopoti, TT Base and Juniper, they will be dominated by individuals in the J_2 and J_1 stage-classes. For Dembo, it will be dominated by J_2 and A_1 stage-classes (Figure 4.6).

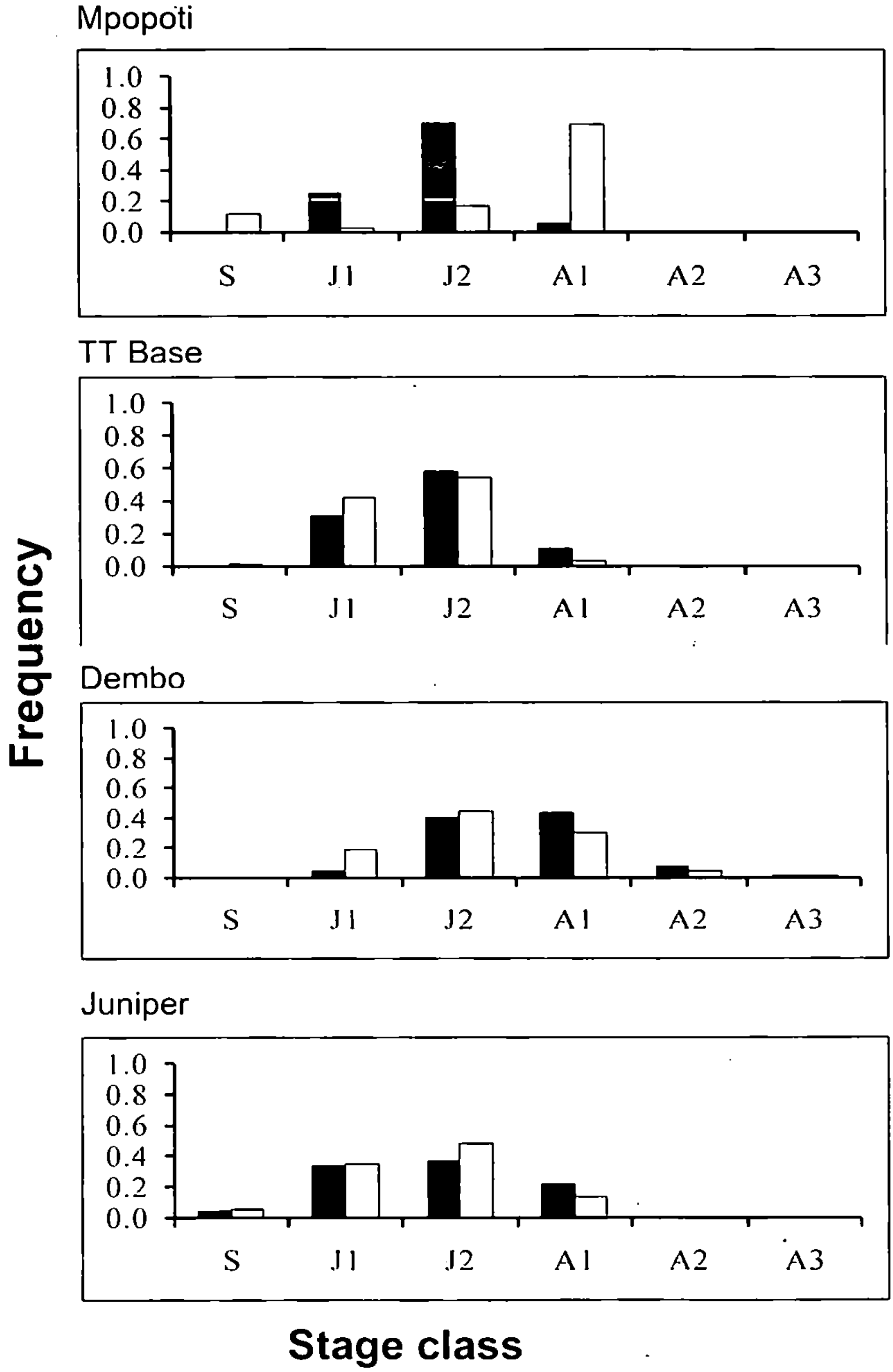


Figure 4.6: Comparison of observed (dark columns) and projected (clear columns) stage-class distribution for the four study populations.

Population projection predicted long-term growth (i.e., λ>1) in TT Base, Dembo and Juniper. TT Base, the population with the highest cover, had the highest λ of all. Mpopoti was the only population with λ<1. TT Base also had the highest damping ratio (ρ). The period of oscillation, P_i, could only be calculated for Dembo and its value was 31 years (Table 4.3).

4.4.3 Life- cycle stages critical to population growth

Changes in survival made the highest impact, as measured by elasticity, on population growth rate. Stage class J_2 was critical for all populations except Mpopoti. For Mpopoti, A_1 was more important. When employing sensitivity, a similar pattern was observed and survival also had the highest impact. TT Base, Dembo and Juniper had their largest sensitivity in the J_2 category. Mpopoti, the youngest population had largest sensitivity in the A_1 stage class (Figure 4.7).

The demographic triangle of B. holstii was similar to the one calculated for other woody species (see Franco & Silvertown 2004). B. holstii had low elasticity of fecundity and growth and high elasticity of survival. However, there were intra-population differences. Mpopoti had the lowest elasticity of fecundity and Juniper's growth elasticity was twice as large as that of the other three populations (Figure 4.8).

Table 4.3: Projected demographic scalar parameters for the four study populations. These parameters are: population growth rate (λ), damping ratio (ρ) and period of oscillation (P_i).

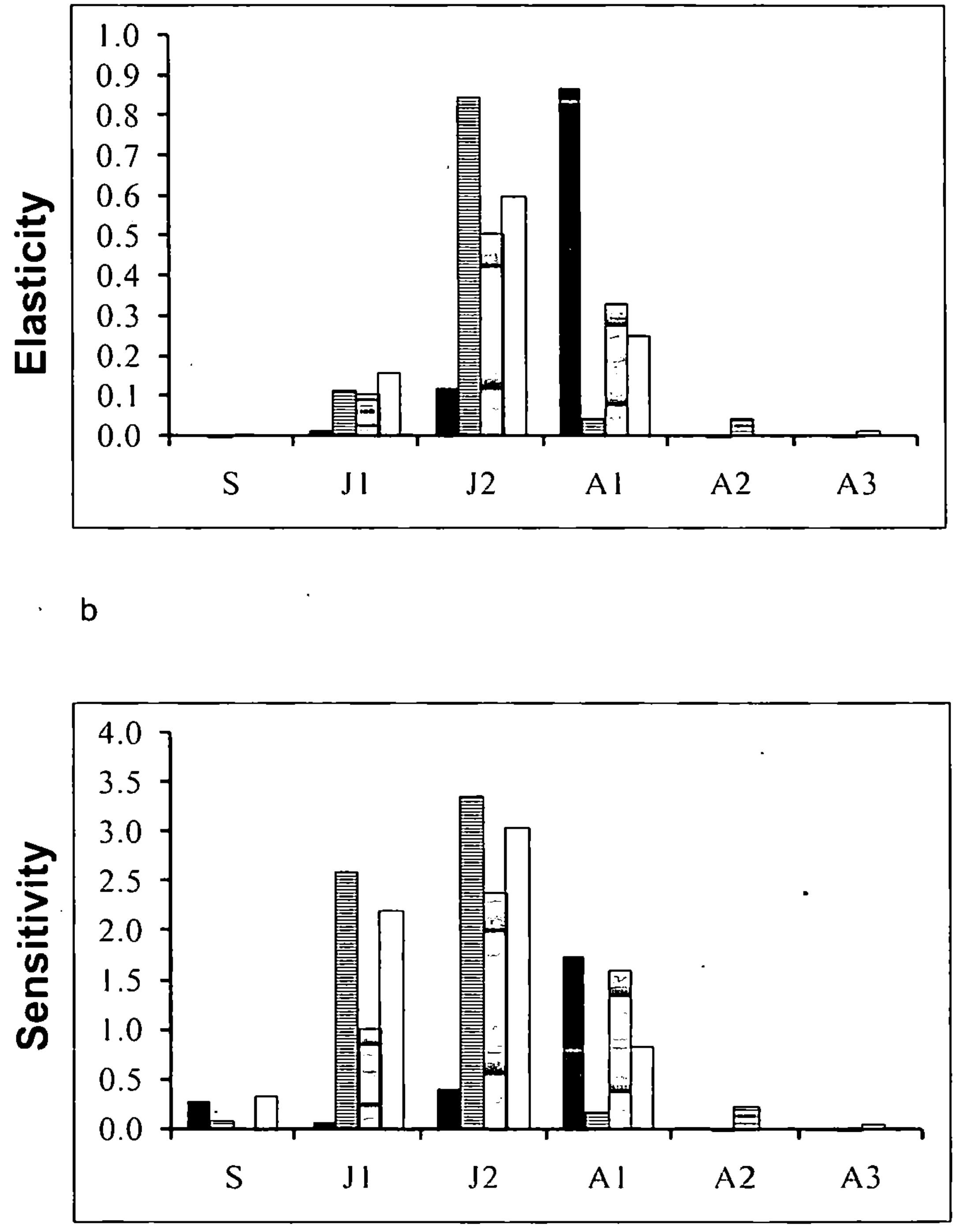
Site	Demographic parameters λ (y^{-1})	ρ	P_i* (y)
Mpopoti	0.762	1.14	-
TT Base	1.736	2.33	-
Dembo	1.262	2.28	30.5
Juniper	1.222	1.22	-

* Because there were no complex roots for Mpopoti, TT Base and Juniper, *Pi* could only be calculated for Dembo.

4.4.4 Impact of man-made interventions

Except for very few cases where the individuals died naturally, the most common cause of mortality was man-made. The man-made causes were fire and uprooting. Fire was the principal cause of mortality, eliminating the aerial parts of all individuals. With the exception of the Juniper population, where disturbance occurred as uprooting of adult individuals, fire occurred in all populations.

a



b

Figure 4.7: Elasticity (a) and sensitivity (b) values contributed by each class for Mpopoti (black columns), TT Base (horizontal stripes), Dembo (shaded) and Juniper (clear) populations.

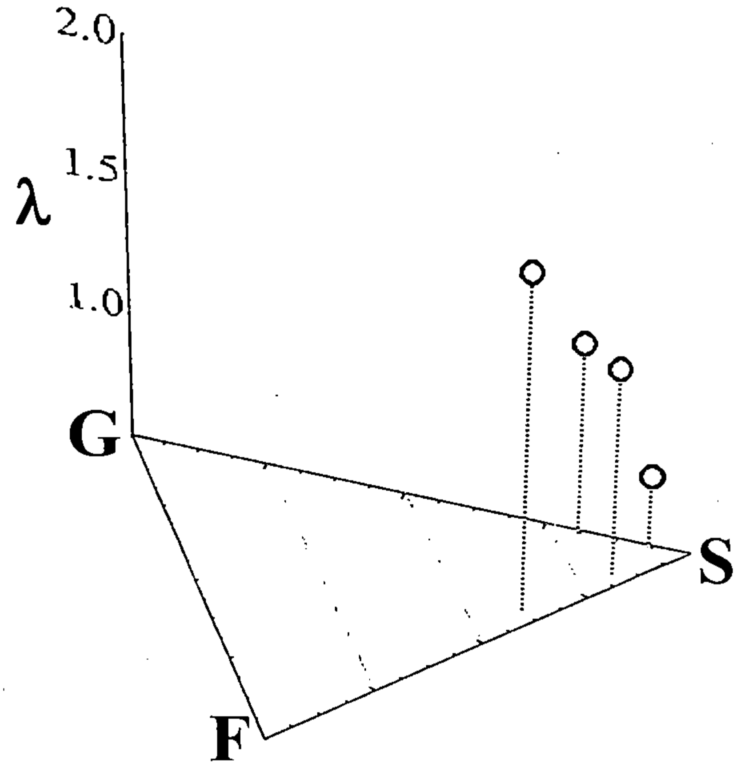


Figure 4.8: Distribution of population growth rate, λ in elasticity space. From left to right the points correspond to populations TT Base, Dembo, Juniper, and Mpopoti.

The stage class that was commonly affected by fire was *S* class while the least to be affected in all populations was A_1 (except for Mpopoti). Uprooting affected all adult classes, *A1-A3*. With the exception of Mpopoti, all populations experienced higher mortality in 2005/06 than in 2006/07 (Figure 4.9).

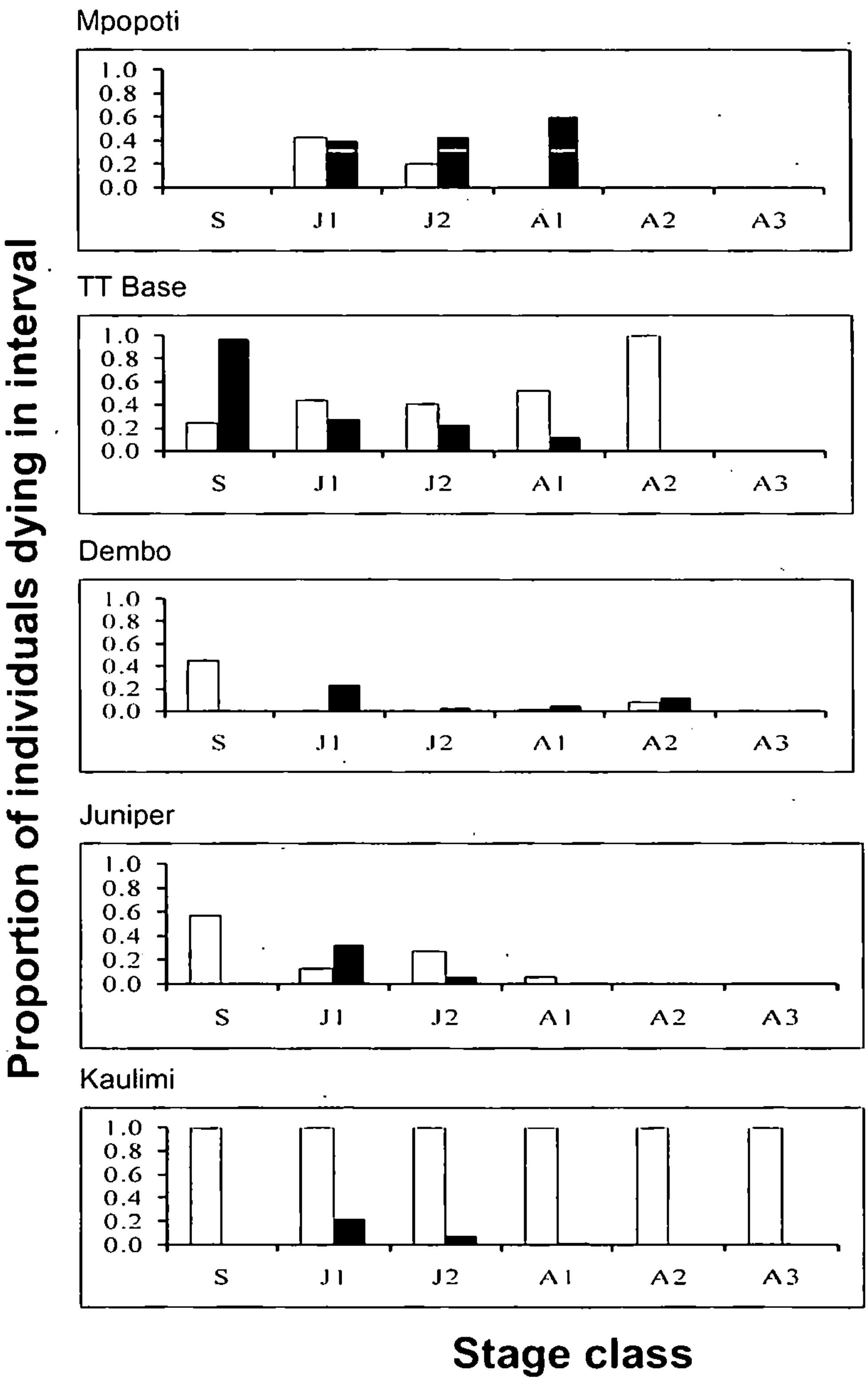


Figure 4.9: Extent of mortality observed in each stage class during 2005/2006 (clear columns) and 2006/2007 (dark columns).

4.5 Discussion

4.5.1 Population structure

The populations of *Berberis holstii* are young (see also chapter 3 section 3.4.3). This is a consequence of the high periodic anthropogenic mortality exerted primarily by fire and secondarily by harvesting. While harvesting concentrates on the larger adult individuals, burning is carried out within a maximum of three years, a period too short to allow the recruits to reach maturity. The population structure of Dembo shows that, if these two factors were removed, many individuals would be able to grow to maturity.

Young populations do not usually reproduce (Escalante *et al.*, 2004). However, ramets of *B. holstii* are able to reproduce at small sizes, presumably as a consequence of their genets having stored root reserves over many years. Early fruiting is not unusual in other species of *Berberis*. For example, *B. buxifolia* fruits at the age of one year (Arena *et al.*, 2003). Rapid maturation is probably a factor that has allowed *B. holstii* to succeed under the conditions prevalent at Nyika.

Despite fruit production being high, seedling recruitment was very low and it did not occur every year. In addition, few seedlings established during the study period. This contrasts with other *Berberis* species, e.g., *B. thunbergii* whose seedlings become established quickly and their recruitment contributes the most to population increase (Ehrenfeld, 1999). Although some seedlings of *B. holstii* emerged after fire, their abundance was negligible compared to the number of resprouts. Other *Berberis* species are able to propagate vegetatively (Peterson Jr., 2003).

However, because asexual reproduction restricts the opportunities for recombination, and thus limits genetic variability on which selection can operate, it potentially increases the risk of extinction (Bonner, 1996, Fenner and Thompson, 2005). The ability to resprout vigorously following burning allows *B. holstii* to form virtually monospecific stands that undergo self-thinning as they develop.

4.5.2 Projection of population growth

Three of the four populations were projected to have positive growth. The only population with $\lambda<1$ was Mpopoti, but this is the youngest population and, assuming no disturbance occurs in the near future, it would be expected to achieve $\lambda>1$.

4.5.3 Life-cycle stages critical to population growth

Sensitivity and elasticity analyses showed that stage classes J_2 and A_1 are critical life-cycle stages (Figure 4.7). These two stage classes also make highest contribution to fruit production (Figure.4.5); hence they are critical to the persistence of *B. holstii*.

4.5.4 Effects of fire and harvesting

The study confirmed the recurrent influence of fire and harvesting. Fire has a larger influence because it occurs frequently and affects most individuals in a population. Because of its wider spatial coverage, fire can transform the structure of populations from uneven-aged, presumably genetically diverse populations to even-aged, clonally-derived, and potentially genetically-impoverished ones. This transformation occurred during the study period at Kaulimi. However, despite the large-scale effect of fire, the populations seem rather resilient to it. The fact that DNPW's burning programme is not done at once for the entire park but rotates between sites (Department of National Parks and Wildlife, 2004) helps maintain *B. holstii* populations in a mosaic of different successional stages. These different stages may be sufficient to allow genetic flow between populations if, as in other *Berberis* species, fruits are dispersed over the species range by birds (e.g., *B. darwinii* (Allen and Wilson, 1992)). Harvesting, on the other hand, seems to exert a relatively minor effect.

4.5.5 Management recommendations

In the absence of fire and harvesting, *B. holstii* is able to reach large sizes, presumably over many years, as was the case with Kaulimi before it was burnt. Since fire (Lemon, 1968) and harvesting are characteristic of Nyika, management strategies need to take these two elements into account. Elasticity analysis showed that J_2 and A_1 are critical to population growth rate.

It would therefore be desirable to protect at least a few of these individuals when prescribed burning is applied around *B. holstii* populations. In addition to their contribution to the local population's growth rate, these individuals would also contribute to maintaining a minimum level of genetic variability via recombination.

Although the projections show that the populations are predicted to grow, there is little seedling recruitment. Provided this lack of recruitment is not a consequence of density-dependent mortality (e.g., through shading by adults), it could be increased by the construction of fire breaks around selected populations. Allowing some populations to reach more advanced seral stages would help investigate the longer-term dynamics of *B. holstii* and the influence of density-dependence and dispersal, among other things.

Because there is abundant fruit production, another possible intervention might be to collect the seeds and use them in *ex-situ* propagation. Some of the seedlings could then be re-introduced into the park while others can be transplanted to suitable areas (see Chapter 3).

4.6. Summary

This chapter assessed the structure and dynamics of wild populations of *B. holstii*. The following findings were of particular relevance:

i. Although there are fears that harvesting may threaten the future of *B. holstii*, fire was a more immediate, widespread threat. Fire maintains the populations in a homogeneous young stage delaying, or even preventing, the contribution of sexual reproduction to population growth. Periodic fire may also contribute to a decrease in genetic diversity.

ii. Despite these threats, *B. holstii* populations were projected to grow if some individuals are allowed to reach reproductive stages.

iii. Despite high fruit production, seedling recruitment and establishment are low, jeopardising genetic variability and, thus, fitness.

iv. Life-cycle stages J_2 and A_1 are critical to population growth. This occurs because of their high contribution to the processes of survival, growth and fecundity.

v. Both *in-situ* and *ex-situ* conservation measures are recommended. Areas with high coverage of *B. holstii* should be protected from fire by excluding them from burning programmes and putting regularly maintained fire breaks around them. Seeds could also be harvested and germinated *ex-situ* for reintroduction into their natural habitat and cultivation into suitable areas for public utilisation and commercial use.

Chapter 5

Seed germination

5.1 Introduction

Seedling recruitment is a crucial event in the life cycle of a plant and this part of the study set out to investigate the requirements for seed germination of *Berberis holstii.*

5.1.1 Seed germination

A seed is the mechanism by which a plant perpetuates (at least part of) its genotype and tries novel genetic combinations. Being independent of the mother plant, seeds confront a variety of environmental and biological risks. Among the former are, for example, episodes of drought and/or low temperatures that the seedling would not tolerate and the seed must therefore overcome before it germinates. Among the latter, the seed must also avoid being eaten by a variety of animals and microorganisms.

Seeds require specific conditions to germinate. These conditions may include light, moisture, air, temperature and nutrients (Figueroa and Lusk, 2001, Evenari, 1980-81). Temperature is one of the most important conditions that determine germination and establishment of seedlings (Probert, 2000). However, even in the right environment, seeds of some species remain dormant depending on the maturity of the seed at dispersal and other internal or external conditions (Baskin and Baskin, 1989). Germination studies seek to understand and quantify the proportion of seeds which germinate and the rate at which they germinate under various conditions.

Different aspects are covered in germination studies. These include determination of seed quality (i.e. suitability of seed for sowing in terms of, for example, health, size and germination capacity), establishment of pre-germination requirements (i.e., conditions required to facilitate germination such as stratification and scarification) and assessment of germination responses (Silva *et al.*, 2008, Nery *et al.*, 2007, Thomson, 1979).

In order to quantify the course of germination, distribution models are used (O'Neill *et al.*, 2004). Examples of such distributions include: Normal, Gamma, logistic, exponential, Gompertz, Weibull and Richards (Orozco-Segoria *et al.*, 1998, O'Neill *et al.*, 2004). The models are used to estimate parameters such as germination rate, germination index, coefficient of velocity, median time to germination and heat sums (Scott *et al.*, 1984).

5.2 Objectives of the study

The overall aim of this chapter was to investigate the germination response of *Berberis holstii* under different conditions. Specific objectives included:

i. Determining cold stratification, light and temperature requirements for germination.

ii. Investigating the loss of viability with seed age.

5.3 Materials and methods

5.3.1 Data collection

5.3.1.1 Seed collection and storage

Mature fruits (ripe and dark purple in colour) were collected from plants in Nyika Plateau in May/June of 2005 and 2006. The flesh was removed and the seeds washed, dried, stored in paper bags and transported to the University of Plymouth where the germination trials took place. Each fruit had 1-3 oval seeds ~6mm long, 2mm wide and ~200mg in weight.

In the laboratory, half the seeds collected were packed in plastic bags, labelled and stored in a refrigerator at 5°C (stratification treatment). The other half was stored at room temperature. The seeds were kept in this state until imbibition and germination trials were undertaken at different periods. These periods corresponded to recently collected, one-year old and two-year old seeds.

Prior to the trials, the seeds were sterilised by submerging them in 10% Sodium hypochlorite for 5 minutes. They were then rinsed three times in distilled water and drained (Fuller and Pizzey, 2001, Rodriguez-Ortega *et al.*, 2006).

5.3.1.2 Seed sowing

0.8% water agar was prepared, autoclaved at 120°C for 15 minutes, and poured into Petri dishes under a laminar flow hood (Fuller and Fuller, 1995). Agar was used because of its moisture retention capacity (Ellis *et al.*, 1985).

Water agar was specifically preferred because it does not contain nutrients which would encourage the growth of micro-organisms (Ellis *et al.*, 1985).

The seeds were sown onto the agar after it set. They were evenly distributed using pincers that were sterilised by heating over a Bunsen burner. The sown seeds were exposed to different treatments with each treatment comprising 100 seeds in five samples (Petri dishes) of twenty seeds each.

5.3.1.3 Germination treatments

The seeds were exposed to the experimental treatments described below:

Light / dark

The response of seeds to light (photoblastism) was investigated in 9cm-diameter Petri dishes in a Sanyo growth cabinet at a constant temperature of 24°C with a 12:12h day-light photoperiod. Seeds under the light treatment were exposed to this daily photoperiod provided by cool white fluorescent light with daily luminance 40-W bulbs. Those in darkness were wrapped in three layers of aluminium foil and kept in the same cabinet (Baskin and Baskin, 1998, Conner, 1987). Fluorescent tubes were used because they emit considerable red but little far-red light (Baskin and Baskin, 1998).

Germination under the light treatment was recorded every 24 hours, while samples in darkness were opened on the final day of the experiment (Baskin and Baskin, 1998). This final day was day 22 for the experiments under constant temperature described above, and day 40 for the experiments under fluctuating temperature described below.

Temperature

Seeds were germinated under two types of temperature regimes: constant temperatures over a temperature gradient and fluctuating temperatures of either 20/10°C or 20/5°C. The latter two regimes roughly simulated the two extreme seasonal conditions that occur on the Nyika Plateau: the warm, rainy season and the cold winter (Figure 5.1). These experiments were also replicated for stratified and non-stratified (control) seeds, as well as for light/dark conditions, as in the constant temperature experiment described above. Because the effect of stratification was already known by the time the temperature gradient experiment was undertaken, this experiment was conducted with seeds stored at room temperature (non stratified) only. Also, because the light/dark experiment was conducted first and germination was higher under light, the temperature gradient experiment did not include germination of seeds in darkness.

On the temperature gradient, the seeds were exposed to seven temperatures. The gradient was provided by a Grant thermostatic bath which consisted of two water baths (cold and hot) separated by a 40×20 cm aluminium plate. The seven temperatures were determined by DS-1920 temperature *i*-Buttons (http://datasheets.maxim-ic.com/en/ds/DS1920.pdf) which were located equidistantly on the temperature gradient bar. The seven locations had mean temperatures of: 10°C, 12°C, 17°C, 21°C, 26°C, 30°C and 31°C and their germination is reported as G1 to G7 in this ascending order of temperature. The standard deviation of all seven temperatures was 0.4°C.

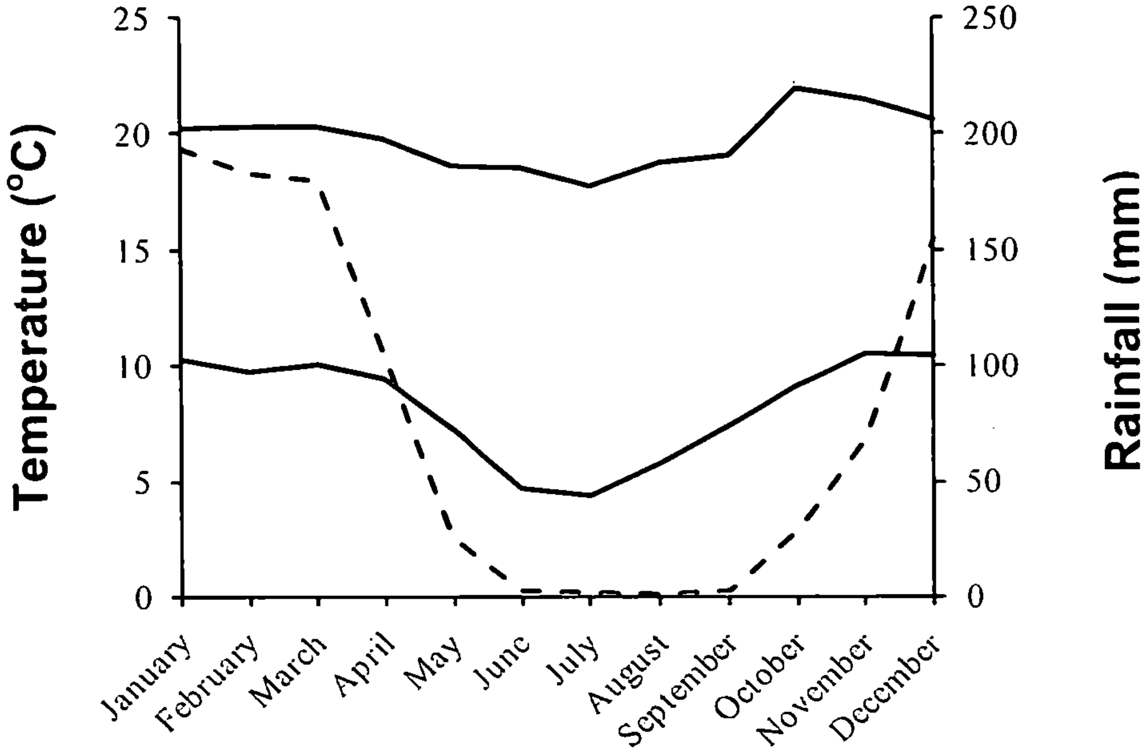


Figure 5.1: Mean monthly minimum and maximum temperatures (solid lines) and rainfall (dotted line) for Chilinda camp from January to December.

Seed age

The loss of viability of seeds with time was investigated. This involved germination of recently collected, one year old and two year old seeds under light/dark and constant and fluctuating temperature treatments.

Viability tests

Complete germination rarely occurs when undertaking germination experiments (Scott *et al.*, 1984). Therefore, the seeds that fail to germinate at the end of each germination trial need to be tested to see if they are alive or dead. There are various techniques for testing viability. The quickest and most commonly used is the Tetrazolium test (Bedell, 1999) which was used in this study. The test was based on Baskin & Baskin (1998), the Association of Official Seed Analysts (1985) recommendations, and the International Seed Testing Association (1985) procedures as follows:

i. The seeds were soaked in water for six hours to make them easy to dissect and to facilitate staining by Tetrazolium chloride. The time limit of six hours was selected based on the imbibition tests which showed maximum imbibition after 6 hours (data not shown).

ii. Each seed was sliced from the radicle end and immersed in 0.1% solution of 2,3,5 – triphenyl – 2H – tetrazolium chloride (TTC).

iii. Seeds from each treatment level of each experiment were placed in individual 5cm diameter plastic Petri dishes, which were then wrapped with 2 layers of aluminium foil and incubated at room temperature for 16 hours.

iv. After this incubation period, the seeds were cut lengthwise to evaluate the stains of the embryos. If the embryo was viable, it turned red or pink because the production of hydrogen ions during respiration, upon combining with TTC, makes it turn that colour. Non-viable seeds were those that did not turn red or pink.

5.3.2 Data analyses

Curve-fitting of the cumulative germination curves (the proportion of germinated seeds through time) was employed to compare treatment responses (Scott *et al.*, 1984). A new model developed by Franco *et al.*'s (2007) was used to determine the course of germination. This model was preferred because it is simple and provides a standard account of the germination process (Franco *et al.*, 2007). The model has the form:

$$G = S_0\left(1-\left(1-\frac{g}{1+e^{-b(t-t_0)}}\right)^t\right)$$

Given the observed final percentage of germinated seeds (S_0) and the empirically recorded proportion of germination (G) over time (t), it is possible to estimate the intrinsic rate of germination (g), the change in germination rate over time (b) and the time-lag of this response (t_0). S_0 was obtained from the data while g, b and t_0 were estimated by non -linear regression using SPSS 14.0 for Windows (SPSS Inc., 2006). The Levenberg-Marquardt method with sum of squared residuals loss function was employed.

The estimated values of g, b and t_0 were fed back into the model equation to plot the expected cumulative germination curve. For the temperature gradient experiment, the relationship between parameter values and temperature was investigated employing second degree polynomials. These allowed estimation of the optimum temperatures for each parameter as the point at which the first derivative is equal to zero.

The first derivative of Franco *et al.*'s model presented above quantifies the changing (seed population) rate of germination with time:

$$\frac{dG}{dt} = -S_0\left(1-\frac{g_0}{1+e^{-b(t-t_0)}}\right)^t\left(\ln\left(1-\frac{g_0}{1+e^{-b(t-t_0)}}\right)-\frac{g_0 b e^{-b(t-t_0)} t}{\left(1-\frac{g_0}{1+e^{-b(t-t_0)}}\right)\cdot\left(1+e^{-b(t-t_0)}\right)^2}\right)$$

This is a probability density function, scaled by S_0, whose essential parameters (mean, median, skew, kurtosis and time taken for specific percentiles to germinate ($t^{\%}$)) can be calculated. These parameters were calculated in Maple 10 (Maplesoft, 2005).

For chilling and light/dark treatments, a t-test was used to determine differences between treatments, while one-way Analysis of Variance (ANOVA) was used to compare means among temperature treatments and age groups (Zar, 1999).

5.4 Results

5.4.1 Germination response

Stratification

Chilled and non-chilled seeds germinated equally well under constant temperature. The course of germination was the same at 24°C. The onset of germination occurred rather quickly: 3 days for chilled seeds and 4 days for unchilled ones. Similarly, there was no significant difference in the final percentage of germination (chilled = 72%; non-chilled = 68%) (t=0.539; df=18; p>0.05) (Figure 5.2). All non-chilled seeds were capable of germinating under the two alternate temperature regimes. However, chilled seeds did not germinate in light at 20/5°C (Figure 5.3).

Photoblastism

Germination was not dependent on light. The seeds germinated in light and dark. Nonetheless, they germinated better in light than in dark under the constant temperature of 24°C (Figure 5.2), and the difference between light and dark treatments was significant (t=2.924, df=18, p<0.05). Germination in dark was higher than in light under alternate temperatures (Figure 5.3). However, given the low germination in the 20/5°C treatment, this result must be taken with caution.

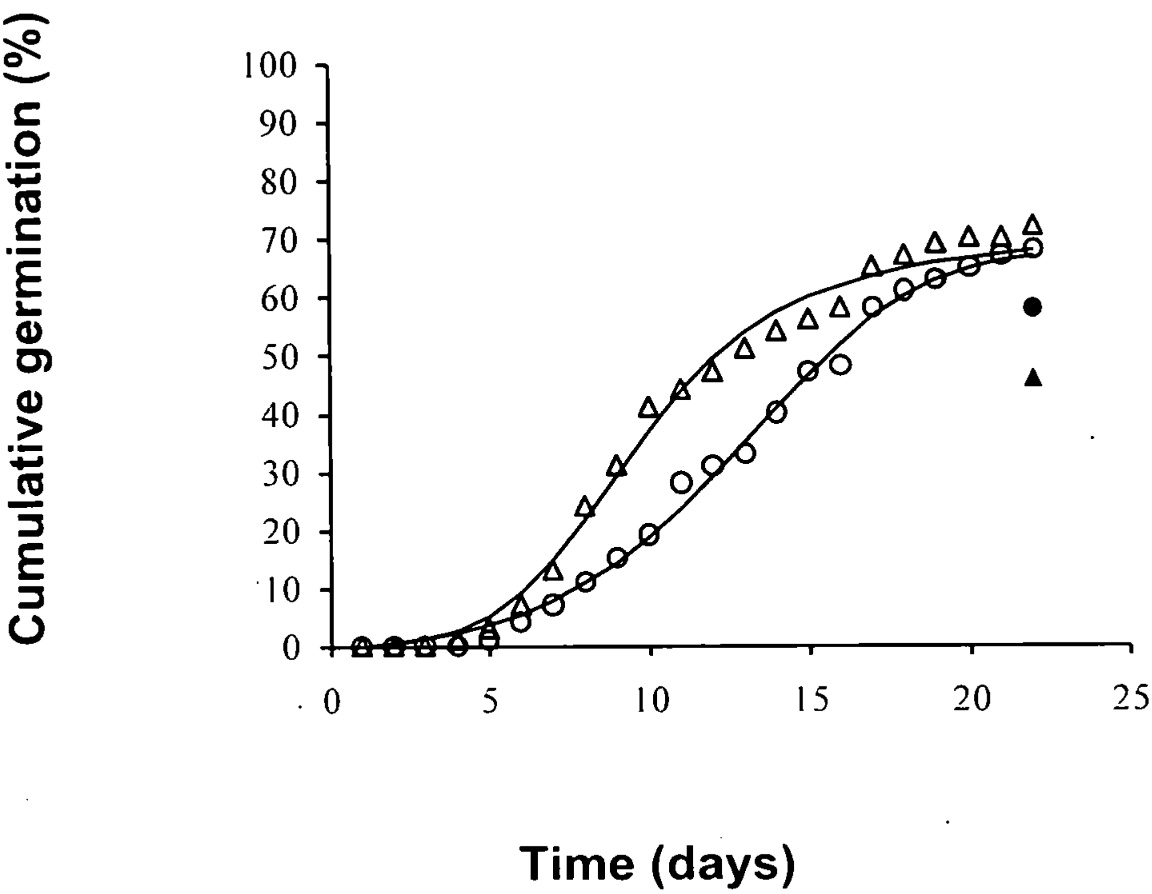


Figure 5.2: Response of *Berberis holstii* seeds to light. Seeds were germinated in light (open symbol) and dark conditions (filled symbol) under constant temperature of 24°C. Seeds were either pre-stored at room temperature (circles) or pre-chilled (triangles).

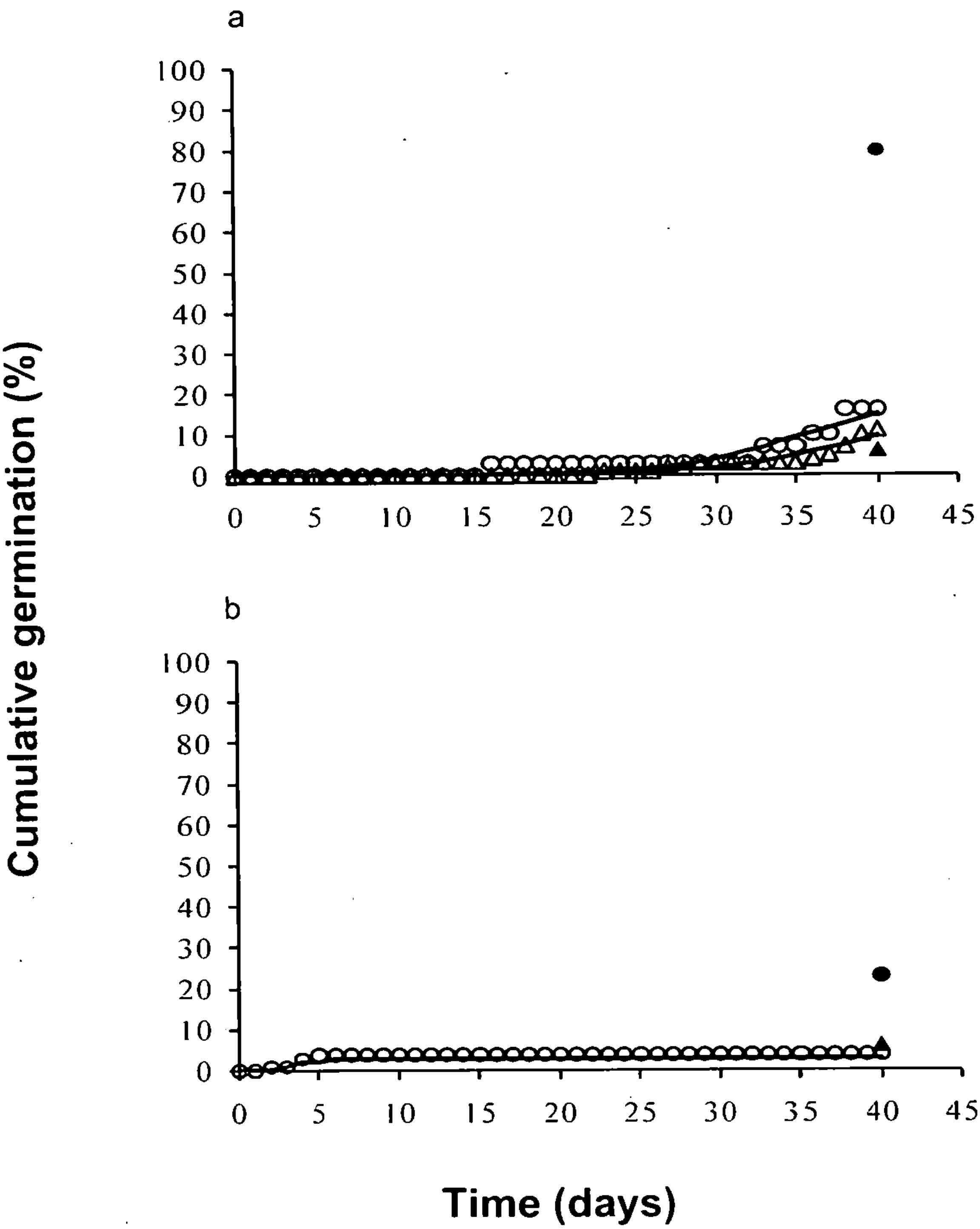


Figure 5.3: Response of *Berberis holstii* seeds to fluctuating temperatures 20/10°C (a) and 20/5°C (b). Seeds were either pre-stored at room temperature (circles) or pre-chilled (triangles) and germinated in light (open symbols) or dark conditions (filled symbols).

Temperature

The seeds germinated better at a constant temperature of 24°C and at the fluctuating 20/10°C temperatures in the dark (Figures 5.2 and 5.3). Under these conditions they exhibited ~70-80% germination. Germination at 20/5°C in the dark was 23% (Figures 5.2 and 5.3). On the temperature gradient, the seeds germinated between 10°C and 30°C. Germination parameters peaked at around 20°C (optimum) and decreased away from it on either side. The shortest time-lag was attained at around 20°C while the longest time-lag occurred at 10°C (8 days versus 24 days respectively) (Figures 5.4 and 5.5).

Seed age

The seeds did not lose viability after two years of storage under laboratory conditions. Germination of one year old seeds was highest irrespective of treatment (Figures 5.5 and 5.6). As expected, on the temperature gradient, there were significant differences in the germination response of the seeds between the seven temperatures (newly collected seeds: $F = 7.059$, df = 4, $p<0.001$; one year old seeds: $F = 11.473$, df = 5, $p<0.001$; two years old seeds: $F = 29.231$, df = 6, $p<0.001$).

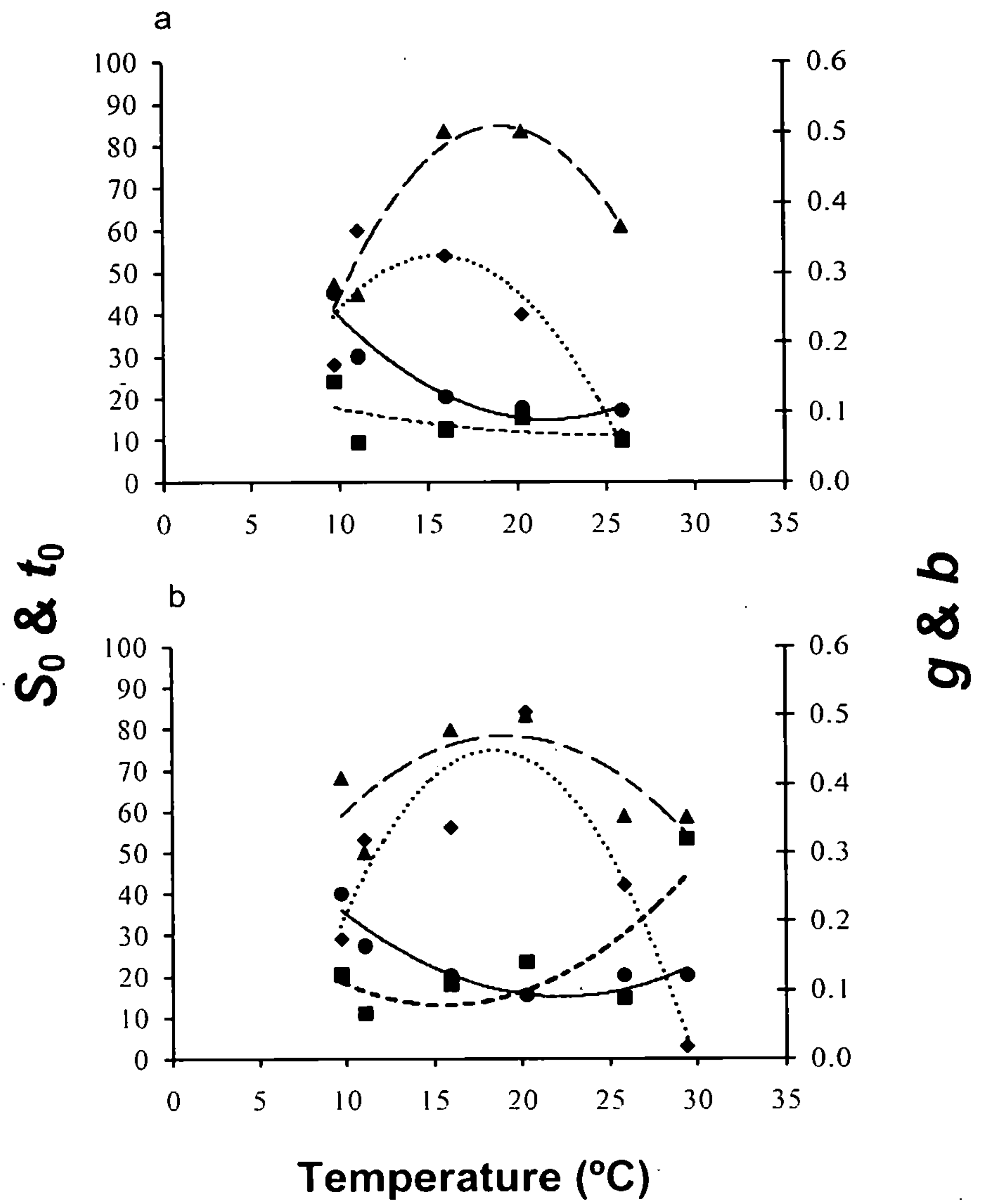


Figure 5.4: The response of germination parameters for recently collected (a), one-year old (b) and two-year old (c) seeds to temperature. Parameters are: S_0 = final germination percentage (rhomboids), g = intrinsic rate of germination (squares), b = change in germination rate with time (triangles), t_0 = time-lag (circles). The fitted lines are: long-dashed = b; round dotted = S_0; short-dashed = g; solid = t_0.

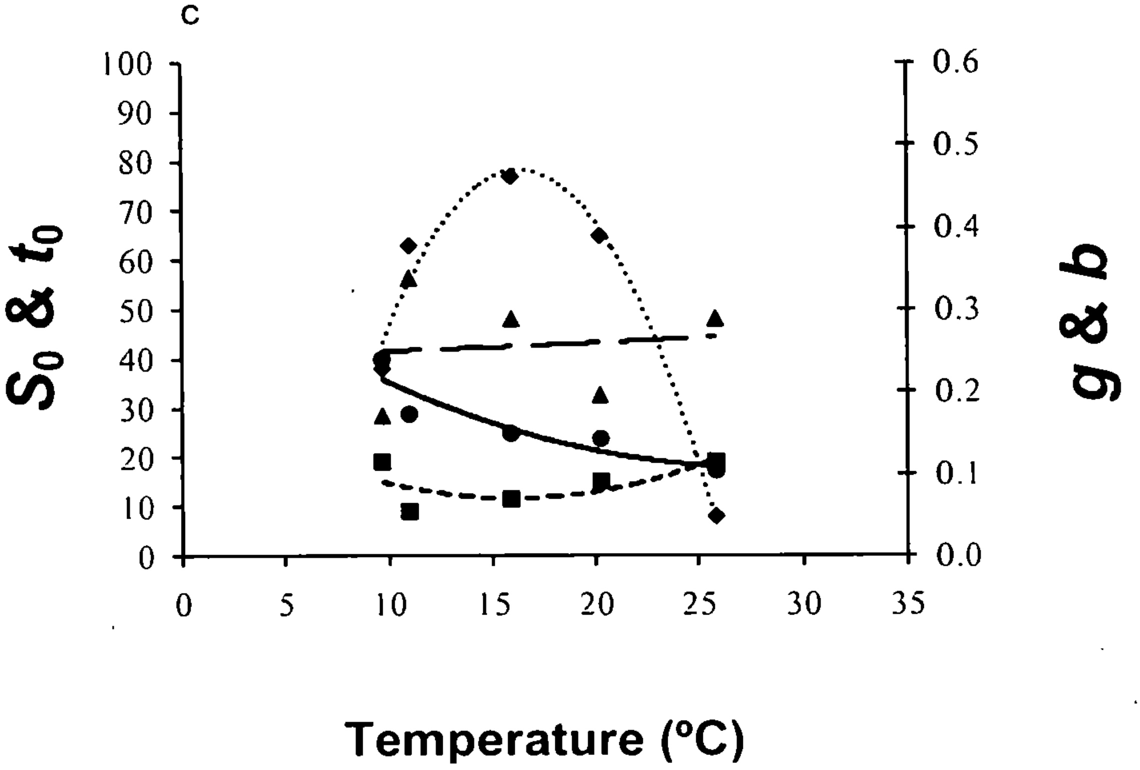


Figure 5.4: Continued.

Final cumulative germination percentage (S_0), change in germination rate over time (b) and time-lag (t_0) showed quadratic relationships with temperature. The optimal temperature for parameters S_0, g and b varied between 15.4 and 19.4°C (Table 5.1). For t_0, however, the temperature that produced the shortest delay in germination was always high, including the prediction (extrapolation) from the quadratic model that a high temperature outside the range employed in the experiment would yield the shortest delay (Table 5.1). That is, t_0 decreased with temperature within the range of temperatures employed in the experiment.

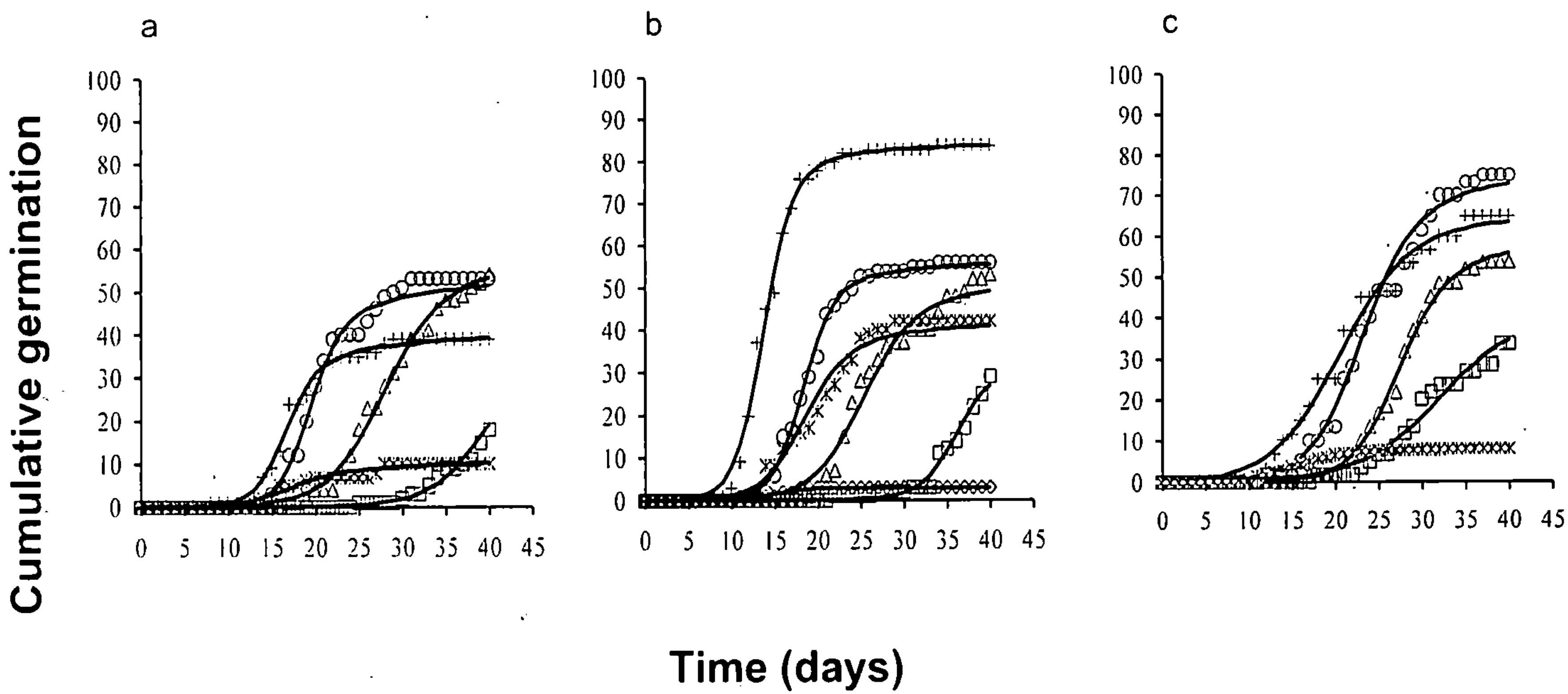


Figure 5.5: Germination response of recently collected (a), one-year old (b) and two-year old (c) seeds on a temperature gradient. The temperatures were: 10°C (square), 12°C (triangle), 17°C (circle), 21°C (cross), 26°C (asterisk) and 30°C (rhomboid). Temperature levels at which germination did not occur were excluded.

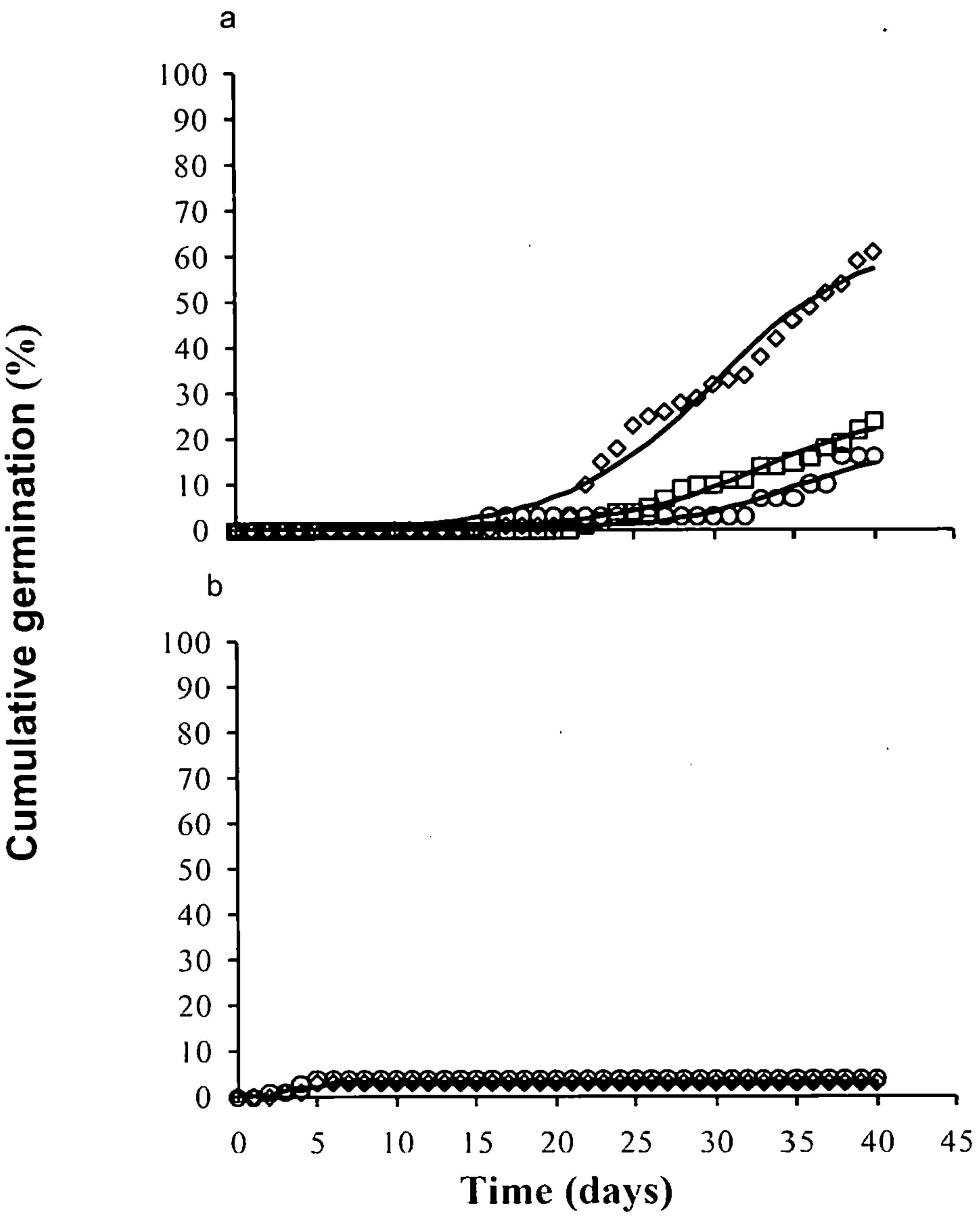


Figure 5.6: Germination response of recently collected (squares), one-year old (rhomboids) and two-year old seeds (circles) to fluctuating temperatures of 20/10°C (a) and 20/5°C (b).

For newly collected and two year old seeds, the intrinsic rate of germination (*g*) remained relatively constant but rose sharply beyond 20°C for one year old seeds. t_0 decreased with temperature for all the age groups while the highest change in *b* occurred at ~20°C for recently collected and one year old seeds. There was no clear trend for two year old seeds (Figure 5.4 and Table 5.1).

Germination rate

In terms of daily germination, the seeds attained higher daily germination rate under the temperature gradient than under fluctuating temperatures (Figures 5.7 and 5.8). On the temperature gradient, the rate reached values as high as 12 seeds per day while the maximum rate for fluctuating temperatures was 3 seeds d^{-1}.

On the temperature gradient, the highest germination rate was attained with one year old seeds at 21°C. For the other two seed ages (i.e., recently collected and two-year-old), the highest rate of germination was attained at the lower temperature of 17°C. Under alternate temperature, the germination rate was lower than the rate obtained at constant temperature experiment. The highest germination rate was reached at 20/10°C for one-year-old seeds (3 seeds d^{-1}). In addition to the rate being low, compared to the constant temperature experiment, there was a long time lag and corresponding skew at 20/10°C (Figure 5.8).

Table 5.1: Germination parameters of recently collected (0y), one-year old (1y) and two-year old seeds (2y) germinated on a temperature gradient.

Temperature (°C)	r^2			S_o			g			b			t_0		
	0y	1y	2y	0y	1y	2y	0y	1y	2y	0y	1y	2y	0y	1y	2y
10	0.986	0.984	0.987	28.0	29.0	38.0	0.14	0.12	0.12	0.28	0.41	0.17	45.0	40.0	40.0
12	0.995	0.985	0.995	60.0	53.0	63.0	0.06	0.07	0.05	0.27	0.30	0.34	30.0	27.3	28.8
17	0.993	0.998	0.994	54.0	56.0	77.0	0.08	0.11	0.07	0.50	0.48	0.29	20.5	20.0	25.0
21	0.996	0.998	0.993	40.0	84.0	65.0	0.09	0.14	0.09	0.50	0.50	0.20	17.7	15.2	23.9
26	0.977	0.988	0.981	11.0	42.0	8.0	0.06	0.09	0.12	0.37	0.35	0.29	17.3	20.0	17.5
30		0.982			3.0			0.32			0.35			20.0	
S_o	0.83	0.88	0.97												
g	0.25	0.87	0.46												
b	0.95	0.50	0.95												
t_0	0.88	0.63	0.88												
Optimal temperature				16.3	18.4	16.2	18.8	15.4	16.0	18.9	19.4	18.8	33.1	22.3	36.01

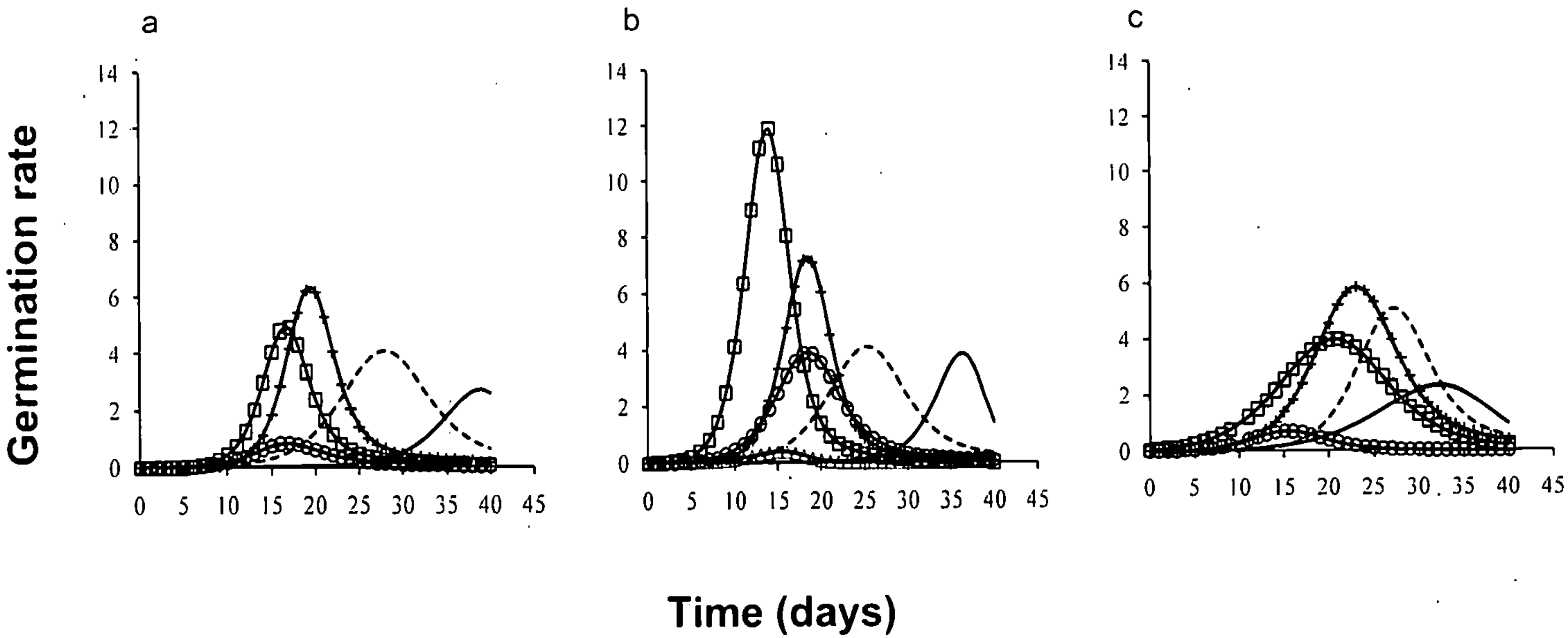


Figure 5.7: Daily germination rate of recently collected (a), one year old (b) and two year old seeds germinated over a temperature gradient. The temperatures were: 10°C (unmarked solid line), 12°C (dotted line), 17°C (line with crosses), 21 °C (line with squares), 26°C (line with circles) and 30°C (line with triangles).

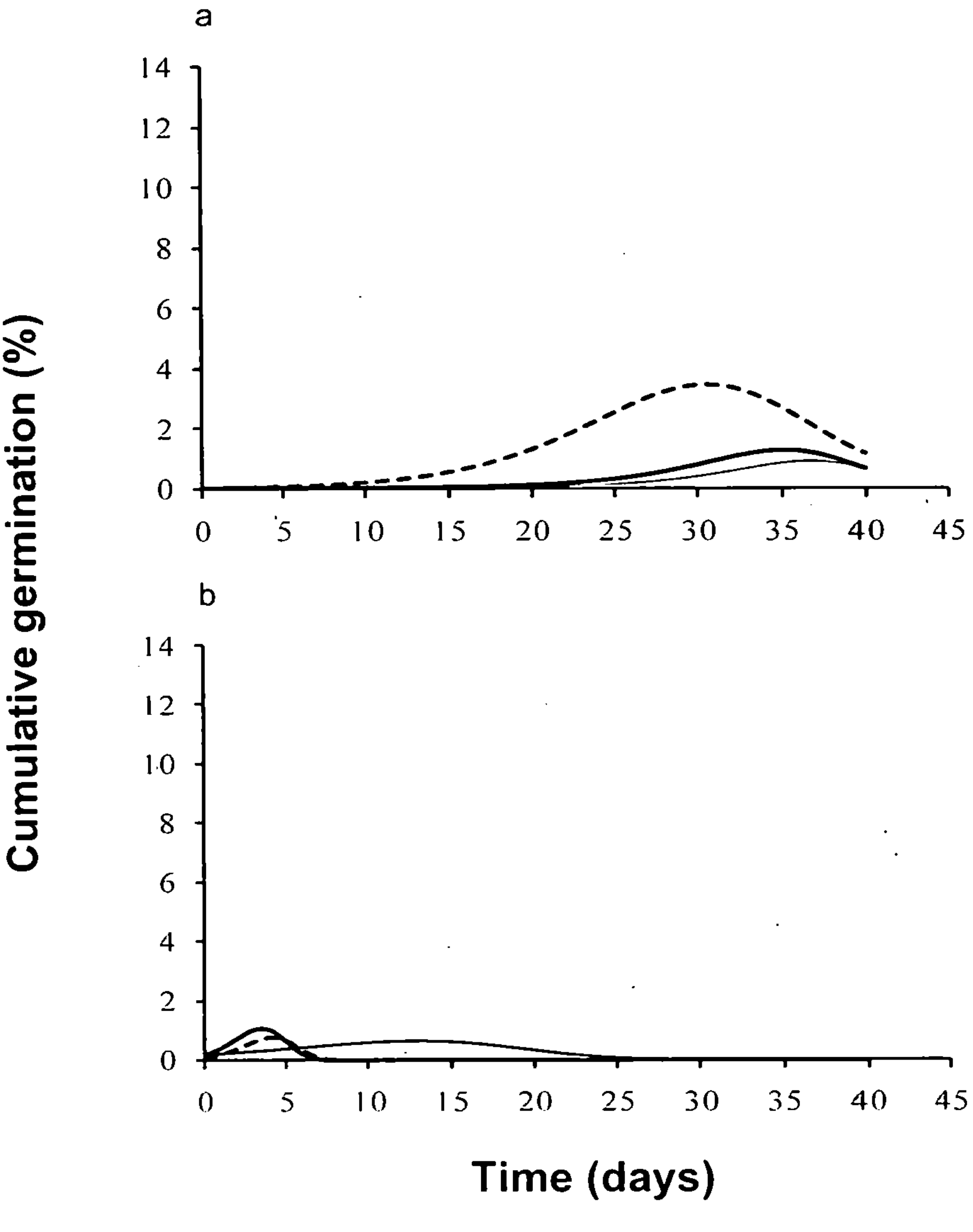


Figure 5.8: Daily germination rate of one year old (dotted line) and two year old (solid line) seeds under fluctuating temperatures 20/10°C (a) and 20/5°C (b). Two year old seeds were either pre-chilled (thin line) or pre-stored at room temperature (thick line).

Ignoring the highest temperatures where low germination provides a poor estimate of parameter values, the fastest germination, as measured by the inverse of the time that it takes for a percentile of the seed population to germinate ($1/t^{\%}$) occurred near 20°C for recently collected and one year old seeds. This optimum, however, did not occur in two-year-old seeds (Figure 5.9).

5.4.2 Viability of the seeds

In the chilling and light/dark treatments, few viable seeds remained out of the seeds that failed to germinate at 24°C. For the seeds that had been pre-chilled and exposed to light, all the viable seeds germinated. This was followed by seeds that had been stored at room temperature and sown under light (Figure 5.10). For 20/10°C treatment, there was almost an equal proportion of viable ungerminated seeds (pre-stored at room temperature) between those germinated in light and those germinated in darkness (15%). At 20/5°C, all seeds that were viable germinated provided they were pre-stored at room temperature and germinated in light (Figure 5.11).

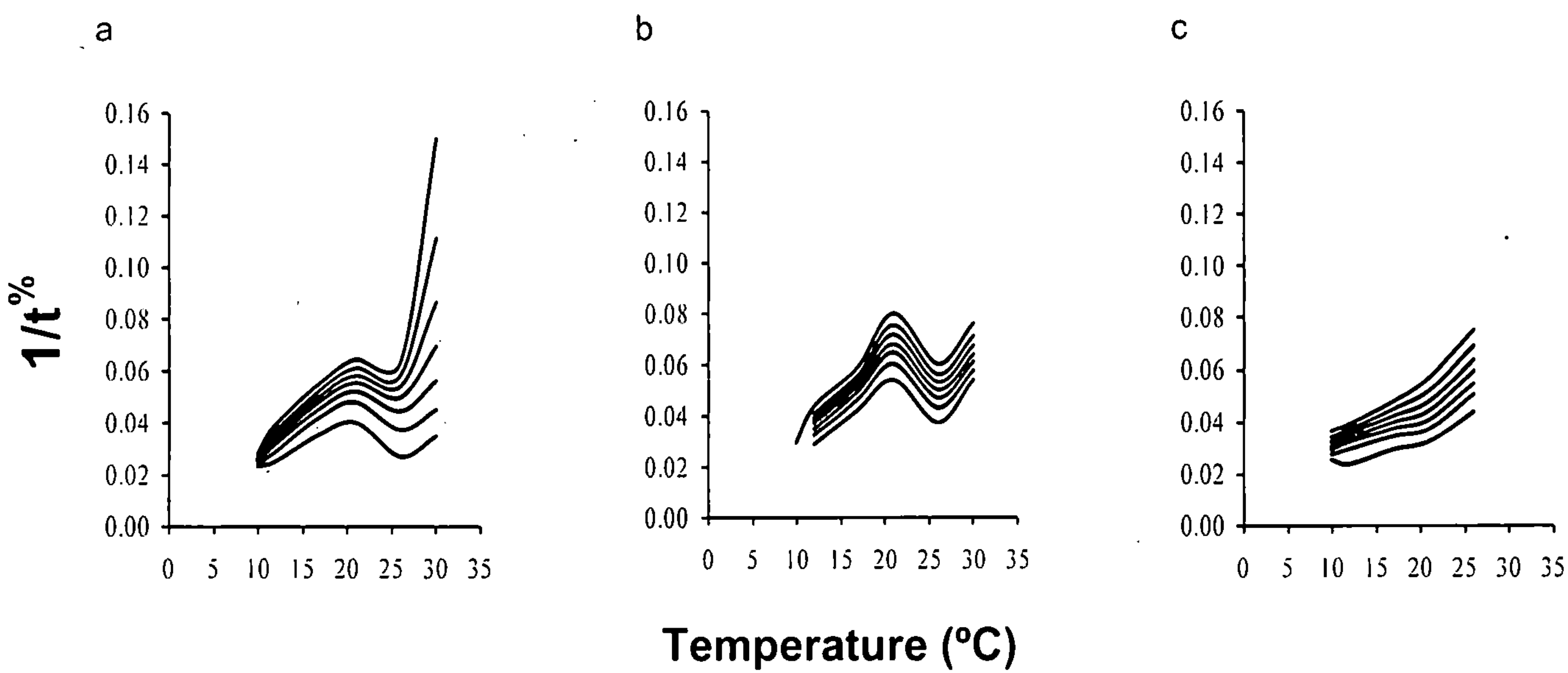


Figure 5.9: The inverse of time taken for seven percentiles of germination to be achieved ($t^{\%}$) for recently collected (a), one year old (b), and two year old (c) seeds. These percentiles range from 30 to 90 ordered from top to bottom in steps of 10.

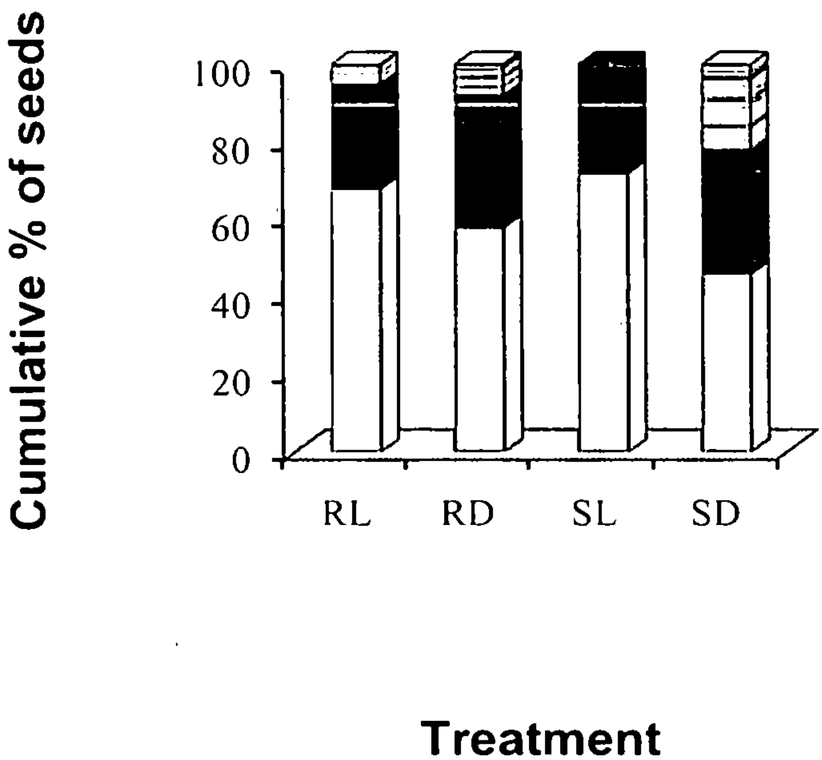


Figure 5.10: Viability of seeds under four combinations of light and stratification treatments sown at 24°C. Seeds were either pre-stored at room temperature (R) or stratified (S) and germinated in light (L) or dark (D) conditions. White shade = germinated seeds; black = non-viable seeds; shaded = viable ungerminated seeds.

In the temperature gradient, the seeds died at temperatures away from the optimum. The proportion of viable, ungerminated seeds was small and relatively constant. Given the fact that the proportion of dead seeds increases away from the optimum temperature, it is likely that these live, ungerminated seeds were dying as a result of high temperature (Figure 5.12).

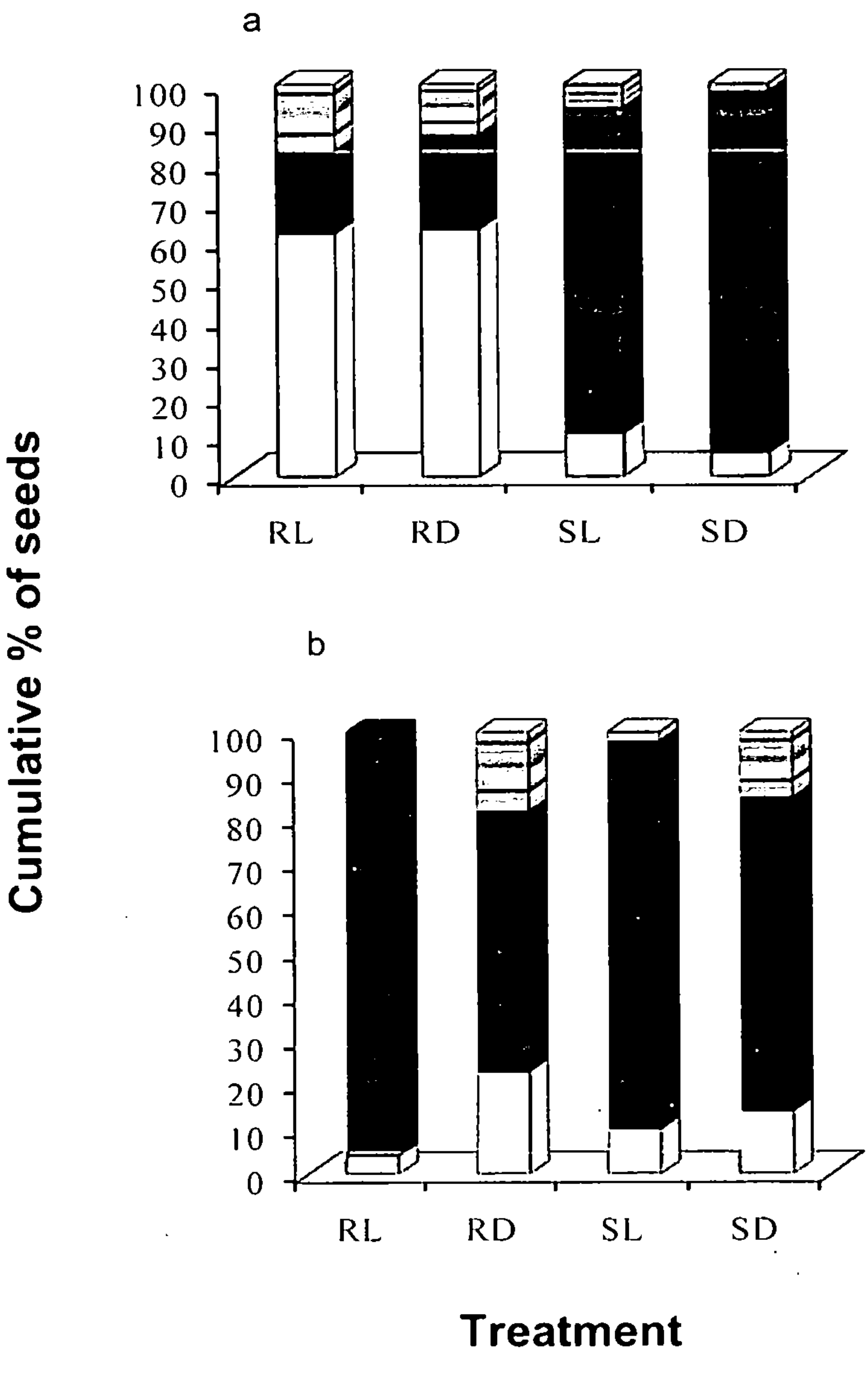


Figure 5.11: Viability of seeds under fluctuating temperatures 20/10°C (a) and 20/5°C (b). Seeds were either pre-stored at room temperature (R) or stratified (S) and germinated in light (L) or dark (D) conditions. White shade=germinated seeds; black=non-viable seeds; shaded=viable, ungerminated seeds.

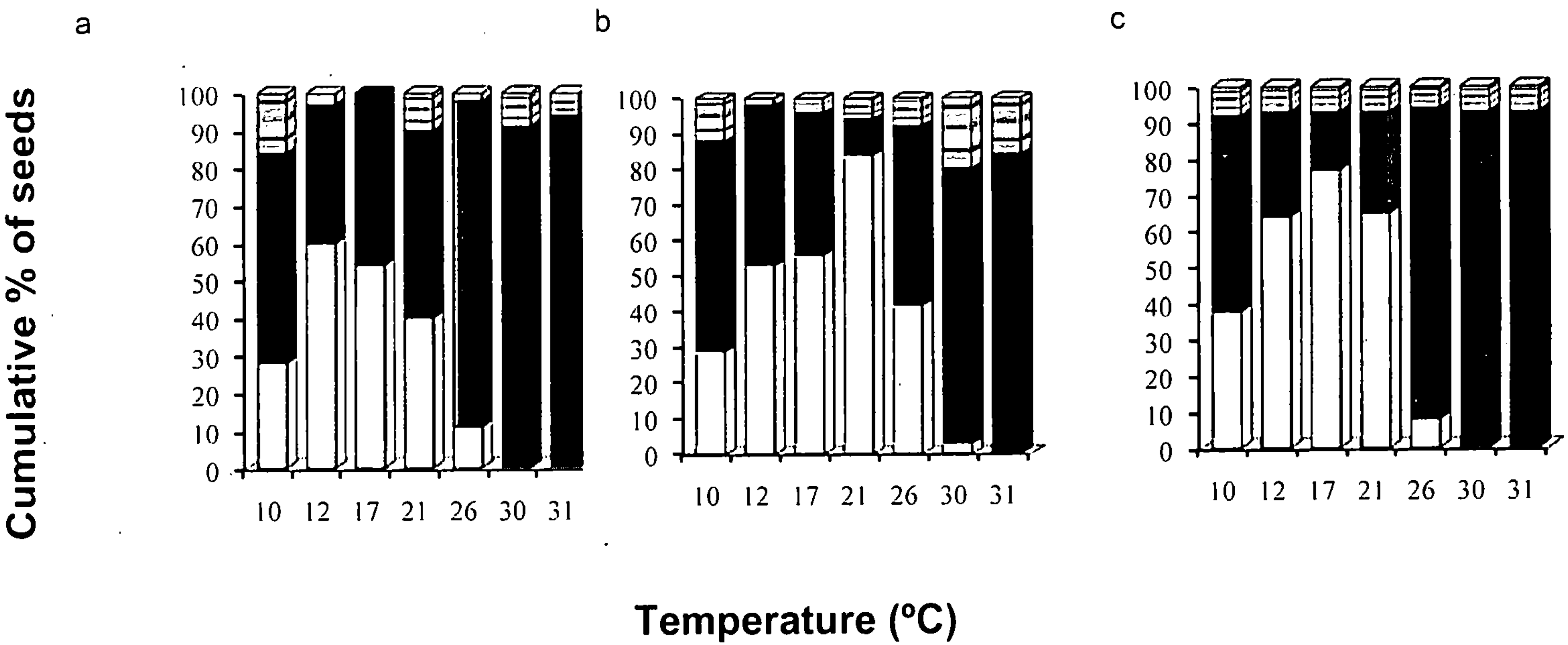


Figure 5.12: Viability of recently collected (a), one-year old (b) and two-year old seeds (c) germinated on a temperature gradient. White shade = germinated seeds; black = non-viable seeds; shaded = viable, ungerminated seeds.

5.5 Discussion

5.5.1 Germination response

Stratification

Although seeds did not require stratification to germinate, cold-stratified seeds germinated faster than those kept at room temperature. As observed by Fountain and Outred (1991), many temperate species require cold stratification to germinate. As with other members of the genus, this is expected for *Berberis holstii* inhabiting the climatically temperate Nyika plateau (Meadows, 1982).

Photoblastism

Although seeds germinated in both light and darkness under a constant temperature of 24°C, the final percentage of germination was lower in the dark. This suggests that seeds in the dark may be more prone to attack by pathogens than seeds under light conditions, particularly if the aluminium foil employed to wrap the Petri dishes kept a moister environment in them. The higher germination in the dark than under light at a fluctuating temperature of 20/10 °C suggests that the aluminium foil may have buffered the changes in temperature in the growth cabinet. Ecologically, the ability of the seeds to germinate in light and dark means that the seeds can germinate either buried or exposed on the surface of the soil, provided other factors, such as adequate temperatures necessary for germination, are also present. These characteristics suggest that *B. holstii* cannot form a persistent soil seed bank (Fenner and Thompson, 2005, Pons, 2000).

Persistent soil seed banks are useful in habitats which are exposed to frequent fire disturbances like Nyika. However, as the Population Dynamics Chapter has shown, *B. holstii* seems to be able to cope with this periodic disturbance by means of vegetative rather than sexual propagation.

Temperature

Berberis holstii seeds had their highest percentage of germination at a constant temperature of 17-21°C. Fluctuating temperatures, including 20/10°C did not produce good germination presumably because the sudden changes simulated in the growth cabinets were detrimental to the seeds. This is particularly evident in the 20/5°C treatment.

Under constant temperature, the seeds germinated between 10°C and 30°C with the optimum in the range 17-20°C. Thus, dormancy release occurred over a wide range of temperatures. Extrapolation of the results presented in Figure 5.4 suggests that temperatures below 8°C and above 30°C completely prevent germination, with the seeds dying (Figure 5.12). The optimum temperature of 20°C is the mean monthly maximum temperature prevalent in the Nyika Plateau.

Seed age

Interestingly, seeds did not lose viability during the two years of storage. This raises the possibility of artificial storage for conservation purposes. The higher germination ability of one-year-old seeds suggests the need for post-dispersal ripening.

Under field conditions, where seeds are dispersed at the end of the autumn (May), this behaviour would allow them to remain dormant during the winter and be ready for germination in the spring (September-November). Given their weak response to cold stratification, delayed ripening could also operate as a mechanism to prevent germination during mild winters, which would leave the seedlings exposed to sudden drops in temperature or drought during the rest of winter or in the spring.

5.5.2 Viability of the seeds

The results of the viability tests of seeds that failed to germinate revealed that suboptimal conditions were lethal to the seeds. That is, suboptimal conditions not only did not bring seeds out of dormancy, but their mortality increased. Thus, none of the non-germinated seeds that had been pre-chilled and germinated under light, at constant temperature, was viable. Similarly, seeds that had been stored at room temperature and germinated under light had the lowest number of viable non-germinated seeds.

5.5.3 Implications on dormancy

The ability of recently collected seeds to germinate suggests that the seeds are non-dormant during dispersal (Gleiser *et al.*, 2004) and that the few seeds that seemed dormant would have germinated with time. Based on the trials conducted in this study, it is evident that chilling, light, temperature and age play a role in breaking dormancy. When combined with light, chilling had the effect of breaking dormancy under constant temperature.

Light also broke dormancy under constant temperature, but it inhibited germination under alternate temperatures. The most effective temperature to break dormancy was 20°C; however, fluctuating temperatures, particularly 20/5°C had a negative effect on germination. Storage for one year had the best effect on dormancy-breaking.

5.6 Summary

Seedling recruitment is important for the dispersal of *Berberis holstii* in both space and time. It is also essential for the creation of novel genotypes essential for continuous adaptation. This chapter assessed germination requirements of *B. holstii*. The following findings were significant:

i. Seeds did not require chilling to germinate, but cold-stratified seeds germinated faster than those kept at room temperature.

ii. Seeds germinated in light and darkness implying they are unlikely to form a persistent soil seed bank, an attribute which is common in species of habitats exposed to frequent fire disturbances.

iii. Light enhances germination of the seeds.

iv. Seeds germinated between 10 and 30°C with the optimum at ~20°C. Temperatures away from the optimum are lethal to the seeds, the intensity of seed mortality increasing away from this optimum.

v. Seeds did not lose viability during the two years of storage, raising prospects of artificial storage for conservation purposes.

vi. A combination of the following conditions provide optimal germination: ripe, one-year-old seeds, chilling prior to germination, and germination under light at 20°C.

Chapter 6

General discussion and conclusions

6.1 Introduction

The economical, cultural, medical, ecological and evolutionary importance of biological diversity is undisputed and this importance is recognised by the Convention on Biological Diversity (CBD, 2000). Although this importance permeates every level of society in every country, biological diversity probably plays a more direct role in the daily livelihood of people in tropical, economically underdeveloped countries. In these countries, biological resources provide a variety of essential benefits covering healthcare, food and fuel.

Due to an ever-increasing worldwide population, these biological resources are being depleted at a fast rate. In order to conserve them, many measures can be put in place. One of them is the creation of a global network of protected areas (Soutullo *et al.*, 2007). These efforts, however, face problems that deter them from achieving their conservation objectives (Stoner *et al.*, 2007). The challenges are different between developed and developing countries (Shafer, 1999). In the latter, one of the contributing factors is the lack of resources and income-generating alternatives.

This study used Nyika National Park in northern Malawi to highlight the plight of a protected area in a resource-limited country by reference to one plant species. The park is faced with a conflict between conservation and the demand for resources from local communities. The study focussed on *Berberis holstii*, a plant resource that is on highest demand among the people living within and outside the park. The plant is of particular conservation interest because it is an African endemic, the only representative of its genus in tropical Africa.

In Malawi, its southernmost limit, it is restricted to the Nyika Plateau. In addition, efforts to ban its utilisation have proved futile and attempts to propagate it outside the park have failed.

Although the study was specific to Nyika, the findings are of wider interest because *Berberis* is an important genus worldwide. The genus is widely distributed, particularly in the northern hemisphere, where it originates, with centres of diversity in Asia, North America and South America (Kim *et al.*, 2004, Bottini *et al.*, 2007). There are over 500 species of *Berberis* but only two exist in Africa. *B. vulgaris*, in northern Africa but with a wider natural distribution in central and southern Europe and western Asia (Tehranifar, 2003, Elkhateeb *et al.*, 2007, Ivanovska and Philipov, 1996, Kulkarni and Dhir, 2007, Peychev, 2005, Williams and Karl, 1996), and *B. holstii*, restricted to the eastern mountain range of Africa. *Berberis* species are valuable because of their medicinal properties due to the alkaloids they contain (Istatkova *et al.*, 2007). They are also used as ornamentals, preservatives and dye. The fruits can be eaten raw or processed into preserves (Aslantas *et al.*, 2007, Heywood and Chant, 1982, Whittemore, 1997). Because of the medicinal value of *Berberis* species, a substantial amount of pharmacological research has been conducted (Istatkova *et al.*, 2007). Little is known, however, about the ecology of *B. holstii.*

The study provided background information on the importance of biological resources, particularly in developing countries (Chapter1). It then investigated why *B. holstii* is on demand in Nyika (Chapter 2). Chapter 2 also documented sites where *B. holstii* is collected.

This information was used in Chapter 3 to map *B. holstii*'s distribution. In order to understand the distribution pattern, the sites were investigated in terms of their floristic and environmental characteristics. Chapter 4 investigated the demographic properties of five populations in sites varying in time since last disturbance and population structure. Linkages to anthropogenic disturbance were assessed and preliminary sustainable management practices were suggested. Chapter 5 investigated the seed germination requirements of *B. holstii*.

6.2 Ethnobotany

As mentioned in Chapter 2, ethnobotany is important because it ensures that ethnobotanical knowledge, which has traditionally been passed orally, is transferred in a reliable way. Ethnobotanical information is important because it gives insights into the synergies that exist between humans and their environment. Documentation of ethnobotanical information started during the Assyrian, Indian and Chinese civilizations (around 1500 BC) (Given and Harris, 1994). Since its inception, ethnobotany was regarded as non-scientific; but became recognised as science around the mid 20^{th} century (Schultes and Von Reis, 1995). Nowadays there is realisation of the importance of traditional knowledge in bio-prospecting and global efforts of biodiversity conservation (Cotton, 1996). Ethnobotany is currently regarded as part of ethnobiodiversity and ethnoecological disciplines (Barrera-Bassols *et al.*, 2006).

Ethnobotanical research is now a complex discipline because of its ability to address theoretical and applied issues concerning the relationships between people and plants (Turner, 2000). Ethnobotany also increases awareness on poorly-known wild resources, hence guiding their scientific study (Jaric *et al.*, 2007, McClatchey, 2005). Ethnobotany is also important in the management of protected areas. These areas comprise a matrix of social and ecological problems, hence their study can be approached from both the social and natural sciences (Lovejoy, 2006). Ethnobotany is an approach through which conflicts which often exist between local people and protected area managers can be resolved through a better understanding of people's perceptions of the problems they face and the solutions they feel would be effective; hence, mutual agreements can be sought (Maikhuri *et al.*, 2000). Despite the importance of ethnobotany, there still remain several countries where little ethnobotanical research has been done (Qureshi *et al.*, 2007, Cotton, 1996, Kokwaro, 1993). Moreover, few ethnobotanical studies have been conducted in protected areas (Maikhuri *et al.*, 2000). Therefore the information collected in this study contributes to fill this gap. The information also contributes to the objectives of the Convention on Biological Diversity, Agenda 21 and the Agreement on Forestry which advocate for preservation of indigenous knowledge (Turner, 2000).

Toledo (1992) and Davidson-Hunt (2000) recommend the need for people with different expertise to work together in order to better understand the relationship between humans and their environment. This study provides an alternative approach which can be pursued in future studies.

Instead of different people teaming up (which might be impractical and expensive in some cases), ethnobotany scholars should be trained to use multi-disciplinary approaches as has been used in this study (e.g. Biogeography, Demography and Germination ecology). This will enable future ethnobotanists to undertake research with a wider scope hence increase their understanding on issues related to biodiversity conservation.

Among the findings of this study, 47 uses of *B. holstii* were recorded, 30 of which were medicinal. Cough, malaria, stomachache, sexually transmitted infections and pneumonia were the most commonly mentioned uses. The non-medicinal uses were for income generation and luck. These uses account for the demand of *B. holstii*.

Although no pharmacological studies of *B. holstii* have been conducted, the fact that some of the medicinal uses are similar to those of other *Berberis* species suggests that it may contain similar properties. For example, in the case of the topmost mentioned ailments, the following Berberis species have been confirmed to have the required properties:

- Cough: *B. lyceum* has properties that suppress cough (Asif *et al.*, 2007).
- Malaria: *B. erectica* has antimalarial properties (Fokialakis *et al.*, 2007).
- Stomachache: *B. aristata* and *B. lyceum* have properties for treating acute dysentery (Asif *et al.*, 2007, Sack and Froehlich, 1982).

- Sexually transmitted infections: *B. heterophylla, B. aetnensis* and *B. sibirica* have antifungal activity against *Candida* species which is responsible for genital tract infections (Freile *et al.*, 2003, Iauk *et al.*, 2007, Istatkova *et al.*, 2007, Levine *et al.*, 1998, Wawer *et al.*, 1999).
- Pneumonia: *B. aristata, B. asiatica, B. chitria* and *B. lycium* have antimicrobial activity against *Streptococcus pneumoniae,* the main cause of pneumonia (Heffelfinger *et al.*, 2000, Ruiz-González *et al.*, 1999, Singh *et al.*, 2007).

Despite limited transport and the illegality of the practice, people travel long distances (up to 150km) to collect the plant. Although there are 57 plant species that people report can be used as *B. holstii*'s substitutes, people prefer the latter.

The demand for *B. holstii* has potential conservation consequences. In some places, collection of *B. holstii* has resulted in local extinction of the populations. Extinction has occurred in five of the 71 sites that were studied, and is therefore cause for concern. In the long run, the harvesting methods used are not sustainable. This is because, by collecting the roots of large reproductive individuals and not putting back the soil after collection, thus preventing the possibility of propagation from root remnants, the negative effect on the population is magnified. In addition to this, because the distance travelled to collect the plant can be long, people tend to collect as much as possible (up to 25kg per trip).

Hedberg *et al.* (1982) and Kokwaro (1993) report that roots are used in Tanzania and Kenya, respectively, and Burrows and Willis (2005) mention the utilisation of roots in Malawi. The use of leaves and stem bark is reported here for the first time. If the medicinal properties of the plant are real and these properties are present in different plant organs, diversification of organ use may allow a more efficient use of the plant. For example, cautious use of leaves (which are produced continuously throughout the growing season) could prolong the use of individual plants considerably. Similarly, their ability to propagate vegetatively could be used to people's advantage.

6.3 Biogeography

There is need for comprehensive inventories and mapping of plant and animal species (Lovejoy, 2006). Integration of biogeographic data, Geographical Information System (GIS) and demographic data facilitates visualisation of spatial and temporal distributions; informing of possible changes that might occur in species distribution as a result of anthropogenic and natural disturbances; and delineation of areas that are biologically significant (Monaco *et al.*, 2003). An understanding of biogeographic affinities is important for efficient conservation of evolutionary history and its management to be achieved (Lourie and Vincent, 2004). However, protected areas often lack detailed biogeographic information that is critical in making comparisons between the distribution of species in these areas and the wider ecological context (Monaco *et al.*, 2003).

As mentioned in Chapter 1, protected areas play an important role in biodiversity conservation. Over the past 30 years, this role has evolved from a mere aesthetic purpose to a more dynamic and complex role (Lovejoy, 2006) where management decisions are unavoidable. Such decisions can often be informed by detailed biogeographic information, for example employing GIS data, which is amenable to efficient analytical methods (Monaco *et al.*, 2003).

Biogeographic studies have been effective in reserve selection (Prendergast *et al.*, 1999) and this study has shown that biogeographic information can aid the understanding of the factors influencing the distribution of an individual species in an area that has already been designated as protected. Thus, in addition to its value in the identification of potential reserve areas, biogeography is also useful in the investigation of the spatial and temporal dynamics of the biological diversity of protected areas.

In this study, 94 sites were documented to contain *B. holstii* (based on herbaria, literature and interview records). Of these, 65 were confirmed. Eight new sites were recorded during field surveys. The documentation by this study of eight new sites means the species may be more abundant in Nyika than previously thought. However, the study also found that the distribution of *B. holstii* is restricted to the plateau. This restricted distribution may be critical if predicted climatic changes leave *B. holstii* with nowhere to migrate to (Pauli *et al.*, 2003).

In addition to the climatic factors (as measured by altitude) that limit the distribution of *B. holstii*, this study found that its requirement for open and periodically disturbed areas, slightly acidic sandy or loamy soil with high Magnesium, intermediate Nitrogen and low Phosphorus and Potassium further restrict the areas where it can grow.

In general, the study revealed the relevance of investigating the variety of factors that limit the distribution of a species as they relate to their prospects for long-term conservation.

6.4 Demography

Population Viability Analysis (PVA) is an important tool in conservation biology. It provides a better understanding of the biology of threatened populations, aids in planning and conservation decision-making, estimates risks and values of conservation management strategies and identifies the contributions made by different life cycle stages and life history attributes to population growth (Keedwell, 2004, Menges, 2000). PVAs are contributing to a database of comparative demography of the world's biological diversity (Heppell *et al.*, 2000). Despite PVAs' importance in the conservation and management of threatened species, and their potential application in the designation of protected areas (Gaston *et al.*, 2002), few PVA studies have been conducted on species in protected areas, particularly species subject to regular poaching and disturbance.

Unlike the majority of demographic studies reported in the literature, where continuous recruitment allows the population to tend towards a stable structure, *B. holstii* recruits after the population has been killed by fire. More precisely, the aerial part of the plant dies and the population recovers the following year through vegetative propagation (ramet production) and seed germination. This means that the matrix projection from young populations recovering from a recent fire (e.g., Mpopoti) produces values of $\lambda<1$.

Although in a stable population this would mean that the population is going extinct, in a young population it simply means that the individuals are still too young to reproduce. This cohort population structure does not lend itself to the type of demographic analysis where all stages coexist (structured population models), despite the fact that the overall population is likely to contain cohorts at different stages of development. In cases such as this, a longer period of study that allows estimation of the changing structure and dynamics of the different populations (cohorts) is necessary to estimate their fate more accurately.

The complexity of natural populations and the factors that drive their dynamics has stimulated the development of new approaches to include factors such as periodic disturbance, metapopulation structure, megamatrix models that take into account the heterogeneity of the environment, and the incorporation of genetic factors (Menges, 2000, Hanski, 1999). However, these approaches were not relevant in this study because, for example, metapopulation models would have required establishing migration between populations, which, although likely, seems to occur at a very low rate. This is because seedling establishment is rare and, when it occurs, determining the origin of the seed is difficult. A study of seed dispersion and establishment is therefore recommended. Megamatrix models, on the other hand, require information on the transition probabilities between different kinds of populations. Given the potential longevity of *B. holstii*'s cohorts, this could only be achieved by extending the study over a longer period of time.

The literature on the subject may give the impression that PVAs are straightforward. This study has shown that this is not always the case. Specifically, the spatial structure of the different cohorts adds a level of complexity that demands a longer period of study. Because the information derived from each population did not always allow closure of the life-cycle graph (i.e., some transitions did not exist) the resulting matrices were reducible and non-convergent. There is a need to develop methods to project populations with complex spatial structure of the stage classes, without losing sight of the dynamics of the individual populations. A simple possibility would be the framework designed by Hemerik and Klok (2006) which caters for species that have scarce data on reproduction and survival. This framework, however, is better suited for species which mature within the first year of life.

Numerous PVAs have been conducted in which management recommendations are made. However, there is lack of follow-up studies to assess the long-term effect of the proposed management recommendations. Unless follow up studies are carried on, the predictions of PVAs, cannot be verified. Once again, this calls for longer-term studies.

This study found that *B. holstii* populations in Nyika tend to be young. This is because the fire regime used to maintain the grassland on which game depend, and which is what attracts tourists to the area, periodically reduces *B. holstii*'s cover and, if the plants survive, growth is reinitiated from the root crown. The opportunity for seedling recruitment, on the other hand, occurs either after these fire events or, presumably, when canopy gaps allow recently germinated seedlings to grow.

Although the burning period implemented by the Department of National Parks and Wildlife (DNPW) is three years, this period can be reduced, for example by fires caused by poachers. Because of their continual reduction, populations tend to have positive growth. This strongly depends on the survival and reproduction of ramets in the *J2* and *A1* stage classes. This study reiterated the importance of PVAs in conservation biology. More importantly, the study revealed some of the difficulties confronted by PVAs and the need to develop methods that attempt to resolve them.

6.5 Germination studies

6.5.1 Germination models

In recent years, and perhaps as a consequence of the failure of distribution models to model seed germination, threshold models of seed germination have gained popularity. These, however, are based on weak biological and statistical assumptions and a new model by Franco *et al.* (2008) promises to reinstate germination as a distribution process that unfolds over time. This model provides four germination parameters which uniquely identify four essential properties of the course of germination: the intrinsic rate of germination (g), the rate of change of this germination with time (b), the final proportion of germinated seeds (S_0), and the time-lag of the course of germination (t_0). The versatility of the model provides an excellent fit to the variety of monotonic germination curves found in the literature. Its logical consistency questions the validity of threshold models and the statistical treatment of data common in the literature on the subject.

This model provided a simple but thorough account of the process of germination and of the influence that different environmental cues have on the process. It allowed quantification of the optimum temperature for germination or, more accurately, of the optimum temperature for each of the four parameters. Thus, it is possible to identify, for example, that temperatures above the optimum for S_0 are still increasing germination rate; in other words, that the optimum temperature for g is higher than that for S_0. This means that, because metabolism increases with temperature, seeds may germinate faster at high temperatures while at the same time they die from heat exhaustion. This differentiation allows the investigator to choose between rapid germination or higher proportion of germination, or to balance his/her needs for speed and quantity. In the context of *B. holstii*, it allows us to plan the efficient use of the seeds of a species of conservation concern for propagation. The model thus allows a better understanding of the germination process than that provided by previous models.

6.5.2 Seed viability tests

Although viability tests have existed for a long time, the viability of seeds at the end of a germination trial is not always investigated. A variety of reasons may justify not conducting a viability test, such as working with small seeds whose embryos are difficult to expose without essentially destroying the seed. However, in other cases the justification is not clear. Whatever the reason, it is not uncommon to assume that those seeds that did not germinated did not have the conditions to break dormancy.

However, the results of the experiments conducted with seeds of *B. holstii* indicate that those seeds that did not germinate were either dead or, if they were alive, the increase in the proportion of dead seeds away from the germination optimum strongly suggested that they were in the process of dying. These results highlight the need to characterise the state and fate of all seeds in the experiment, as this information is essential to understand the exact physiological effect of the treatment to which the seeds were subject.

In addition to investigating the optimum requirements for germination under constant conditions (previously cold-stratified and germinated under light at ~20°C) the study found that seeds have a period of maturation which extends over their first year after dispersal. Not surprisingly for a temperate species, temperatures above 30°C are lethal to the seeds. Although seeds can maintain their viability in the laboratory for at least two years (the maximum age of seeds studied here), their ability to germinate in light and darkness makes them unlikely to form a persistent seed bank. Their ability to maintain viability under storage means that the seeds can potentially be stored in artificial seed banks. This also opens the possibility to propagate them outside their natural habitat – although, rather than limitations regarding seed germination, the difficulty to maintain plants outside Nyika stems from the temperate requirements of the vegetative plants.

6.6. Implications of policy on conservation of *Berberis holstii*

The existence of the separate Forestry Act (FA) suggests that despite the fact that the Forestry Department (FD) is responsible for the conservation and management of plants, its mandate does not extend to plant resources in the national parks and game reserves. On the other hand, the National Parks and Wildlife Act (NPWA) focuses on the conservation of animals. This means that plants that warrant safekeeping inside the national park are not afforded legal protection. It is worrying that Nyika National Park Master Plan does not envisage the protection of potentially threatened plants such as *B. holstii.*

Those plant species listed as threatened (*Juniper procera,* another temperate species at its southern limit, *Acokanthera laevigata* and *Asplenium* sp.nov., which occur only in Nyika) are recognised because of their perceived ecological uniqueness. However, the endemic and in demand *B. holstii* is not listed. The existing difference in legislation between animals and plants may explain why poaching of wild animals seems to be less common than the illegal harvesting of plants.

6.7 Limitations of the study

6.7.1 Language

The variety of languages spoken by people living in the vicinity of the park limited the reliability of some of their responses. Although a herbarium technician, conversant with the dominant language (Tumbuka) accompanied the researcher during the interviews, some answers could not be translated. Consequently, uncertain answers were excluded from the analyses.

6.7.2 Plant species identification

It was difficult to confirm all the alternative plant species that were mentioned. Firstly, some plants were found in places that were inaccessible. Secondly, other plants could not be identified because they were neither flowering nor fruiting. Therefore, only 57 of the 85 plant species reported in vernacular terminology were properly identified.

6.7.3 Population structure and dynamics

Although firebreaks were constructed around the plots, two of the plots were burnt either accidentally during DNPW operations or intentionally by poachers. This resulted in tags being burnt. Efforts to trace the original labelling were not always possible and individuals that could not be traced were assumed dead.

Although integration of demographic studies and genetic information in threatened small populations is recommended in population viability studies (Menges, 2000), it was not feasible to investigate the population genetics of *B. holstii* in this study.

6.8 Contribution of the study

Despite the aforementioned limitations, this study provides essential information for the conservation of *B. holstii*. As recommended by Gaston *et al.* (2002), compilation of data on species perceived to be at risk is one of the important phases in the conservation of biological diversity in protected areas.

This is the first demographic study of a plant species in Malawi and Nyika. It is therefore the first step in the introduction of this approach for the conservation and management of other important species. Similarly, this is the first time that the distribution of a traditionally important plant resource has been mapped accurately in a protected area. In the past, attention has been focused on animals, such as elephants. The ethnobotanical study and the investigation of the seed requirements of *B. holstii* are also original.

6.9 Recommendations

6.9.1 Monitoring

Since DNPW scouts already patrol the entire park and they use GPS during the patrols; they can be assigned to record any new localities of *B. holstii* that they come across. Similarly, any populations under threat or extinct should be documented. The information can then be used to update the map that has been developed in this study accordingly. The same technique can be used in the monitoring of other plant species that might be at stake in future.

6.9.2 Conservation

It would be important to protect some areas from fire and utilisation to enable the *B. holstii* to grow to its maximum capacity (as was the case with Kaulimi in 2005). Such areas should be in different ecological zones to ensure that if any catastrophe happens to one area, the other populations can be safe and can also be used as source of new plants. The areas should be protected with firebreaks that should be maintained regularly.

Considering that Chilinda is within the plateau and has readily available personnel, it would be convenient if a *B. holstii* nursery was established there. The nursery and the sites protected from fire could be used for civic education to raise awareness on how big *B. holstii* can grow if undisturbed. In order to show benefits of conservation, people could be allowed to collect from the nursery occasionally as an incentive. The *B. holstii* from the nursery could also be sold and the proceeds could be used to maintain the nursery and for community development.

People should be encouraged to use alternative plant species. Interestingly, there is already pharmacological evidence that the most frequently used plant species have properties for curing the frequently mentioned ailments. *Cassia abbreviata* has antimalarial and antispasmodial properties (Parry and Duri, 1994, Parry and Matambo, 1992, GesslerMsuya et al., 1995). It also alleviates stomach pains (Malan *et al.*, 1996). *Rhamnus prinoides* has antimalarial activity (Muregi *et al.*, 2007, Muregi *et al.*, 2003) and anthraquinones which are used as laxatives (Abegaz and Peter, 1995). It also has flavonoids that are used as anti-inflammatory, anti-viral and anti-histamine (Nindi *et al.*, 1999). *Zanthoxylum chalybeum* has protoberberine alkaloids (Kato *et al.*, 1996) and is used as an antimalarial drug (Gessler *et al.*, 1994, GesslerTanner *et al.*, 1995). In addition, it has antibacterial, antifungal and antimicrobial properties (Matu and van Staden, 2003, Olila *et al.*, 2001, Olila, 1993). These plant species are readily available in many parts of Malawi and are easier to propagate than *B. holstii*. If communal herbal gardens in which these plants could be propagated were to be established, people might be motivated to use them.

6.9.3 Future research

i. This study has documented uses which people report to use. Given the variety of ailments that *Berberis holstii* is reputed to cure or palliate, it would be beneficial to investigate these claims from a pharmacological point of view. Considering the detrimental effects that use of roots has on the survival of the plant, it would be desirable to investigate if properties that exist in roots are also present in aerial parts.

ii. The study mapped several sites where *B. holstii* is reported to exist. It will be important if the sites which could not be visited were followed up. This would confirm whether or not *B. holstii* is restricted to Nyika National Park.

iii. Considering that the habitats studied were those with *Berberis holstii,* it will be important to study the habitats that do not contain *B. holstii.* This would determine the conditions that are avoided by *B. holstii*

iv. It would be worthwhile to investigate if there are habitats in Malawi that are similar to those where *B. holstii* grows. If such sites were identified, they could be explored to find out if *B. holstii* exists in those habitats. If it does not, *B. holstii* could be transplanted to those habitats to see if it can survive.

v. In order for transplantation to be successful, detailed investigations will be necessary to determine the growth and rooting requirements.

vi. Although harvesting seems to exert a relatively minor effect, a more precise quantification of its prevalence across the park is necessary. Establishment of sustainable harvest quotas would also be important.

vii. The study found that fire may contribute to a decrease in *B. holstii*'s genetic diversity. Genetic studies are recommended to assess this.

Appendices

Appendix 2.1: Guidelines for In-Depth Interviews.

Aim of study *(please introduce the aim of the study clearly)*

It is known that *Berberis holstii,* locally known as Kayunga, plays an important role in the livelihood of people. However, it is restricted to Nyika National Park only. The impact of harvesting and consequently its conservation status remain unknown. Mrs. Cecilia Promise Maliwichi-Nyirenda thus intends to study the distribution and level of abundance of *B. holstii*; intensity of use and harvesting implications; and degree of genetic differentiation. To achieve these objectives, it is imperative that precious views of all stakeholders be incorporated.

Interview details

- Name of Interviewer: ________________
- Date of Interview: ____________________
- Place of Interview:

  District: ______________ *Traditional Authority:* ___________

1.1.1..... *Respondent's particulars*

1. What is your name?
2. Where do you come from?

   *District:*________ *Traditional Authority:* ______________

   *Group Village Headman:*_______ *Village:* ______________
3. When were you born? (how old were you when Ngwazi Dr. H. Kamuzu Banda came to Malawi / when Malawi attained multiparty democracy) _____
4. Sex: __________
5. Which tribe do you belong to? ___________
6. What is your denomination? ___________
7. What is your marital status? ___________
8. What is the highest level of education you have attained? At which school were you awarded the highest qualification? ___________
9. How do you earn your living? ___________
10. What do you do during your leisure time? ___________

Importance of Plants from Nyika National Park (*To note the important plants in community's livelihood*)

i. Are plants very important in your day-to-day living? ___________
ii. Why? ____
iii. What are the ten plants that you consider very important? (*please rank them in descending order i.e. 1= very important; put corresponding reasons for the rank given and uses*)

1. ___________________
2. ___________________
3. ___________________

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

iv. Please mention uses of the above-mentioned plants

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________

v. Where do you get them?

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________

vi. Do you get some plants from Nyika National Park?

____

vii. What are the plants that you mostly get from Nyika National Park?

____

____

viii. Are these found in Nyika National Park only?

____

ix. How can you compare the importance of the topmost plants to Kayunga[1]?

1. ________________
2. ________________
3. ________________
4. ________________
5. ________________
6. ________________
7. ________________
8. ________________
9. ________________
10. ________________

Uses of *Berberis holstii* (*Importance of Kayunga to key informant and entire community*)

a. Have you ever heard about Kayunga? ______________________
b. Who told you about Kayunga? ______________________
c. When did you hear about Kayunga? ______________________
d. What exactly were you told about Kayunga? ______________________
e. What are the other local names of Kayunga? ______________________
f. After you heard about Kayunga, have you seen the actual plant? ________
g. Where did you see it? (*please probe for specific directions to get to the place*)

____

h. Have you ever used Kayunga? ______________________
i. Since when? ______________________
j. For how long have you used it? ______________________
k. What have you used it for? ______________________
l. How often do you use Kayunga? ______________________
m. Do you use it alone? ______________________
n. Why? ______________________
o. What about other family members? ______________________
p. Are there any beliefs that are associated with use of Kayunga? __________
q. What are they? ______________________
r. Why do you think there are such beliefs? ______________________
s. After you heard about Kayunga, did you pass the information to others? ___
t. Why? ______________________
u. Who did you pass the information to? ______________________
v. What type of message did you pass? ______________________

w. What parts did you use? ______________________
x. How did you use them (please mention part used and corresponding use)

____

[1] Kayunga is a local name for *Berberis holstii*

y. Do you know other people who use Kayunga? ______________________

z. What are their contacts? ______________________________________

aa. What do they use Kayunga for? ______________________________

bb. When Kayunga is not available, do you use other plant species as alternatives?

____

cc. Why? ____

dd. What plant species do you use as alternatives? ___________________

ee. What parts do you use? (*Please mention part used and corresponding use*)

____

____

____

____

____

Harvesting Techniques of Kayunga (*To know how Kayunga is harvested*)

- Do you know where Kayunga is found? ___________________
- How far away is it? (*please ask in terms of time taken to walk to the site*)

____

- What type of transport do you use to go and collect Kayunga?

____

- Have you ever collected Kayunga?

  ____

- Where do you collect it?

  ____

- For how long have you been collecting Kayunga?

  ____

- How much do you collect per trip?

  ____

- How many times do you collect Kayunga in a month, 3 months, 6 months and one year?

3 months: ______________________________________

6 months: ______________________________________

A year: ______________________________________

- Do you know other people who collect Kayunga?

  ____

- For how long have you seen them collecting Kayunga?

  ____

- Do you know how often they collect Kayunga in one months, 3 months, 6 months and one year?

3 months: ______________________________________

6 months: ______________________________________

A year: ______________________________________

- How much do they collect at a given trip? (*ask in terms of sack*)

____

- What plant parts are mostly collected?

  ____

Level of Abundance of *Berberis holstii*

(*One important aspect of this study is to know, from your perspective, the availability of Berberis holstii to the past, present and future generations*)

- How readily available was Kayunga before people moved out of Nyika?

____

- What were the contributing factors?

____

- How was the availability of Kayunga between the time people moved out of Nyika and before Malawi attained multiparty democracy?

____

- How do you rate the availability of Kayunga after multiparty democracy to the present?

____

- What are the contributing factors?

____

- What do you think will be the availability of Kayunga in future?

____

- Why?

____

Propagation initiatives

(*Due to environmental degradation which Malawi is facing, there are efforts to have community woodlots or backyard gardens to lessen the pressure on the wild stocks. We would therefore like to know if there are any initiatives that are being undertaken with respect to Kayunga*)

- Do you know if there are any plant propagation initiatives that are taking place or have taken place?

____

- What type of initiatives are / were they?

____

- Where did they take place?

____

- Who carried them out?

____

- Why?

____

- How was it done?

____

- Was it successful?

____

- How?

____

Storage

- Is it possible to store Kayunga? ______________________________
- In what forms is it stored? ______________________________
- Why? ______________________________

- How long does it stay before it goes bad? ____________________

Sustainable use strategies

- Are you aware of any policy measures that have been put in place to safeguard sustainability of Kayunga? ____________________
- What are the measures? ____________________
- Who instituted the measures? ____________________
- How much and how often is Kayunga supposed to be collected? __________
____
- Why? ____________________
- Who monitors that Kayunga is sustainably collected? ____________________

Marketability

- Do you know if Kayunga is sold? ____________________
- Why? ____________________
- Have you ever sold Kayunga? ____________________
- Why? ____________________
- To who have you sold Kayunga? ____________________
- Do you know anyone who is involved in selling Kayunga? (*Give contact details*)
____
- Who are the customers? ____________________
- At how much is Kayunga sold (*please indicate part sold, quantities and respective cost*) ____________________

History of Nyika National Park

- Have you ever lived in Nyika before people got relocated? __________
- Where did your parents / ancestors originally come from? __________
- Do you know the tribes that inhabited Nyika? ____________________
- Who are they? ____________________

  Where did they come from? ____________________

  Do you know where they went after relocation? ____________________
- Which places did they inhabit in Nyika? (*please probe for good direction*)
____

Appendix 2.2: Household Questionnaire.

Name of interviewer ------------------------------ **Date of interview**------------------

Place of interview:

District -- **Traditional Authority** -----------------------

Group Village Headman ---------------------- **Village** --

This questionnaire has been designed against the background that *Berberis holstii*, locally known as Kayunga, is one of the important plant species in the livelihood of people living around Nyika National Park. Although it is restricted to Nyika National Park only, the impact of harvesting and consequently its conservation status remain unknown. Mrs Cecilia Promise Maliwichi-Nyirenda therefore intends to study the population dynamics, distribution, level of abundance, intensity of use and harvesting implications of *B. holstii*. As one tool of achieving these objectives, this questionnaire sets out to incorporate the precious views of all stakeholders whose contribution will be vital to the output of this study.

Demographic particulars of respondent

Name of respondent (optional) --

Age: ◻ less than 20 ◻ 20 – 34 ◻ 35 – 50 ◻ 50+

Sex: ◻ Female ◻ Male

Tribe: ◻ Tumbuka ◻ Phoka ◻ Lambya ◻ Nyakyusa ◻ Other (specify) ------

Denomination: ◻ Christian ◻ Moslem ◻ Other (specify) -----------------------

Marital status: ◻ Never married ◻ Married ◻ Divorced ◻ Widowed

Highest level of education: ◻ None◻ Primary ◻ Secondary

◻ Tertiary ◻ Other (specify) --------------------------------

Employment Record: ◻ Subsistence farmer ◻ Businessman / woman

◻ Salaried employment ◻ Traditional Healer

◻ Other (specify) ---

Where do you come from?

District: ------------------------------- *Traditional Authority:* ----------------------

Group Village Headman: ------------------- *Village:* -------------------------------

1. **Knowledge and use of *Berberis holstii***

   a. Have you ever heard about *Berberis holstii*?

   ◻ Yes ◻ No

   (if YES, please proceed; otherwise that is the end of the interview)

   b. When did you hear about *Berberis holstii*? ------------------------------------

c. Where did you hear the information from?

□ parents □ relatives □ friends □ other (specify) ------------------------

d. Have you ever used *Berberis holstii*? □ Yes □ No

(*if YES, proceed to c i; if NO, continue with c iii*)

1. What have you used *Berberis holstii* for?
□ food □ medicine □ fuel □ building material □ aphrodisiac □ other (specify)---------

2. What parts of *B. holstii* have you used?
□ roots □ stem □ leaves □ seeds □ other (specify)-----------------------

3. For how long have you used *B. holstii*?
□ less than 1 year □ 1 – 5 years □ 6 -10 years

□ 10 – 15 years □ more than 15 years

4. Have you ever heard of other uses of *Berberis holstii* apart from the uses you have mentioned above?

□ yes □ no

if NO, go to question 2

if YES,

5. what uses have you heard?
□ food □ medicine □ fuel □ building material □ aphrodisiac □ other (specify)---------

6. what parts of *B. holstii* have you used?
□ roots □ stem □ leaves □ seeds □ other (specify)-----------------------

7. **Harvesting techniques of *Berberis holstii***

a. i. Have you ever collected *B. holstii?* □ Yes □ No

a. ii.. Please give reason(s) for your answer in a.i ----------------------------

----

a.iii. if NO, proceed with question c.i.

a.iv. if YES,

8. where do you collect *B. holstii,* how far away is the place from here and what type of transport do you use?

(*to the interviewer: if the respondent is failing to give the answer in km, please ask the respondent how many hours it takes to reach the place*)

Place of collection	*Distance (km)*	*Type of transport used*		
		Public Transport	foot	bicycle
----------------------------	----------------	□	□	□
----------------------------	----------------	□	□	□
----------------------------	----------------	□	□	□
----------------------------	----------------	□	□	□

9. Does it cost you any money to get to the place where you collect *B. holstii?*

□ yes □ no

if NO, go to question b.i

if YES,

10. how much does it cost?
□ less than MK100 □ Between MK100 and MK500
□ More than MK500 but less than MK1000 □ More than MK1000

11. What parts do you collect?
□ leaves □ bark □ roots □ other (specify) -----------------

12. How many trips do you make per year to collect *B. holstii*?
□ less than 4 □ more than 4 but less than 6 □ more than 6 but less than 12 □ more than 12 □ other (specify) ---

13. How much do you collect per trip?
□ less than 1kg □ between 1 and 5kg
□ between 5kg and 10kg □ more than 10kg

b. i. Do you know places where other people collect *B. holstii*? □ Yes □ No

if NO, go to question 3

if YES,

14. where do they collect *B. holstii*, how far away is the place from here and what type of transport do they use?

(to the interviewer: if the respondent fails to express the distance in km, please probe by asking how many hours it takes to reach the place)

Place of collection	*Distance (km or hours)*	*Type of transport used* Public transport	foot	bicycle
----------------------------		□	□	□
----------------------------		□	□	□
----------------------------		□	□	□
----------------------------		□	□	□

15. What parts do they collect?
□ leaves □ bark □ roots □other (specify) -----------------------

16. How many trips do they make per year to collect *B. holstii*?
□ less than 4 □ more than 4 but less than 6 □ more than 6 but less than 12
□ more than 12 □ other (specify) --

17. How much do they collect per trip?
□ less than 1kg □ between 1 and 5kg □ between 5kg and 10kg □ more than 10kg

Availability

18. How can you rate the availability of *Berberis holstii* in the past, now and in future? (*please tick all that applies*)

	scarce	moderate	abundant
i. Before the park was expanded in 1978:	□	□	□
ii. 1978 – 1993:	□	□	□
iii. 1994* to date:	□	□	□
iv. Future:	□	□	□

* 1994 is the year when Malawi attained multiparty democracy and believed to be a point where rapid biodiversity degradation started.

19. Storage

a. When *B. holstii* is collected, how long does it keep before it becomes stale? ----

b. What mechanisms are used to keep *B. holstii* for a long period of time? ----------

----

----

20. Use of alternative plant species

a. In case *Berberis holstii* is not available, are there any other plant species that are used instead?

□ yes □ no

a. i. Please give reason (s) for the answer above --

----

a. ii. if YES, what are the plants that are used; which parts are used and what purpose are they used for?

Alternative plant species	*Part(s) used*					*Purpose*					
	R	St	L	Se	O	Fo	Fu	B	A	M	O
----------------------------	□	□	□	□	---------	□	□	□	□	□	------
----------------------------	□	□	□	□	---------	□	□	□	□	□	------
----------------------------	□	□	□	□	---------	□	□	□	□	□	------
----------------------------	□	□	□	□	---------	□	□	□	□	□	------

Nb: legend:

Part(s) used: R = roots; St = stem; L = leaves; Se = seeds; O = Other (specify)

Purpose: Fo = food; M = medicine; Fu = fuel; B = building material;

A = aphrodisiac; O = other (specify)

If NO, go to question 6.

6. Propagation initiatives

a. Are you aware if *Berberis holstii* is propagated? □ yes □ no

a. i. If no, why do you think there are no such efforts? --

a. ii. if yes, who is carrying out the propagation (*please mention name and contact details*)?

----

7. **Sustainable use strategies**

Policy

a. Are you aware of any policy measures that have been put in place to safeguard sustainable utilisation of *Berberis holstii*? □ yes □ no

If yes, a. i. who instituted the measures? --

a. ii. what are the measures?

21. --
22. --

a. iii. If no, what do you think are the contributing factors?

23. --
24. --

Harvest quotas

b. Are you aware of any restrictions on how much *Berberis holstii* one is supposed to collect at any given trip? □ yes □ no

b. i. If yes, how much is allowed?

□ < 1kg □ 1- 5kg □ 6 – 10kg. □ > 10kg

b. ii. If no, why do you think there are no such restrictions?

25. --
26. --

8. **Marketability**

a. Do you know if *Berberis holstii* is sold? □ yes □ no

Please give reason for your answer ---

if YES, a.i. To who is it sold? ---

1. ii. At how much is it sold (*please indicate part sold, quantities and respective cost*)

Part sold	Cost	Quantity

Appendix 2.3: A list of all the uses of *Berberis holstii*.

Use	Frequency (%)
Mentioned during questionnaire interviews	
Abortion prevention*	1.5384615
Aphrodisiac*	1.5384615
Asthma	0.7692308
Backache	0.7692308
Bloody urine	0.7692308
Body pains*	0.7692308
Business success	1.5384615
Ceaseless menstruation	0.7692308
Cough*	42.307692
Demonic possession	6.9230769
Entice one to come back after going far away	0.7692308
Fever*	0.7692308
Football	0.7692308
Headache*	0.7692308
Impotence*	1.5384615
Love potion*	2.3076923
Luck charm*	2.3076923
Malaria*	7.6923077
Medicinal (unspecified)	0.7692308
Pneumonia	2.3076923
Protection charm	0.7692308
Settle family misunderstanding	0.7692308
Sexually transmitted infections*	6.1538462
Sore throat	0.7692308
Stomachache*	7.6923077
To foretell the future (psychic)	0.7692308
To increase fish catch	3.0769231
To reverse witchcraft curse	1.5384615
Yellow fever*	0.7692308

* Uses also mentioned during Participatory Rapid Appraisal

Appendix 2.3: Continued.

Use	**Frequency (%)**
Mentioned during Participatory Rapid Appraisal	
Abortion*	0.854701
Aphrodisiac*	5.128205
Bilharzia	0.854701
Body cleansing for prostitutes	0.854701
Body protection	3.418803
Boil	0.854701
Catch thieves	0.854701
Cough*	13.67521
Demonic spiritual possession	0.854701
Epilepsy	0.854701
Fever*	1.709402
Body pains*	0.854701
Headache*	2.564103
hunting animals	1.709402
Impotence*	1.709402
induce labour	2.564103
Induce pregnancy	1.709402
Infertility	0.854701
Influenza	0.854701
Love Potion*	0.854701
Luck charm*	9.401709
Make unfaithful woman settle down	0.854701
Malaria*	8.547009
Mental disturbance	1.709402
Pneumonia*	11.11111
Prophesy	1.709402
Puberty in boys	0.854701
Remove spells	0.854701
Rheumatism	0.854701
Safe child delivery	0.854701
Sex reversal	0.854701
Sexually transmitted infections*	6.837607
Snake bites	1.709402
Stomachache*	5.982906
Sunken fontanelle	1.709402
Withdrawn behaviour	0.854701
Yellow fever*	1.709402

* Uses also mentioned during questionnaire interviews

Appendix 2.4: Plant species used as alternatives to *Berberis holstii*.

Use	Plant species name		Part(s) used	Number of times mentioned
	Scientific	Local		
Asthma	*Antidesma venosum*	Mpululu	leaves	1
Body aches	*Zanthoxylum chalybeum*	Zobara	stem bark & roots	5
Burns	*Sclerocarya birrea* subspp. *caffra*	Msewe	roots	2
	Eucalyptus spp.	Bluegum	leaves	4
	Citrus limon	Lemons	fruit	1
	Bauhinia petersiana	Mpandula	roots	1
	Dracaena reflexa	Mphembela	roots	1
	Xanthophylum chalybeum	Mpupwe	leaves	1
	Vernonia magdalena	Mululuska	leaves	1
	Asparagus africana	Nkolankhanga	leaves	1
	Vernonia glabra	Fuska / Fusa	roots	2
	Ficus spp.	Kachere	roots	2
	Hagenia abyssinica	Mkwale	roots	2
	Dichrostachys cinerea	Mpangala	roots	2
	Pericopsis angolensis	Mwanga	roots	2
	Piliostigma thonningii	Chitimbe / Visekese	roots	2
	Thunbergia spp.	Nthuma	roots	1
	Cassia abbreviata	Muwawani	roots/stem bark	17
	Rhamnus prinoides	Lupindula	leaves & roots	7
	Zanthoxylum chalybeum	Zobara	stem bark & roots	5
Cough	*Mikania cordata*	Matholisa / Mbozga	leaves & roots	3
Demonic possession	*Rhamnus prinoides*	Lupindula	leaves & roots	5
Diarrhoea	*Steganotaenia raliaceae*	Mpololo / Munyongoloka	leaves & roots	2
Headache	*Zanha Africana*	Chibangalume	roots	1
Heart pains	*Jateorrhiza bukobensis*	Mjokajoka	bark	1

Appendix 2.4: Continued.

Use	Plant species name		Part(s) used	Number of times mentioned
	Scientific	Local		
Honey	*Sclerocarya birrea* subspp. *caffra*	Msewe	roots	1
Labour stimulant	*Rhamnus prinoides*	Lupindula	leaves & roots	9
	Mikania cordata	Matholisa / Mbozga	leaves & roots	3
Luck	*Securidaca longipedunculata*	Muwuluka	leaves	1
	Steganotaenia raliaceae	Mpololo / Munyongoloka	leaves & roots	3
	Aloe spp.	Chinthembwe	not mentioned	1
	Vernonia glabra	Fuska / Fusa?	roots	3
	Ficus spp	Kachere	roots	3
	Hagenia abyssinica	Mkwale	roots	3
	Dichrostachys cinerea	Mpangala	roots	3
	Pericopsis angolensis	Mwanga	roots	3
	Cassia abbreviata	Muwawani	roots/stem bark	19
	Rhamnus prinoides	Lupindula	leaves & roots	8
Malaria	*Erythrina abyssinica*	Muwalewale	roots	1
Poor sight	*Trichia emetica*	Nkhamsonga	roots	1
Psychic	*Glycine max*	Soya	leaves	1
Rheumatism	*Azidarachta indica*	Neem	bark, leaves & roots	1
Ringworms	Ficus spp.	Nkuyu	latex	1
Skin infection	*Dicoma anomala*	Palijekanthu	roots	1

Appendix 2.4: Continued.

Use	Plant species name		Part(s) used	Number of times
	Scientific	Local		
Stomachache	*Zanthoxylum chalybeum*	Zobara	stem bark & roots	5
	Piliostigma thonningii	Chitimbe / Visekese	roots	3
	Thunbergia spp.	Nthuma	roots	2
	Cassia abbreviata	Muwawani	roots/stem bark	18
	Sclerocarya birrea subspp. *Caffra*	Msewe	roots	3
	Glycine max	Soya	leaves	2
	Azidarachta indica	Neem	bark, leaves & roots	2
	Psorospermum febrifugum	Kavundula	roots	2
Toothache	*Choristylis rhamnoides*	Nsolo	stem bark	1
	Solanum panduriforme	Nthula	not mentioned	1
Winning court cases	*Afzelia quanzensis*	Sambamfumu	not mentioned	1
Wounds	*Lanea discolor*	Kawombo	stem bark	1
Not specified	*Rhamnus prinoides*	Lupindula	leaves & roots	6
	Lotus sp.	Mpeta	roots	1

Appendix 3.1: List of sites studied.

Site Legend	Site Name	Site Legend	Site Name
S1	5km from Juniper	S18	Juniper Hagenia
S2	Airstrip	S19	Kasaramba big tree
S3	Chilinda Hill	S20	Kasaramba before big tree
S4	Chilinda Lodge	S21	Kaulimi outlet
S5	Chingunda1	S22	Kaulimi Hagenia
S6	Chingunda2	S23	Kaulimi last site
S7	Dembo near plot	S24	Kaulimi car park
S8	Dembo plot	S25	Kaulimi before last site
S9	Dembo	S26	Kaulimi plot
S10	Dembo before bridge	S27	Kaulimi before plot
S11	Futi Hill	S28	Mphalayamawe
S12	Jalawe 1	S29	Mpopoti Berberis bush
S13	Jalawe rock	S30	Mpopoti down slope
S14	Jalawe 2	S31	Mpopoti left forest
S15	Juniper Chilinda last bends	S32	Mpopoti Balilo1
S16	Juniper roadside	S33	Mpopoti Balilo2
S17	Juniper plot	S34	Mpopoti monument

Appendix 3.1: Continued.

Site Legend	Site Name	Site Legend	Site Name
S35	Mpopoti new site near monument	S50	North Rumphi Wovwe bridge
S36	Mpopoti new site near S35	S51	North Rumphi Wovwe grassland
S37	Mpopoti right overlooking lake	S52	North Rumphi Wovwe left forest
S38	Mpopoti below S37	S53	North Rumphi Wovwe right forest
S39	Mpopoti roadside	S54	North Rumphi Wovwe roadside
S40	Mpopoti peak overlooking lake	S55	North Rumphi left forest
S41	Mpopoti where car over boiled	S56	North Rumphi right forest
S42	Mpopoti plot	S57	North Rumphi grassland
S43	Nganda	S58	Police Transmitter forest
S44	Nguyi ya Msaka left	S59	Police Transmitter before Pteridium
S45	Nguyi ya Msaka down	S60	Police Transmitter grassland
S46	Nguyi ya Msaka right	S61	Police Transmitter near airstrip
S47	North Rukuru thicket	S62	Police Transmitter grassland1
S48	North Rukuru rock crevice	S63	Police Transmitter grassland2
S49	North Rukuru river source	S64	Police Transmitter thicket
		S65	TT Base plot

Appendix 3.2: Characteristics of the study sites.

Site	Altitude	Aspect	Habitat type	Pressure exerted	Impact of pressure	Status of *B. holstii*	*B. holstii* size	*B. holstii* coverage*
S1	2407	0.774	grassland	Fire	severe	regenerating	medium	3
S2	2356	1.202	forest edge	none	none	fine	medium	4
S3	2416	1.888	rocky	none	none	stunted	young	2
S4	2352	0.567	inside forest	uprooting	substantial	regenerating	young	3
S5	2510	0.774	grassland	uprooting	severe	regenerating	young	2
S6	2421	1.914	grassland	Fire	substantial	regenerating	young	2
S7	2377	1.254	forest edge	none	none	fine	adults	2
S8	2373	1.508	forest edge	none	none	fine	adults	6
S9	2376	1.984	forest edge	none	none	stunted	young	1
S10	2231	0.116	grassland	Fire	substantial	regenerating	young	2
S11	2432	2.035	rocky	Fire &	severe	regenerating	young	5
S12	2273	1.459	forest edge	none	none	fine	medium	3

*Coverage: 1=<1% cover; 2=1-5%; 3=6-25%; 4=26-50%; 5=51-75%; 6=76-100%

Appendix 3.2: Continued.

Site	Altitude	Aspect	Habitat type	Pressure exerted	Impact of pressure	Status of *B. holstii*	*B. holstii* size	*B. holstii* coverage
S13	2272	1.706	rocky	Fire	substantial	regenerating	young	2
S14	2255	0.613	forest edge	none	none	fine	medium	3
S15	2298	2.038	roadside	infrastructural	severe	stunted	young	1
S16	2123	0.621	inside forest	none	none	fine	medium	2
S17	2111	0.340	inside forest	uprooting	severe	regenerating	medium	3
S18	2120	1.508	inside forest	none	none	fine	young	2
S19	2450	0.261	roadside	Fire	severe	regenerating	medium	2
S20	2451	0.261	roadside	Fire	severe	regenerating	medium	2
S21	2335	0.124	inside forest	Fire	severe	stunted	young	1
S22	2351	1.830	inside forest	Fire	severe	regenerating	young	2
S23	2346	0.148	inside forest	Fire	severe	regenerating	young	2

Appendix 3.2: Continued.

Site	Altitude	Aspect	Habitat type	Pressure exerted	Impact of pressure	Status of *B. holstii*	*B. holstii* size	*B. holstii* coverage
S24	2344	0.652	inside forest	Fire &	severe	regenerating	young	2
S25	2339	0.538	inside forest	Fire	severe	regenerating	young	2
S26	2341	0.502	inside forest	animal	severe	regenerating	young	6
S27	2337	0.733	inside forest	Fire	severe	regenerating	young	2
S28	2361	1.254	roadside	Fire	substantial	regenerating	medium	3
S29	2419	0.291	grassland	none	none	regenerating	adults	5
S30	2400	0.148	forest edge	Fire	substantial	regenerating	adults	6
S31	2392	0.124	forest edge	Fire	substantial	regenerating	adults	6
S32	2473	1.747	grassland	Fire	substantial	regenerating	adults	3
S33	2494	1.401	grassland	Fire	substantial	regenerating	adults	3
S34	2490	0.124	rocky	Fire	substantial	regenerating	adults	2

Appendix 3.2: Continued.

Site	Altitude	Aspect	Habitat type	Pressure exerted	Impact of pressure	Status of *B. holstii*	*B. holstii* size	*B. holstii* coverage
S35	2488	2.038	rocky	Fire	substantial	regenerating	medium	2
S36	2470	1.830	rocky	Fire	substantial	regenerating	young	2
S37	2471	0.990	rocky	Fire	substantial	regenerating	young	5
S38	2470	1.830	rocky	Fire	substantial	regenerating	young	2
S39	2430	2.097	grassland	infrastructural	substantial	stunted	young	1
S40	2472	0.148	rocky	Fire	severe	regenerating	young	2
S41	2465	0.116	rocky	Fire	substantial	fine	adults	2
S42	2390	1.953	forest edge	none	none	fine	adults	4
S43	2280	1.184	inside forest	none	none	fine	medium	3
S44	2353	0.774	forest edge	none	none	fine	medium	3
S45	2351	1.034	forest edge	animal browsing	severe	untraceable	young	2

Appendix 3.2: Continued.

Site	Altitude	Aspect	Habitat type	Pressure exerted	Impact of pressure	Status of *B. holstii*	*B. holstii* size	*B. holstii* coverage
S46	2363	1.888	forest edge	none	none	fine	medium	2
S47	2247	1.401	forest edge	Fire	severe	regenerating	young	4
S48	2233	1.122	rocky	Fire	substantial	stunted	young	2
S49	2364	0.110	forest edge	none	none	fine	adults	5
S50	2099	1.254	forest edge	uprooting	substantial	regenerating	adults	2
S51	2156	0.116	grassland	Fire	severe	regenerating	adults	3
S52	2233	2.091	forest edge	Fire	minimal	regenerating	medium	3
S53	2246	2.091	forest edge	Fire	minimal	regenerating	medium	2
S54	2132	1.625	roadside	infrastructural	minimal	regenerating	medium	1
S55	2331	1.459	forest edge	Fire	substantial	regenerating	medium	2

Appendix 3.2: Continued.

Site	Altitude	Aspect	Habitat type	Pressure exerted	Impact of pressure	Status of *B. holstii*	*B. holstii* size	*B. holstii* coverage
S56	2331	0.364	forest edge	Fire	minimal	fine	medium	2
S57	2335	0.407	grassland	Fire &	substantial	regenerating	adults	3
S58	2327	0.859	forest edge	uprooting	minimal	fine	adults	5
S59	2356	1.579	grassland	Fire	substantial	fine	young	2
S60	2331	1.698	grassland	Fire	minimal	fine	young	3
S61	2338	0.394	forest edge	Fire &	minimal	fine	medium	4
S62	2321	1.786	grassland	Fire	severe	regenerating	young	2
S63	2313	1.069	grassland	Fire	severe	regenerating	young	2
S64	2292	0.204	woodland	none	none	fine	adults	4
S65	2395	0.433	roadside	animal	severe	regenerating	medium	5

Appendix 3.3: Vascular plant species growing in association with *Berberis holstii.*

Plant species	Family	Habit	Growth form	Life cycle
Acalypha chirindica	Euphorbiaceae	shrub/tree	straggling	perennial
Acalypha psilostachya	Euphorbiaceae	herb/shrub	erect	perennial
Acalypha villicaulis	Euphorbiaceae	herb/shrub	erect	perennial
Achyrocline schimperi	Asteraceae	shrub	erect	perennial
Achyrospermum cryptanthum	Lamiaceae	shrub	scandent	annual
Adiantum poirettii	Pteridaceae	herb	scandent	annual
Adiantum poirettii var poirettii	Pteridaceae	herb	scandent	annual
Aeollanthus buchnerianus	Lamiaceae	herb	erect	perennial
Aeschynomene abyssinica	Fabaceae	herb/shrub	erect	perennial
Aeschynomene nyassana	Fabaceae	shrub	erect	perennial
Agarista salicifolia	Ericaceae	tree	erect	evergreen
Ageratinastrum polyphyllum	Asteraceae	herb	erect	perennial
Agrocharis incognita	Apiaceae	herb	scandent/straggling	annual/perennial
Agrostis eriantha	Poaceae	herb	erect	annual/perennial
Agrostis lachnacantha	Poaceae	herb	erect	annual/perennial
Alchemilla ellenbeckii	Rosaceae	herb	scandent	perennial
Anthospermum ternatum	Rubiaceae	herb/shrub	erect/straggling	biennial/perennial
Anthospermum tomentosa	Rubiaceae	herb	erect	perennial
Anthospermum usambarense	Rubiaceae	shrub	erect	perennial
Anthospermum whyteanum	Rubiaceae	shrub	erect	perennial
Apodytes dimidiata	Icacinaceae	shrub/tree	erect	perennial
Arachniodes foliosa	Dryopteridaceae	herb	scandent	perennial
Ardisiandra wettsteinii	Primulaceae	herb	scandent	perennial
Argyrolobium rupestre	Fabaceae	herb	erect/prostrate	perennial

Appendix 3.3: Continued.

Plant species	**Family**	**Habit**	**Growth form**	**Life cycle**
Argyrolobium tomentosum	Fabaceae	shrub	erect	perennial
Artemisia afra	Asteraceae	shrub	erect	perennial
Arthraxon micans	Poaceae	herb	straggling	annual
Arthropteris monocarpa	Oleandraceae	herb	scandent	annual
Asparagus africanus	Asparagaceae	shrub	erect	perennial
Asparagus asparagoides	Asparagaceae	herb	scandent	perennial
Asparagus plumosus	Asparagaceae	herb	scandent	perennial
Asparagus racemosus	Asparagaceae	shrub	scandent	perennial
Asparagus setaceus	Asparagaceae	herb/shrub	erect/scandent	perennial
Asparagus virgatus	Asparagaceae	shrub	erect	perennial
Astragalus atropilosulus	Fabaceae	herb	erect	perennial
Athyrium schimperi	Athyriaceae	herb	scandent	perennial
Becium obovatum	Lamiaceae	herb	erect	perennial
Berkheya echinaceae subsp. *polyacantha*	Asteraceae	herb	erect	perennial
Berkheya zeyheri	Asteraceae	herb	erect	perennial
Bersama abyssinica	Melianthaceae	shrub/tree	erect	perennial
Blepharis grandis	Acanthaceae	herb	erect	perennial
Blumea axillaris	Asteraceae	herb	erect	annual/perennial
Blumea crispata	Asteraceae	herb	erect	annual/perennial
Bothriocline inyangana	Asteraceae	herb	erect	perennial
Bothriocline longipes	Asteraceae	herb/suffrutex	erect	perennial
Brachythrix sonchoides	Asteraceae	herb/suffrulescent	erect	perennial
Buchnera sessiliflora	Schrophulariaceae	herb	erect	annual/perennial
Buddleja pulchella	Buddlejaceae	shrub	scandent	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Buddleja salicifolia	Buddlejaceae	shrub	erect	perennial
Buddleja salviifolia	Buddlejaceae	shrub	erect	perennial
Bulbostylis contexta	Cyperaceae	herb	erect	perennial
Bulbostylis filamentosa	Cyperaceae	herb	erect	perennial
Bulbostylis macra	Cyperaceae	herb	erect	perennial
Burkea africana	Fabaceae	tree	erect	perennial
Carex cyrtosaccus	Cyperaceae	herb	erect	perennial
Carex echinochloe	Cyperaceae	herb	erect	perennial
Carex meyennii	Cyperaceae	herb	erect	perennial
Carex spicato-paniculata	Cyperaceae	herb	erect	perennial
Chamaecrista mimosoides	Fabaceae	herb	erect	perennial
Cheilanthes inaequalis	Pteridaceae	herb	scandent	perennial
Cheilanthes multifida	Pteridaceae	herb	scandent	perennial
Chlorophytum nyikensis	Anthericaceae	herb	erect	perennial
Chlorophytum stolzii	Anthericaceae	herb	erect	perennial
Chrysanthemoides monilifera	Asteraceae	herb	erect	perennial
Cineraria grandiflora	Asteraceae	herb	scandent	perennial
Clausena anistata	Rutaceae	shrub/tree	erect	perennial
Clematis chrysocarpa	Ranunculaceae	shrub	scandent	perennial
Clematis scabiosifolia	Ranunculaceae	liana	scandent	perennial
Clematis simensis	Ranunculaceae	liana	scandent	perennial
Clerodendrum myricoides	Verbenaceae	shrub	scandent	perennial
Cliffortia nitidula	Rosaceae	shrub	erect	perennial
Clutia abyssinica	Euphorbiaceae	shrub	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Clutia abyssinica var. *pedicellaris*	Euphorbiaceae	shrub	erect	perennial
Clutia paxii	Euphorbiaceae	shrub	erect	perennial
Clutia whytei	Euphorbiaceae	herb	erect	perennial
Coelachne africana	Poaceae	herb	scandent	perennial
Commelina africana	Commelinaceae	herb	scandent	annual
Commelina benghalensis	Commelinaceae	herb	scandent	annual
Conyza aegyptiaca	Asteraceae	herb	erect	annual/biennial
Conyza bonariensis	Asteraceae	herb	erect	annual
Conyza subscaposa	Asteraceae	herb	erect	perennial
Conyza tigrensis	Asteraceae	herb	erect	perennial
Conyza welwitschii	Asteraceae	herb	erect	perennial
Crossandra puberula	Acanthaceae	herb	erect	perennial
Crotalaria goetzei	Fabaceae	shrub	erect	annual
Crotalaria nyikense	Fabaceae	shrub	erect	annual
Crotalaria pallida var *pallida*	Fabaceae	shrub	erect	annual
Crotalaria pilosiflora	Fabaceae	shrub	erect	annual
Crotalaria recta	Fabaceae	shrub	erect	perennial
Crotalaria virgulata	Fabaceae	shrub	erect/prostrate	annual/perennial
Cucumis hirsutus	Cucurbitaceae	herb	scandent	perennial
Cussonia spicata	Araliaceae	tree	erect	perennial
Cyathula cylindrica	Amaranthaceae	herb	straggling	perennial
Cycnium adonense	Scrophulariaceae	herb	erect/prostrate	perennial
Cynanchum rungweense	Apocynaceae	shrub	scandent	annual
Cynoglossum geometricum	Boraginaceae	herb	erect	annual/perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Cynoglossum lanceolatum	Boraginaceae	herb	erect	biennial/perennial
Cyperus alopecuroides	Cyperaceae	herb	erect	perennial
Cyperus auriculatus	Cyperaceae	herb	erect	perennial
Cyperus collinus	Cyperaceae	herb	erect	perennial
Cyperus exaltatus	Cyperaceae	herb	erect	perennial
Cyperus fischerianus	Cyperaceae	herb	erect	perennial
Cyperus keniensis	Cyperaceae	herb	erect	perennial
Cyperus margaritaceus	Cyperaceae	herb	erect	perennial
Cyperus pseudoleptocladus	Cyperaceae	herb	erect	perennial
Cyperus rupestris	Cyperaceae	herb	erect	perennial
Cyperus semitrifidus	Cyperaceae	herb	erect	perennial
Cyperus tenax	Cyperaceae	herb	erect	perennial
Cyperus tomaiophyllus	Cyperaceae	herb	erect	perennial
Cyphostemma vandenbrandeanum	Vitaceae	herb	prostrate/scandent	perennial
Delphinium dasycaulon	Ranunculaceae	herb	erect	perennial
Delphinium leroyi	Ranunculaceae	herb	erect	perennial
Desmodium repandum	Fabaceae	herb	erect/prostrate	perennial
Dichrostachys cinerea	Mimosaceae	shrub/tree	scandent	perennial
Dicliptera verticillata	Acanthaceae	herb	erect	perennial
Diclis ovata	Scrophulariaceae	herb	prostrate	annual
Digitaria diagonalis	Poaceae	herb	erect	perennial
Diospyros natalensis	Ebenaceae	tree	erect	perennial
Diospyros whyteana	Ebenaceae	shrub/tree	erect	perennial
Dipplolophium buchananii	Apiaceae	herb	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Disa ochrostachya	Orchidaceae	herb	erect	annual
Dodonaea viscosa	Sapindaceae	shrub/tree	erect	perennial
Dolichos kilimandscharicus	Fabaceae	herb	erect/prostrate	annual/perennial
Dombeya burgessiae	Sterculiaceae	shrub	erect	perennial
Dregea macrantha	Asclepidiaceae	shrub	scandent	perennial
Dryopteris athamantica	Dryopteridaceae	herb	scandent	perennial
Dryopteris concolor	Dryopteridaceae	herb	scandent	perennial
Dryopteris inaequalis	Dryopteridaceae	herb	scandent	perennial
Dryopteris squamiseta	Dryopteridaceae	herb	scandent	perennial
Dyschoriste verticillaris	Acanthaceae	herb	erect	perennial
Ehrharta erecta var. *abyssinica*	Poaceae	herb	straggling	perennial
Ekebergia capensis	Meliaceae	tree	erect	perennial
Eragrostis caniflora	Poaceae	herb	erect/scandent	perennial
Eragrostis capensis	Poaceae	herb	erect/scandent	perennial
Eragrostis exelliana	Poaceae	herb	straggling	annual
Eragrostis hispida	Poaceae	herb	erect	perennial
Eragrostis mollior	Poaceae	herb	erect	perennial
Eragrostis racemosa	Poaceae	herb	erect	perennial
Eragrostis tenax	Poaceae	herb	erect	perennial
Eragrostis volkensii	Poaceae	herb	straggling	perennial
Erica benguelensis	Ericaceae	shrub	erect	perennial
Erica benguelensis var. benguelensis	Ericaceae	shrub/tree	erect	perennial
Eriosema asparagoides	Fabaceae	herb/shrub	erect	perennial
Eriosema bauchiense	Fabaceae	herb	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Eriosema burkei	Fabaceae	herb	erect	perennial
Eriosema ellipticum	Fabaceae	shrub	erect	perennial
Eriosema montanum	Fabaceae	shrub	erect	perennial
Eriosema nutans	Fabaceae	herb	erect/prostrate	perennial
Erythroxylum emarginatum	Erythroxylaceae	shrub/tree	erect	perennial
Euclea natalensis	Ebenaceae	shrub/tree	erect	perennial
Eulalia villosa	Poaceae	herb	erect	perennial
Euphorbia cyparissioides	Euphorbiaceae	herb	erect	perennial
Euphorbia depauperata	Euphorbiaceae	herb	erect	perennial
Euphorbia schimperiana	Euphorbiaceae	herb	erect	perennial
Exotheca abyssinica	Poaceae	herb	erect	perennial
Fadogia homblei	Rubiaceae	suffrutex	erect	annual
Fadogia stenophylla	Rubiaceae	herb/suffrutex	erect	annual
Festuca abyssinica	Poaceae	herb	erect/straggling	perennial
Festuca africana	Poaceae	herb	erect	perennial
Festuca costata	Poaceae	herb	erect	perennial
Galium burkei	Rubiaceae	herb	erect	perennial
Galium bussei	Rubiaceae	herb	scandent	perennial
Galium chloroionanthum	Rubiaceae	herb	scandent	perennial
Galium cordifolia	Rubiaceae	herb	erect	perennial
Galium spurium subsp. africanum	Rubiaceae	herb	erect/prostrate	annual
Geranium aculeolatum	Geraniaceae	herb	scandent	perennial
Gerbera ambigua	Asteraceae	herb	acaulescent	perennial
Gerbera piloselloides	Asteraceae	herb	acaulescent	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Gerbera viridifolia	Asteraceae	herb	acaulescent	perennial
Gladiolus atropurpureus	Iridaceae	herb	erect	perennial
Gladiolus dalenii	Iridaceae	herb	erect	perennial
Gnidia cotinifolia	Thymelaeaceae	herb	erect	perennial
Gnidia glauca	Thymelaeaceae	shrub/tree	erect	perennial
Gymnosporia buxifolioides	Celastraceae	shrub/tree	straggling	perennial
Gymnosporia senegalensis	Celastraceae	shrub/tree	erect	perennial
Hagenia abyssinica	Rosaceae	tree	erect	perennial
Halleria elliptica	Scrophulariaceae	shrub	erect	perennial
Halleria lucida	Scrophulariaceae	shrub/tree	erect/straggling	perennial
Haplocarpha scaposa	Asteraceae	herb	erect	perennial
Haumaniastrum ruandensis	Lamiaceae	herb	erect	annual
Haumaniastrum villosum	Lamiaceae	herb	erect	annual/perennial
Hebenstreitia angolensis	Selaginaceae	herb	erect	perennial
Hebenstreitia comosa	Selaginaceae	herb	erect	perennial
Hedythyrsus thamnoideus	Rubiaceae	shrub	erect	perennial
Helichrysum angustifrondeum	Asteraceae	herb	erect	perennial
Helichrysum ceres	Asteraceae	herb	erect	perennial
Helichrysum densiflorum	Asteraceae	herb	erect	perennial
Helichrysum foetidum	Asteraceae	herb	erect	biennial
Helichrysum forskahlii	Asteraceae	herb	erect	perennial
Helichrysum gerberifolium	Asteraceae	herb	erect	perennial
Helichrysum kirkii	Asteraceae	herb	erect	perennial
Helichrysum longifolium	Asteraceae	herb	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Helichrysum nudifolium	Asteraceae	herb	erect	perennial
Helichrysum odoratissimum	Asteraceae	herb	erect/prostrate	perennial
Helichrysum patulifolium	Asteraceae	herb/shrub	erect	perennial
Helichrysum petersii	Asteraceae	herb	erect	perennial
Helichrysum setosum	Asteraceae	herb/shrub	erect	perennial
Helichrysum splendidum	Asteraceae	herb/shrub	erect	perennial
Helichrysum sulphureo-fuscum	Asteraceae	herb	erect	perennial
Helichrysum tillandsiifolium	Asteraceae	herb	erect	perennial
Helictotrichon elongatum	Poaceae	herb	erect	perennial
Helictotrichon milanjianum	Poaceae	herb	erect	perennial
Heliotropium zeylanicum	Boraginaceae	herb	erect/prostrate	perennial
Hemizygia bracteosa	Lamiaceae	herb	erect	annual
Hesperantha petitiana	Iridaceae	herb	erect	perennial
Heteromorpha arborescens	Apiaceae	shrub/tree	erect	perennial
Heteromorpha trifoliata	Apiaceae	tree	erect	perennial
Heteropogon contortus	Poaceae	herb	erect	perennial
Hyparrhenia cymbaria	Poaceae	herb	erect/straggling	perennial
Hyparrhenia dregeana	Poaceae	herb	erect	perennial
Hyparrhenia filipendula var. filipendula	Poaceae	herb	erect	perennial
Hyparrhenia formosa	Poaceae	herb	erect	perennial
Hyparrhenia newtonii	Poaceae	herb	erect	perennial
Hyparrhenia pilgeriana	Poaceae	herb	erect/straggling	perennial
Hyparrhenia schimperi	Poaceae	herb	erect	perennial
Hypericum conjungens	Clusiaceae	herb/shrub	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Hypericum peplidifolium	Clusiaceae	herb	erect/prostrate	perennial
Hypericum quartinianum	Clusiaceae	shrub/tree	erect	perennial
Hypericum revolutum	Clusiaceae	shrub/tree	erect	perennial
Hypericum scioanum	Clusiaceae	herb	erect/prostrate	perennial
Hypoestes forskaolii	Acanthaceae	herb	erect	perennial
Impatiens assurgens	Balsaminaceae	herb	erect	perennial
Impatiens eryaleia	Balsaminaceae	herb	erect	perennial
Impatiens gomphophylla	Balsaminaceae	herb	erect/prostrate	annual
Impatiens polyantha	Balsaminaceae	herb	erect/straggling	perennial
Indigofera hedyantha	Fabaceae	herb	erect	perennial
Indigofera longibarbata	Fabaceae	herb	erect	annual
Indigofera lyallii	Fabaceae	shrub/tree	erect	perennial
Indigofera mimosoides	Fabaceae	shrub	erect	perennial
Indigofera nyikensis	Fabaceae	shrub	erect	perennial
Inula glomerata	Asteraceae	herb	erect	perennial
Inula mannii	Asteraceae	shrub	erect	perennial
Inula paniculata	Asteraceae	shrub	erect	perennial
Jasminum odoratissimum subsp. goetzeanum	Oleaceae	shrub	scandent/straggling	perennial
Juniperus procera	Cupressaceae	tree	erect	perennial
Justicia linearispica	Acanthaceae	herb	erect	perennial
Justicia mollugo	Acanthaceae	herb	erect	annual
Justicia nuttii	Acanthaceae	herb	erect	perennial
Justicia phyllostachys	Acanthaceae	herb	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Justicia striata	Acanthaceae	herb	erect	perennial
Kniphofia grantii	Asphodelaceae	herb	erect	perennial
Kniphofia linearifolia	Asphodelaceae	herb	erect	perennial
Kniphofia princeae	Asphodelaceae	herb	erect	perennial
Kniphofia reynoldsii	Asphodelaceae	herb	erect	perennial
Kotschya aeschynomenoides	Fabaceae	shrub	erect/prostrate	perennial
Kotschya africana	Fabaceae	shrub	erect	perennial
Kotschya strigosa	Fabaceae	shrub	erect	perennial
Lapeirousia erythrantha	Iridaceae	herb	erect	perennial
Lapeirousia setifolia	Iridaceae	herb	erect	perennial
Launaea rarifolia	Asteraceae	herb	erect	perennial
Lecaniodiscus fraxinifolius	Sapindaceae	shrub/tree	erect	perennial
Leonotis decadonta	Lamiaceae	shrub/tree	erect	annual
Leonotis nepetifolia	Lamiaceae	shrub	erect	annual/perennial
Leonotis ocymifolia var. *raineriana*	Lamiaceae	shrub/tree	erect	annual
Leonotis pole-evansii	Lamiaceae	shrub	erect	perennial
Lippia plicata	Verbenaceae	shrub	erect	perennial
Lithospermum afromontanum	Boraginaceae	shrub	erect/straggling	perennial
Lobelia trullifolia	Lobeliaceae	herb	erect/straggling	annual/perennial
Lobelia trullifolia subsp. trullifolia	Lobeliaceae	herb	erect/straggling	annual/perennial
Loudetia simplex	Poaceae	herb	erect	perennial
Macaranga capensis	Euphorbiaceae	tree	erect	perennial
Macrotyloma axillare	Fabaceae	herb	scandent	perennial
Maesa lanceolata	Myrsinaceae	shrub/tree	erect	evergreen

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Mariscus deciduus	Cyperaceae	herb	erect	perennial
Mariscus sp.	Cyperaceae	herb	erect	perennial
Maytenus ripens	Celastraceae	tree	erect	perennial
Melinis ambigua	Poaceae	herb	erect	perennial
Melinis repens	Poaceae	herb	erect	annual/perennial
Melinis repens var *nigricans*	Poaceae	herb	erect	annual
Mohria caffrorum	Anemiaceae	herb	scandent	perennial
Mohria lepigera	Anemiaceae	herb	scandent	perennial
Momordica foetida	Cucurbitaceae	herb	prostrate/scandent	perennial
Morella salicifolia	Myricaceae	tree	erect	perennial
Morella serrata	Myricaceae	tree	erect	perennial
Myrothamnus flabellifolius	Myrothamnaceae	shrub	erect	perennial
Myrsine africana	Myrsinaceae	shrub	erect	perennial
Mystroxylon aethiopicum	Celastraceae	shrub/tree	erect	perennial
Neonotonia wightii	Fabaceae	herb	scandent	perennial
Nervilia crociformis	Orchidaceae	herb	erect	annual
Nuxia congesta	Buddlejaceae	tree	erect	perennial
Nuxia floribunda	Buddlejaceae	tree	erect	perennial
Orobanche minor	Schrophulariaceae	herb	erect	perennial
Orthosiphon rubicundus	Lamiaceae	herb	erect	perennial
Osyris quadripartita	Santalaceae	shrub/tree	erect	perennial
Oxalis corniculata	Oxalidaceae	herb	scandent	annual
Oxalis obliquifolia	Oxalidaceae	herb	acaulescent	perennial
Oxalis trichophylla	Oxalidaceae	herb	acaulescent	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Panicum adenophorum	Poaceae	herb	erect	annual/perennial
Panicum chionachne	Poaceae	herb	erect	annual/perennial
Panicum delicatulum	Poaceae	herb	erect	annual
Panicum ecklonii	Poaceae	herb	erect	perennial
Panicum inaequilatum	Poaceae	herb	erect/prostrate	perennial
Panicum lukwangulense	Poaceae	herb	erect	perennial
Panicum maximum	Poaceae	herb	erect	annual/perennial
Panicum monticola	Poaceae	herb	prostrate	perennial
Panicum pectinellum	Poaceae	herb	erect	perennial
Panicum phragmitoides	Poaceae	herb	erect	perennial
Panicum pusillum	Poaceae	herb	erect/prostrate	annual
Panicum trichocladum	Poaceae	herb	scandent	perennial
Pavonia urens	Malvaceae	shrub/suffrutex	erect/straggling	annual/biennial/perennial
Pelargonium apetalum	Geraniaceae	herb	prostrate	annual
Pelargonium luridum	Geraniaceae	herb	acaulescent	perennial
Pelargonium whytei	Geraniaceae	herb	straggling	perennial
Pellaea doniana	Pteridaceae	herb	scandent	perennial
Periploca linearifolia	Apocynaceae	herb	erect	perennial
Persicaria nepalensis	Polygonaceae	herb	erect	perennial
Phacelurus huillensis	Poaceae	herb	erect	perennial
Phyllanthus paxii	Euphorbiaceae	herb/shrub	erect	perennial
Physalis peruviana	Solanaceae	herb	erect	perennial
Physotrichia heracleoides	Apiaceae	herb	erect	perennial
Piloselloides hirsuta	Asteraceae	herb	acaulescent	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Pimpinella buchananii	Apiaceae	herb	erect	biennial/perennial
Pimpinella nyasica	Apiaceae	herb	erect	biennial
Pimpinella whytei	Apiaceae	herb	erect	biennial/perennial
Platostoma rotundifolium	Lamiaceae	herb	erect	annual
Plectranthus daviesii	Lamiaceae	shrub	scandent	perennial
Plectranthus esculentus	Lamiaceae	shrub	erect	perennial
Plectranthus goetzii	Lamiaceae	herb	erect	perennial
Plectranthus laxiflorus	Lamiaceae	herb/shrub	scandent	perennial
Plectranthus masukensis	Lamiaceae	herb	erect	annual
Plectranthus pubescens	Lamiaceae	herb	erect	perennial
Plectranthus schizophyllus	Lamiaceae	herb	erect	annual
Plectranthus stenophyllus	Lamiaceae	herb	erect	annual
Plectranthus stenosiphon	Lamiaceae	herb	erect	annual
Plectranthus sylvestris	Lamiaceae	shrub	erect	annual
Plectranthus zombensis	Lamiaceae	herb	erect	annual
Podocarpus milanjianus	Podocarpaceae	tree	erect	perennial
Polygala virgata	Polygalaceae	shrub	erect	perennial
Polygala virgata var. *decora*	Polygalaceae	shrub	erect	Perennial
Polystichum transvaalense	Dryopteridaceae	fern	erect	Perennial
Protea caffra subsp. *mafingensis*	Proteaceae	shrub/tree	erect	Perennial
Pseudarthria hookerii	Fabaceae	herb/shrub	erect	Perennial
Pseudarthria hookerii var hookeri	Fabaceae	shrub	erect	Perennial
Pseudobromus engleri	Poaceae	herb	erect	Perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Psophocarpus lancifolius	Fabaceae	herb	scandent	perennial
Psychotria mahonii	Rubiaceae	tree	erect	perennial
Psychotria zombamontana	Rubiaceae	tree	erect	perennial
Psydrax whitei	Rubiaceae	tree	erect	perennial
Pteridium aquilinum	Dennstaedtiaceae	herb	scandent	perennial
Pteris friesii	Pteridaceae	herb	erect/scandent	perennial
Pycnostachys milanjianum	Lamiaceae	herb/shrub	erect	perennial
Pycnostachys orthodonta	Lamiaceae	herb	erect	annual
Pycnostachys ruandensis	Lamiaceae	herb	erect	annual
Rapanea melanophloeos	Myrsinaceae	tree	erect	evergreen
Rhamnus prinoides	Rhamnaceae	tree	erect	perennial
Rhoicissus tridentata	Vitaceae	shrub	scandent	perennial
Rhus longipes	Anacardiaceae	tree	erect	perennial
Rhus natalensis	Anacardiaceae	shrub	erect	perennial
Rubia cordifolia	Rubiaceae	herb	scandent	perennial
Rubia cordifolia subsp. conotricha	Rubiaceae	herb	scandent	perennial
Rubus apetalus	Rosaceae	shrub	scandent	perennial
Rubus chapmanianus	Rosaceae	shrub	scandent	perennial
Rubus ellipticus	Rosaceae	shrub	scandent	perennial
Rubus iringianus	Rosaceae	shrub	scandent	perennial
Rubus rigidus	Rosaceae	shrub	scandent	perennial
Rumex abyssinicus	Polygonaceae	herb	erect	perennial
Salvia nilotica	Lamiaceae	herb	scandent	perennial
Salvia runcinata	Lamiaceae	herb	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Satureja biflora	Lamiaceae	herb	erect	Perennial
Satureja masukuensis	Lamiaceae	shrub	erect	Perennial
Satureja myriantha	Lamiaceae	shrub	erect	Perennial
Satureja pseudosimensis	Lamiaceae	herb/shrub	erect	Perennial
Satureja vernayama	Lamiaceae	herb/shrub	erect	Perennial
Scabiosa columbaria	Dipsacaceae	herb	erect	perennial
Schistostephium artemisiifolium	Asteraceae	herb	erect	perennial
Schistostephium mollissimum	Asteraceae	herb	erect	perennial
Schrebera alata	Oleaceae	tree	erect	perennial
Scleria racemosa	Cyperaceae	herb	scandent	perennial
Scleria ripestris	Cyperaceae	herb	scandent	perennial
Sebaea microphylla	Gentianaceae	herb	erect	annual
Sebaea sedoides	Gentianaceae	herb	erect	perennial
Selaginella kraussiana	Selaginellaceae	herb	scandent	perennial
Selago caerulea	Selaginaceae	shrub	erect	perennial
Selago thyrsoidea	Selaginaceae	herb/shrub	erect	perennial
Selago viscosa	Selaginaceae	shrub	erect	perennial
Senecio diphyllus	Asteraceae	herb	erect	perennial
Senecio latifolius	Asteraceae	herb	erect	perennial
Senecio maranguensis	Asteraceae	herb	erect	perennial
Senecio purpureus	Asteraceae	shrub	erect	perennial
Senecio striatifolius	Asteraceae	herb	erect	perennial
Senecio subsessilis	Asteraceae	herb/shrub	erect	perennial
Setaria grandis	Poaceae	herb	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Setaria pallide-fusca	Poaceae	herb	erect	annual
Setaria sphacelata	Poaceae	herb	erect	perennial
Silene burchellii	Caryophyllaceae	herb	erect	perennial
Solanum anguivi	Solanaceae	shrub	erect	perennial
Solanum mammosum	Solanaceae	shrub	erect	perennial
Solanum nigrum	Solanaceae	herb	erect	annual
Solanum panduriforme	Solanaceae	herb/shrub	erect	perennial
Solenostemon latifolius	Lamiaceae	herb	erect	perennial
Solenostemon schizophyllus	Lamiaceae	herb	erect	perennial
Sparmannia ricinocarpa	Tiliaceae	shrub	erect	perennial
Spermacoce dibrachiata	Rubiaceae	herb	erect/prostrate	annual/biennial/perennial
Sphaeranthus randii	Asteraceae	herb	erect	annual
Sporobolus centrifugus	Poaceae	herb	erect	perennial
Sporobolus mollier	Poaceae	herb	erect	annual
Sporobolus myrianthus	Poaceae	herb	erect	perennial
Sporobolus pyramidalis	Poaceae	herb	erect	perennial
Stachys pseudonigricans	Lamiaceae	herb	erect	annual
Stellaria mannii	Caryophyllaceae	herb	prostrate	annual/perennial
Stephania abyssinica	Menispermaceae	liana	scandent	perennial
Stomatanthes africanus	Asteraceae	shrub	erect	perennial
Swertia abyssinica	Gentianaceae	herb	erect	annual
Tecomaria capensis	Bignoniaceae	shrub/tree	erect	perennial
Tephrosia aeguptica	Fabaceae	shrub	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Tephrosia aequilata	Fabaceae	shrub	erect	perennial
Tephrosia capensis	Fabaceae	shrub	erect	perennial
Tetradenia riparia	Lamiaceae	shrub	erect	perennial
Thalictrum rhynchocarpum	Ranunculaceae	herb	erect/scandent	perennial
Thalictrum zernyi	Ranunculaceae	herb	erect	perennial
Thelypteris chaseana	Thelypteridaceae	herb	scandent	perennial
Thelypteris confluens	Thelypteridaceae	herb	scandent	perennial
Thelypteris hispidula	Thelypteridaceae	fern	scandent	perennial
Thelypteris pozoi	Thelypteridaceae	herb	erect	perennial
Themeda triandra	Poaceae	herb	erect	perennial
Thesium triflorum	Santalaceae	shrub	scandent	perennial
Thunbergia alata	Acanthaceae	herb	scandent	perennial
Thunbergia crispa	Acanthaceae	shrub	erect	perennial
Thunbergia mollis	Acanthaceae	herb	erect	perennial
Tinnea aethopica	Lamiaceae	shrub	erect	perennial
Trachypogon spicatus	Poaceae	herb	erect	perennial
Tricalysia andongensis	Rubiaceae	tree	erect	perennial
Trichodesma physaloides	Boraginaceae	herb	erect	perennial
Triumfetta annua	Tiliaceae	herb	erect	annual
Usnea exasperata	Usneaceae	lichen	erect	perennial
Vernonia adoensis	Asteraceae	herb/shrub	erect	perennial
Vernonia amygdalina	Asteraceae	shrub/tree	erect	perennial

Appendix 3.3: Continued.

Plant species	Family	Habit	Growth form	Life cycle
Vernonia calyculata	Asteraceae	herb	erect	perennial
Vernonia divaricata	Asteraceae	shrub	erect	perennial
Vernonia karaguensis	Asteraceae	herb	erect	perennial
Vernonia stenocephala	Asteraceae	herb	erect	perennial
Vernonia tolypophora	Asteraceae	shrub	erect	perennial
Veronica abyssinica	Scrophulariaceae	herb	prostrate	annual
Vicia paucifolia	Fabaceae	herb	erect/scandent/straggling	perennial
Vigna fischeri	Fabaceae	herb	scandent	perennial
Vigna platyloba	Fabaceae	herb	scandent	perennial
Vigna unguiculata	Fabaceae	herb	scandent	annual/perennial
Wahlenbergia virgata	Campanulaceae	herb	erect	perennial
Zehneria scabra subsp. *scabra*	Cucurbitaceae	herb	prostate/scandent	perennial
Zonotriche inamoena	Poaceae	herb	erect	perennial

Appendix 3.4: List of soil-related environmental indicators recorded at the study sites.

Site	%Silt	%Clay	Soil class	pH	%OM	%OC	% N	P (µg/g)	K (cmol/kg)	Ca (µg/g)	Mg (cmol/kg)
S3	10	8	Loamy Sand	6.03	5.97	3.46	0.3	1	0.02	3.27	1.02
S4	16	5	Sandy/Sandy Loam	5.76	5.38	3.2	0.285	1	0.02	2.9	0.985
S5	12	5	Loamy Sand	5.86	4.93	2.86	0.25	2	0.025	3.175	0.96
S6	23	10	Sandy Loam	5.91	5.11	2.965	0.26	1	0.025	2.925	0.76
S7	16	15	Sandy Loam/Sandy Clay Loam	5.93	4.26	2.47	0.215	1.5	0.025	3.475	1.07
S8	17	7	Loamy Sand/Sandy Loam	6.05	5.29	3.07	0.265	2	0.025	2.82	0.81
S10	13	32	Sandy Clay Loam	5.90	5.42	3.145	0.27	2	0.025	3.09	0.93
S16	12	28	Sandy Clay Loam	5.95	4.03	2.34	0.205	1.5	0.025	3.415	1.055
S17	9	20	Sandy Loam/Sandy Clay Loam	5.99	5.98	4.44	0.11	3	0.025	3.12	0.835
S19	10	7	Loamy Sand	6.01	3.82	2.33	0.18	3	0.03	2.8	0.752
S21	16	4	Loamy Sand	5.73	4.72	2.74	0.24	3	0.03	3.97	1.13

Legend: %OM = %Organic Matter; %OC = %Organic Carbon

Appendix 3.4: Continued.

Site	%S	%	Soil class	pH	%OM	%OC	% N	P (µg/g)	K (cmol/kg)	Ca	Mg
S22	14	4	Loamy Sand	5.8	4.47	2.59	0.22	3	0.02	3.87	1.09
S23	18	8	Sandy Loam	5.9	5.5	3.22	0.28	10	0.02	3.45	1.01
S24	15	7	Loamy Sand	5.9	3.085	1.79	0.155	1	0.015	3.015	1
S25	20	8	Sandy Loam	5.8	4.72	2.74	0.24	2	0.03	3.24	1.06
S26	14	4	Loamy Sand	6.1	4.59	2.66	0.23	3	0.02	3.21	1.01
S27	17	7	Loamy Sand/Sandy Loam	5.9	5.155	2.99	0.26	1	0.025	3.04	0.95
S28	9	13	Sandy Loam	5.9	4.61	2.675	0.23	1	0.01	3.345	1.015
S29	8	7	Sandy/Loamy sand	6.1	3.985	2.31	0.2	2.5	0.01	3.46	1.075
S31	19	6	Loamy Sand/Sandy Loam	5.9	4.945	3.02	0.26	1	0.015	3.265	0.95
S32	7	3	Sandy	6.1	5.785	3.355	0.29	1	0.01	2.855	0.965
S33	11	4	Loamy Sand	5.9	5.815	3.525	0.305	1	0.025	3.63	1.006
S34	9	2	Sandy	6.3	3.45	2	0.175	1	0.025	3.365	1.005
S35	12	3	Loamy Sand	5.9	6.08	3.525	0.305	1	0.015	3.46	1.065
S36	12	3	Loamy Sand	5.9	6.27	3.65	0.28	1	0.015	3.56	1.15
S40	10	3	Sandy/Loamy Sand	5.9	4.905	2.845	0.245	1	0.025	2.905	0.87
S41	5	3	Sandy	6.1	3.905	2.26	0.16	1	0.025	3.395	1.015

Legend: %OM = %Organic Matter; %OC = %Organic Carbon

Appendix 3.4: Continued.

Site	%Silt	%Clay	Soil class	p	%OM	%OC	% N	P (μg/g)	K (cmol/kg)	Ca	Mg
S42	12	4	Sandy/Loamy Sand	6.	4.595	2.69	0.23	1	0.015	3.315	1.045
S44	11	15	Sandy Loam	5.	5.07	2.925	0.255	1	0.015	2.75	0.795
S45	13	18	Sandy Loam	5.	4.75	2.755	0.24	1	0.015	3.245	0.865
S46	13	15	Sandy Loam	5.	3.94	2.285	0.2	1	0.015	3.485	1.07
S50	8	14	Sandy Loam	5.	5.155	2.99	0.26	1.5	0.015	3.105	0.905
S51	8	21	Sandy Clay Loam	6.	6.29	3.59	0.26	2	0.02	2.87	0.75
S52	12	11	Sandy Loam/Loamy Sand	5.	5.465	3.17	0.275	2	0.015	3.025	0.855
S53	11	5	Sandy/Loamy Sand	5.	3.225	1.87	0.16	1	0.025	3.135	0.485
S54	11	11	Sandy/Loamy Sand	5.	5.295	3.07	0.265	1	0.03	3.55	1.03
S55	13	10	Loamy Sand/Sandy Loam	5.	4.76	2.76	0.24	1.5	0.02	3.135	0.96
S56	12	17	Sandy Loam/Sandy Clay Loam	5.	4.53	2.625	0.225	1	0.02	2.46	0.65
S57	7	5	Sandy/Loamy Sand	5.	4.89	2.835	0.245	1.5	0.015	2.885	0.915
S65	11	15	Sandy Loam	6.	5.285	3.065	0.265	1.5	0.025	3.31	0.265

Legend: %OM = %Organic Matter; %OC = %Organic Carbon

Appendix 4.1: Projection matrices for *Berberis holstii.*

	2005-2006						2006-2007					
	S	J_1	J_2	A_1	A_2	A_3	S	J_1	J_2	A_1	A_2	A_3
Mpopoti												
S	0	0	0	0	0	0	0	0	0	0	0	0
J_1	0	0.26	0.02	0	0	0	0	0.23	0.02	0	0	0
J_2	0	0.32	0.74	0	0	0	0	0.38	0.55	0	0	0
A_1	0	0	0.05	1	0	0	0	0	0.05	0.5	0	0
A_2	0	0	0	0	0	0	0	0	0	0	0	0
A_3	0	0	0	0	0	0	0	0	0	0	0	0
TT Base												
S	0	0.29	23.5	4.35	0.87	0	0	0	0	0	0	0
J_1	0.76	0.35	0.02	0.01	0	0	1	0.54	2.47	0	0	0
J_2	0	0.23	0.53	0.07	0	0	0	0.21	0.69	0.06	0	0
A_1	0	0	0.05	0.42	0	0	0	0	0.06	0.77	0	0
A_2	0	0	0	0	0.5	0	0	0	0	0.04	1	0
A_3	0	0	0	0	0	0	0	0	0	0.01	0	0

Appendix 4.1: Continued.

	2005-2006						2006-2007					
	S	J_1	J_2	A_1	A_2	A_3	S	J_1	J_2	A_1	A_2	A_3
Dembo												
S	0	0	0.6	1.7	1.02	0.24	0	0	0	0	0	0
J_1	0.44	0.33	0.02	0.17	0	0	0.67	0.44	0	0	0	0
J_2	0.11	0.5	0.62	0.26	0.21	0	0.33	0.19	0.71	0.01	0	0
A_1	0	0.17	0.31	0.62	0.43	1	0	0	0.26	0.85	0.06	0
A_2	0	0	0.05	0.06	0.21	0	0	0	0	0.09	0.72	0
A_3	0	0	0	0.03	0.07	0	0	0	0	0	0.11	1
Juniper												
S	0	0	0	0	0	0	0	0	0	0	0	0
J_1	0.48	0.68	0.05	0.75	0	0	0	0.43	0.14	0.03	0	0
J_2	0	0.2	0.63	0	0	0	0	0.2	0.71	0.13	0	0
A_1	0	0	0.05	0.95	0	0	0	0.05	0.08	0.88	0	0
A_2	0	0	0	0	1	0	0	0	0	0	1	0
A_3	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4.1: Continued.

	2006-2007					
	S	J_1	J_2	A_1	A_2	A_3
Kaulimi						
S	0.05	0	0	0	0	0
J_1	0.27	0.55	0.04	0	0	0
J_2	0.02	0.23	0.81	0.05	0	0
A_1	0	0	0.09	0.93	0	0
A_2	0	0	0	0	0	0
A_3	0	0	0	0	0	0

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