CHAPTER 1

Introduction

1.1 Introduction

Exploitation of botanical resources has resulted in significant decreases in some plant population sizes, especially species with commercial and utility value, including medicinal flora. While legislation and regulations exist at provincial, national and international levels to protect taxa and restrict activities and trade involving threatened or protected species, in many cases conservation measures only begin once a species has already become threatened (Lange 1998). The harvesting of natural resources is known to provide a buffer for rural communities against poverty and unemployment (Cunningham 1991). In addition, it is the socio-economic circumstances of many of the stakeholders (patients, healers, gatherers and traders) and the increased pressures on the rural and agricultural land bases that have triggered the over-exploitation of indigenous medicinal plants (Arnold 1996, Williams 2004).

A challenge to researchers is how to identify conservation priorities for plants in the context of specific threats posed by indigenous plant use. The growing need to buffer the resulting effects of localised species extinctions and to ensure the sustainable use and the continued supply of plants and plant products has led to the introduction of many wild species used for traditional medicine into cultivation (Sparg *et al.* 2005). It is believed that cultivation as an intervention will address biodiversity and market sustainability issues (Mander *et al.* 2006), as well as assist in generating employment opportunities for stakeholders and small entrepreneurs (Sparg *et al.* 2005).

The problem of medicinal plant exploitation in South Africa is, however, not a recent one. In 1946 Father Jacob Gerstner, a Zululand missionary, wrote about the imminent extinctions of 'doomed' plant species used for traditional medicine and recommended their cultivation be taken up by State nurseries (Gerstner 1946). After 20 years in Zululand, Gerstner considered *Warburgia salutaris* to be number one on his list of plants in danger of imminent extinction, and recommended that its cultivation be taken up as soon as possible. Second on Gerstner's priority list was *Erythrophleum lasianthum*, the bark and roots of which harvesters reportedly were very well paid to collect. Furthermore, witnesses had regularly seen 40 to 50 bags being railed to Durban on a single day. Other taxa of concern to Gerstner, due to the "brisk trade going on", were *Mondia whitei*, *Elaeodendron transvaalense* and several species of *Encephalartos* (Gerstner 1946). In 2006, *W. salutaris* is listed as Endangered in KwaZulu-Natal, species of *Encephalartos* range from Regionally Extinct to Vulnerable, *Mondia whitei* is Lower Risk (conservation dependent) and the other two species have not been evaluated according to the IUCN Red List criteria.

The IUCN Red Lists (RLs) are intended to catalogue the status of taxa threatened with extinction and help convey the urgency and magnitude of measures necessary to protect species (Golding 2002). Red Listing is also a form of risk assessment, i.e. an assessment of the likelihood of a population declining below some critical threshold level and becoming extinct. The categorisation of species on RLs is based on substantial and sound ecological knowledge, and is supported by information from collaborators such as field ecologists, taxonomists and botanists who have observed species in the wild and/or who have knowledge of the conservation threats (Victor and Keith 2004). However, there are taxa that are "imperfectly known" (Golding 2002) due to gaps in information such as population size, the effect of stressors such as pollutants and pathogens, and actual or potential levels of exploitation (e.g. commercial harvesting and horticultural acquisitions). The threat categorisation process therefore requires information on levels of exploitation, and it is partly for this reason that species should be regularly re-evaluated once new information becomes available.

Knowing what species are traded in the medicinal plant markets around the country is a foundation for identifying taxa that are potentially threatened with extinction due to commercial harvesting. Species that are flagged as highly threatened by the trade and that are not on RLs are therefore candidates for conservation status re-evaluation. However, the methods and parameters used to identify priority species pose a challenge to field workers and researchers. The criteria for judging categories of threat and the likelihood of extinction for species on RLs are based on factors such as: population size; the number of mature individuals and the projected or expected rate of decline thereof; extent of occurrence and area of occupancy; and, quantitative analyses that estimate extinction probabilities based on factors such as life history, habitat requirements and threats (IUCN 2006). These broad criteria do not necessarily quantify threats to plants endangered by harvesting for the medicinal plant trade because not all species with restricted distributions are threatened by commercial harvesting. However, using these criteria will substantiate a decision to characterise the trade threats as high or low risk during a risk assessment process. Similarly, assessments of risk due to over-harvesting can support the RL assessment procedure.

Given that protection measures are often afforded to plants once they have already become rare and threatened, and that not all taxa meet the criteria for a category of threat in the Red Listing process, resource assessments would benefit from the development of a specific methodology that short-lists priority species vulnerable to harvesting for local and commercial use. The assessment process should be able to characterise the risks to species and forecast which species would benefit from preventative conservation measures to avoid a population crisis in the future. This thesis researches and explores the concept of risk assessment as it applies to harvesting indigenous plant resources for the medicinal plant trade, and short-lists high risk and high conservation priority species in commercial trade. The approach diverges from the linear ranking methods undertaken in previous studies (see section 1.4) and investigates a statistical multivariate methodology.

By investigating the impact of harvesting indigenous plants by people, one is working at the interface between the knowledge and expertise of local resource users and applied ecological approaches (Cunningham 2001). This interface also integrates cultural and biological diversity, which is part of the discipline of ethnobotany[1], a branch of learning linking diverse fields such as botany, anthropology, economics, conservation and ecology (Phillips and Gentry 1993). In the 1980s, 'quantitative ethnobotany'[2] emerged as an ethnobotanical sub-discipline. Intellectual innovators such as Begossi (1996), Boom (1987) Cunningham (1988, 1993, 1996a, 2001), Hanazaki *et al.* (2000), Martin (1995), Phillips and Gentry (1993), Prance *et al.* (1987) to name a few, either incorporated quantitative techniques to the analysis of ethnobotanical data or investigated novel methodologies for doing so. As research moves away from asking: "*what is this plant and what is it used for?*" towards the economic evaluation of harvested resources, assessing harvesting impacts and linking market information with the condition of the resource in the wild, there is scope for broadening the suite of quantitative techniques by developing new methods or applying methods traditionally used in other disciplines.

1.2 Aims and Objectives

The main aim of the study was to design a risk assessment model to determine the impact of the herbal medicine trade on indigenous plant resources. The goal was to incorporate trade variables correlated with harvesting risk, with biological characteristics of the harvested species that predict which species are most threatened by the trade and are thus high on the list for conservation priority. While the trade study is geographically confined to medicinal plants sold on the Witwatersrand, a region in the province of Gauteng (Figure 3), the methods and model used and developed throughout this study are suited to analysing the national trade in medicinal plants, as well as resource inventories and ethnobotanical studies conducted elsewhere in the world.

The broad objectives of the study included:

- Conducting an ethnobotanical survey of the medicinal plant trade on the Witwatersrand;
- Designing and developing methods to quantify and analyse ethnobotanical data;
- Assessing the diversity, sources and quantities of the species traded;
- Promoting the sustainable use of plant resources through an awareness of the socio-economic values of plants to rural/urban consumers and the rural subsistence economy;
- Relating market information for species (e.g. bark thicknesses and bulb diameters) to the condition of the resources in wild populations;
- Estimating how the abundances of species and the mean sizes of individuals in the targeted populations have changed over time through continued resource extraction;
- Short-listing priority species sold in the medicinal plant markets of the Witwatersrand that are most vulnerable to unsustainable harvesting;
- Facilitating the selection of taxa that are candidates for further research, management and protection within the ambit of conservation and sustainable utilisation programmes.

[1] Ethnobotany defined as "the study of the direct interrelations between humans and plants". Alexiades (1996)
[2] Quantitative ethnobotany is defined as the "application of quantitative techniques to the direct analysis of contemporary plant use data" (Phillips and Gentry 1993). The benefits of such an approach include attention to sampling effort, hypothesis testing and economy of description (Williams *et al.* 2000).

1.3 The Witwatersrand Medicinal Plant Trade

Much has been written about traditional health care in South Africa, and the overview by Grace (2002) is especially comprehensive. However, it is the availability, accessibility, acceptability and adaptability of African ethno-medicines that are the stimuli for the participation of millions of people in using and harvesting medicinal plants on the continent (Anyinam 1987). In terms of the availability of traditional medicinal practitioners (TMP) to the community, past assessments for South Africa estimate a TMP to patient ratio of 1:700 – 1200 (Marshall 1998). Statistics for South Africa in 2001 put the ratio for registered medical practitioners (RMP) to patients at 1: 1581, or 1:4343 for pharmacists (Table 1). In an extensively urbanised province like Gauteng, the RMP ratios are a lot less then the country average, but for provinces like the Eastern Cape that has a greater percentage of its population living in rural areas, the RMP to patient ratio is approximately 1:3639 (Table 1).

Table 1: Number of registered health professionals in relation to the number of people in South Africa and selected provinces where the traditional medicine trade is most important. (Derived from Statistics South Africa 2001, 2004)

	South Africa	Gauteng	KwaZulu-Natal	Eastern Cape	Mpumalanga
Registered medical practitioners (including specialists, excluding pharmacists and nurses)	1 : 1581	1 : 870	1 : 2057	1 : 3639	1 : 3458
Registered pharmacists	1 : 4343	1 : 2082	1 : 6348	1 : 7718	1 : 8133

The availability, accessibility and acceptability of traditional medicines and health care providers in Gauteng have been a stimulus for the development of the traditional medicine trade in the region. Once described as the region that ‘came in from the gold’ (Beavon *c.*1992), the Witwatersrand is a large metropolitan area that emerged from an initially small mining town. Labour for the mines was provided by people that became entrenched in the migrant labour system. The ensuing rural-urban oscillation of black labour from around the country enhanced the introduction of activities related to black ‘rural’ culture into the city in the late 1890s (Dauskardt 1990, 1991). Traditional herbalism was incorporated into the developing urban mine culture to meet the needs of both the black migrant labourers and the continuously expanding, permanent urban population for traditional medicine (Dauskardt 1991). Most of the early herbalists and traders of traditional medicine in herbal chemists established their practises near the migrant labour force in the mines and mine hostels.

Different historical processes, working in different communities and ethnic groups, shaped the development of migrancy (Callinicos 1987). These historical processes also shaped the preponderance of different ethnic and language groups in various sectors of the emerging South African capitalist economy and the current stakeholders of the traditional medicine trade in the Witwatersrand. The dominance of the Zulu ethnic group in the present traditional medicine trade is the result of several historical factors. First, Zulus comprise the largest language group in South Africa, estimated at 23.8% (Population Census 2001, Statistics South Africa 2001). Second, while Zulus were not employed in large numbers in the mines (except as police), they were key cultural brokers or entrepreneurs and introduced rural traditional practices in the urbanizing areas (Prof. P. Bonner, 2001, Dept. History, Wits University, *pers. comm.*). Thirdly, over a period of 50 years from 1860, indentured labourers from India were brought to the province of KwaZulu-Natal to work in the sugarcane plantations. Most of the Indians were the “very working class” Tamil-speaking Hindus who would have developed a very close connection with the Zulu peasant class (Prof. P. Bonner, *pers. comm*.). They were also users of the Ayurvedic medical system commonly practised in parts of India. Some of the Tamil families were also closely connected with the Indian herbal medicine trade. There are people in the state of Tamil Nadu, India, today who trade in plant medicines and who have the same surnames as the Indian traders in South Africa (J. Soundrapandi, 2005, Madras Christian College, India, *pers. comm.*). In 1933, Cawston (1933) described “native and Indian herbalists” as becoming common in Natal, with the latter stocking an assortment of drugs which are used in India.

When the Witwatersrand began to develop, many of the ex-indentured Indians headed to Johannesburg and found that they could fill a niche in the emerging demand for herbal medicine since they were familiar with Zulu customs and traditional practices and were themselves users of traditional medicines. Because Black people were prevented from operating in ‘white areas’ or the central business district during the apartheid era, the Indian and White traders established herbal pharmacies or '*muti*' shops in an increasingly formalizing trade. The traders used their knowledge of Zulu traditional medicines, which they continued to develop, and employ black staff to work in the shops (usually Zulu traditional healers). The result was the co-existence of *muti* shops (White- or Indian-owned) trading medicines primarily in the Zulu vernacular, and Black herbalists (of various language groups) who practised predominantly in the township areas (Dauskardt 1991), until deregulation of apartheid legislation occurred after the May 1994 elections.

The traditional medicine trade can be broadly differentiated into two sectors, namely formal businesses and informal vendors (Williams *et al.* 1997). The formal sector is represented by herb-traders, including traditional healers, trading from premises called *muti* shops (herbal chemists). Commercial gatherers and traders selling plants from pavements and open-air street markets, on the other hand, represent the informal sector – for example, the Faraday Street market. Faraday is probably South Africa's second largest market for medicinal plants after the Warwick Street market in Durban, KwaZulu-Natal. The ethnic diversity of the Witwatersrand traders, healers and gatherers has been influential in determining the floristic diversity and sources of the plants in trade (Williams *et al.* 2000). It is from this diversity of stakeholders in the Witwatersrand medicinal plant trade that vendors/respondents were selected to conduct the research. Two sites in Johannesburg that are of particular interest to the Witwatersrand medicinal plant trade are the Mai Mai Bazaar and the Faraday Street market.

1.3.1 Mai Mai Bazaar

The Mai Mai's origins are linked to the introduction of traditional products and services around the mines and mine hostels. The Bazaar was originally a compound accommodating migrant labourers working for the Salisbury and Jubilee Mine *c.* 1891, and was located at the southern end of Delvers Street (Denny-Dimitriou n.d.). Residents of the compound were encouraged to engage in handicrafts and minor trades, and to sell the products of their efforts. Mai Mai was moved to its current site in 1940. The facility to which it moved was the renovated and refurbished Natalspruit Cleansing Depot, previously housing mule stables and an outspan for carts (Denny-Dimitriou n.d.). The site accommodated 250 stalls (previously the old mule stables), 10 shops and a new compound/hostel. A beer-hall was added later. Known as the '*Harley Street of Jo'burg's muthi men*' in the 1950s (Lacaille 1951), Mai Mai was the domain for medicine men and traders from around the country. The Bazaar had shops selling products ranging from traditional medicines, to jewellery and dance attire. A unique feature of the market was that it was one of the only places in the Johannesburg central business district, apart from the townships, where Black traders could own a business during the apartheid era. In 1964, the hostel compound and some carpenter's shops were demolished to make way for a road alteration, leaving behind the market and the beer-hall that exist today (Denny-Dimitriou n.d.) (Figure 1). In 1997/98 the trading area was expanded and upgraded to include new shops, an amphitheatre and a larger carpenters yard.

Figure 1: Scene from the Mai Mai Bazaar in 1995.

1.3.2 The Faraday Street Market

The Faraday Street medicinal market was established approximately 30 years ago as a ‘Fridays only market’ adjacent to the precinct of the Faraday Street train station, bus terminus and taxi rank (Mr Mvubu *pers. comm.*). The market apparently came into existence after people left the Mai Mai Bazaar when it was formalised. About 20 years ago, the traders began selling at the market every day and convened a committee to represent the vendors.

In 1996/97, as part of a programme addressing the informal trade in Johannesburg, the Greater Johannesburg Metropolitan Council (GJMC) provided the vendors with large steel lockers that were divisible into lockable units (Williams 2003). The provision of the lockers resulted in a more permanent and less transient structure to the market. However, growth in the market resulted in more traders than available lockers, and traders without lockers began to occupy the pavement islands of the adjacent bus terminus. In 2001, the Inner City office of the GJMC began redeveloping the Faraday precinct. By 2003, the traders had been relocated to a new trading area adjacent to the old market, formerly occupied by derelict buildings (Figure 2). New facilities were constructed to accommodate more than 200 permanent traders.

a) Section of the old Faraday market in 2001 under the freeway over-pass and adjacent to a busy road.

b) Part of the newly developed Faraday facilities in 2006 at a site formerly occupied by derelict buildings.

Figure 2: Scenes from the Faraday market in 2001 and 2006.

In 2001 there were at least 166 individual stalls operated by vendors (Williams 2003). A ‘stall’ was usually an area on the ground or on a raised wooden palate on which the plants were arranged. According to the chairman of the market, however, there were at least 249 members of the traders association in Faraday in 2001 (Mr Mvubu 2001, *pers. comm.*). In July 2006, there were ≈180 stalls. In addition to the permanent traders, there are >20 vendors that sell plants only on Fridays or Saturday mornings or at the end of the month. This group are primarily SeSotho speaking women from areas south west of Johannesburg and the Free State. The permanent Faraday traders are primarily Zulu-speaking from KwaZulu-Natal, ‘traditionalist’, averse to ‘politics’, and subsist under very hard circumstances (ICDA & SPDC 2001).

1.3.3 Study Site

The Witwatersrand is a multicultural and cosmopolitan centre for African trade and traditional practices, and the emergence of the mining industry in the region shaped the characteristics of the emerging urban population. This influence extended to the emergence of employment opportunities within the formal and informal business sectors, and ultimately the emergence of the Johannesburg metropole as the biggest centre of trade and commerce in Africa. Activities related to traditional healing expanded with the urbanised population, and the stakeholders trade in a mosaic-like pattern within the urban landscape (Chapter 2, Williams *et al.* 1997).

The paper in Chapter 2 describes the process of establishing where and who the traders are, as well as some of the characteristics of the traditional medicine trade in the region (Williams *et al.* 1997). In Figure 2 of the paper in Chapter 2, the study area is shown in relation to the magisterial districts of 1994. However, the structure and boundaries of the municipalities have changed since 1994 and the map in the paper is outdated. Figure 3 below shows the study area in 2006 within the new boundaries. The former and current municipality names are listed in Table 2.

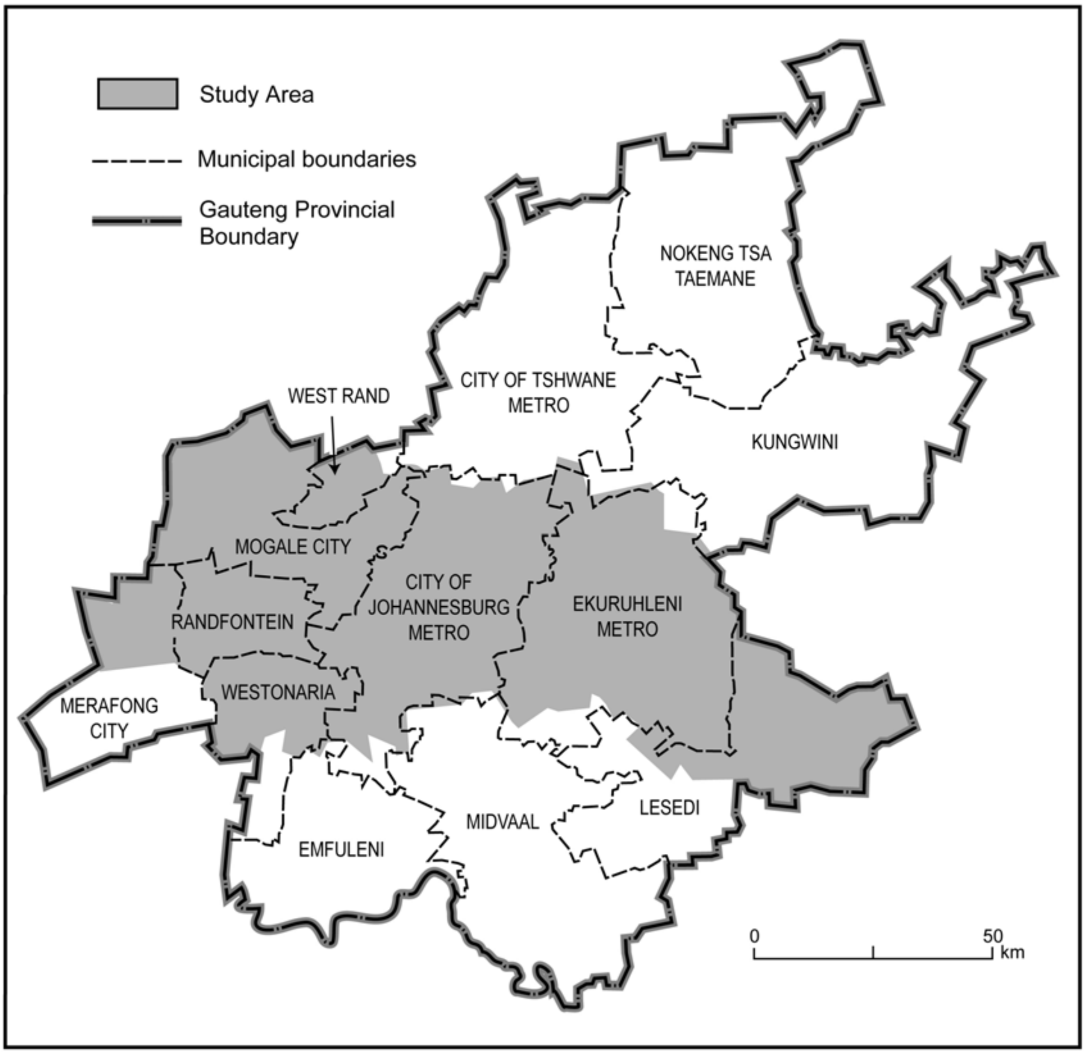

Figure 3: Study area in the province of Gauteng showing the new municipal boundaries and names. The Witwatersrand study area is shaded on the map. This map supersedes Figure 2 in the Chapter 2 paper.

Table 2: Municipal divisions in 1994 and 2006.

1994 municipality name	Region	2006 municipality name
Johannesburg	Johannesburg	City of Johannesburg Metropolitan Municipality
Midrand	Johannesburg	City of Johannesburg Metropolitan Municipality
Randburg	Johannesburg	City of Johannesburg Metropolitan Municipality
Sandton	Johannesburg	City of Johannesburg Metropolitan Municipality
Randfontein	West Rand	City of Johannesburg Metropolitan Municipality
Roodepoort	West Rand	City of Johannesburg Metropolitan Municipality
Krugersdorp	West Rand	West Rand District Municipality
Westonaria	West Rand	West Rand District Municipality
Alberton	East Rand	Ekurhuleni Metropolitan Municipality
Benoni	East Rand	Ekurhuleni Metropolitan Municipality
Boksburg	East Rand	Ekurhuleni Metropolitan Municipality
Brakpan	East Rand	Ekurhuleni Metropolitan Municipality
Edenvale	East Rand	Ekurhuleni Metropolitan Municipality
Germiston	East Rand	Ekurhuleni Metropolitan Municipality
Kempton Park	East Rand	Ekurhuleni Metropolitan Municipality
Springs	East Rand	Ekurhuleni Metropolitan Municipality
Nigel	East Rand	Sedibeng District Municipality

1.4 Risk Assessment, Rapid Vulnerability Assessment, Threat Assessment and Conservation Priority Setting

1.4.1 Risk Assessment (RA)

Risk is the potential, or probability, of an adverse event (Burgman *et al.* 1993). *Risk assessment* (RA) is the process of obtaining quantitative or qualitative measures of risk levels (Burgman *et al.* 1993). *Risk analysis*, in the broad sense, encompasses various risk activities such as risk assessment, risk management, risk communication and comparative risk (Wentsel 1994). When applied to humans, *human health RA* is usually concerned with predicting the adverse outcomes of particular environmental contaminants, or exposures, to human health (such as cancers caused by chemicals and smoking) (Burger 1994). When applied to ecological systems, *ecological RA* is the process for evaluating the likelihood and impact of adverse ecological effects occurring because of exposure to one or more stressors, both man-made and natural (Suter 1993; Burger 1994). A ‘stressor’ describes any chemical, physical or biological entity that can induce adverse effects on individuals, populations, communities or ecosystems (U.S. Environmental Protection Agency 1992), for example industrial contaminants, plant invasions (Groves *et al.* 2001), wetland drainage and earthquakes. There are four basic steps in these types of analyses, namely: 1) hazard identification or the characterisation of ecological effects; 2) dose- or stressor-response relationships; 3) exposure analysis; and 4) risk characterisation (U.S. Environmental Protection Agency 1992, Wentsel 1994).

The concept of RA appears to have been initiated in the United States in the 1970s when quantitative risk analysis was introduced as a discipline (by the U.S. Food and Drug Administration) using scientific data to evaluate health risks, specifically cancer, and involved the use of mathematical and statistical tools to extrapolate the results (Barnard 1994). In 1979, an inter-agency committee of the U.S. government proposed guidelines for identifying and assessing chemical carcinogens (Silbergeld 1993). Since 1981, RA has formed the methodological basis for public policy related to the regulation of occupational and environmental chemicals in the U.S. (Silbergeld 1993). The policies for ecological RA were developed in the mid-1980's from the health RA paradigm and the environmental impact statement process (Burger 1994). In 1992, the U.S. Environmental Protection Agency (EPA) presented its first framework and policy guidelines for ecological RA (U.S. Environmental Protection Agency 1992).

The risk assessment or ‘risk analysis’ process when applied to natural populations of plants and animals, however, is often concerned with calculating the likelihood that populations will decline and remain below a specified size and unacceptably small, critical threshold level (Fogarty *et al.* 1992, Burgman *et al.* 1993). In the case of marine resources, for example, the determination of an ‘acceptable’ risk level under alternative harvesting scenarios sets the basis for exploring and developing strategies for exploiting resources given the predicted risks to the populations as well as allocating the resources to user groups (Fogarty *et al.* 1992). Another example is the stochastic birth-and-death models used to predict population sizes at any time in the future. These models, also known as Population Viability Analysis (PVA), examine the effects of different impacts on populations in order to estimate the risks of population decline. Risk assessment in these cases is about developing Risk Assessment Models (RAMs) that account for the inherent uncertainty of biological systems (Burgman *et al.* 1993). By measuring impacts on populations in terms of risks, it is possible to compare impacts against the 'background risk' of extinction that a population faces in the absence of the impact (Burgman *et al.* 1993). Anthropogenic impacts create 'added risk' (i.e. the increase in risk to a population resulting from human activity) and the opportunity, for example, to quantify the impact of different management practises on species (Burgman *et al.* 1993).

Models (including RAMs) are often simplifications, through a set of equations, of how we think nature operates (Burgman *et al.* 1993). The purpose of a RAM will determine its structure, content and complexity. There is no universal 'best' model or method for quantifying risks that will produce precise and realistic results, mainly because there are limitations on the amount of information that can be obtained, either because of time or resources (Suter and Barnthouse 1993). In general, one can use three methods in the RA process or model design. First are the *physical models*: the material representations of some object or system that is not itself subject to manipulation, or that cannot be manipulated as easily or with as much control as the model, e.g. a laboratory environment where hydrologic systems are constructed and recreated to represent transport processes as an alternative to complex mathematical modelling (Suter and Barnthouse 1993).

Second, are *statistical models or methods* that attempt to derive generalisations by using multivariate analysis, regression, principal components analysis, cluster analysis and other statistical techniques to summarize experimental or observational data (Suter and Barnthouse 1993). The purpose of using statistical models is for hypothesis testing, description and extrapolation. These models summarize the relationship between the variables selected to evaluate risk.

The third type are the *mechanistic models*. These models are what most people associate with the term 'model', the purpose of which is to describe in quantitative terms the relationship between some phenomenon and its underlying causes (Suter and Barnthouse 1993). Whereas in a statistical model the fitted coefficients such as the slope and intercept of a regression line have no intrinsic meaning, the parameters in a mechanistic model have real operational definitions and are amenable to independent measurement (Suter and Barnthouse 1993). An example of this type of model is population-level models for current or potential use developed for long-term management of fish and wildlife populations (e.g. PVAs).

The mechanistic models developed for evaluating harvesting levels in the size of fish populations expressed risk as the 'time to extinction' should current harvesting rates persist (Fogarty *et al.* 1992; Burgman *et al.* 1993). This is sometimes called 'quasi-extinction' risk, i.e. the chance of crossing some small population threshold or a lower boundary that may be unacceptable for conservation, management, economic or aesthetic purposes (Burgman *et al.* 1993). A study that investigated the risk of plants as a stressor was carried out by Richardson *et al.* (1990). In assessing the risk of invasive success in *Pinus* and *Banksia* in South African mountain fynbos, Richardson *et al.* (1990) developed a RAM to predict whether species of *Banksia* were likely to invade fynbos (Honig *et al.* 1992). The empirically based model was designed using *Pinus*, and a number of life history attributes important for invasion into fynbos were identified. The model was then used to investigate the invasive potential of *Banksia*, an Australian genus of the Proteaceae. A correspondence analysis of the life history traits identified as important for a species to invade fynbos (namely: juvenile period, in years; fire tolerance; seed crop variability; degree of serotiny; seed mass and seed-wing loading index) was used to identify a group of species with a high invasive risk potential. Myers (1999) used multivariate statistical methods to select a suite of avian species with similar exposure vulnerabilities to contaminants. The attributes used to measure the risks included foraging tactics, dietary strategies and bioenergetics.

In short, Risk Assessment (RA) is generally the process of quantitatively evaluating, predicting or estimating the risk of populations falling below some critical threshold level due to an impact such as a stressor or any other threat to their persistence, i.e. the probability of partial or total loss of a population (in some RAs, however, the risks of a detrimental population increase are estimated). Risk Assessment Models (RAMs) are models that predict or quantify the probability of extinction in a given time period based on certain impacts and threats. These models are generally stochastic, deterministic models that evaluate the probability of adverse events causing risk to natural populations (Burgman *et al.* 1993) (e.g. the rhino and fish models). However, there is another type of RA that is not model-based, namely the IUCN's Red Lists. Species are grouped into risk categories where the risk levels and the observed or estimated rate of population decline are specified. For example, *Mondia whitei* is categorised as VuA1dD2: Vulnerable with a high risk of extinction in the wild because actual or potential levels of exploitation have resulted in an observed, estimated, inferred or suspected population size reduction of ≥50% in 10 years or 3 generations (Victor 2002). Furthermore, *M. whitei* populations have a very restricted area of occupancy (typically <20 km^2 or ≤5 locations) prone to the effects of stochastic events within a short time period in an uncertain future, and is thus capable of becoming Critically Endangered or even Extinct in a very short time period (Victor 2002).

To date, the conventional RA process does not appear to have been applied to broadly assessing the potential impact of indigenous plant use on plant populations. Instead, a method called 'Rapid Vulnerability Assessment' (RVA) has been used to identify species or resources at risk of over-exploitation and the level of vulnerability to use (Wild and Mutebi 1996, Wong *et al.* 2001). The protocol was developed as a quick way of integrating both scientific data and indigenous knowledge (Wild and Mutebi 1996, Wong *et al.* 2001). RVA thus takes the focus off single-species risk assessment modelling, and concentrates on groups of resources used by communities.

1.4.2 Rapid Vulnerability Assessment (RVA)

Rapid Vulnerability Assessment, or RVA, is a method attributed to Cunningham (1994, 1996a) but formalised by Wild and Mutebi (1996). The protocol rapidly assesses the vulnerability of plants to indigenous use (Aumeeruddy-Thomas *et al.* 1999; Wong 2000). An aim of the RVA is to answer the following questions: which are the priority species, and which species can be harvested with the least chance of over-use? Species vulnerability is evaluated according to a set of criteria of sustainability, including: life-form, habitat specificity, abundance and distribution, growth rate, response to harvesting, plant parts used, patterns of selection and use, demand, seasonal harvesting, traditional conservation practises, commercialisation, and the availability of substitutes for vulnerable species (Wild and Mutebi 1996; Wong *et al.* 2001).

For inexperienced users of the protocol, a numerical scoring system can be developed for each criterion to create a set of management categories. Overall, however, the integration of ecological, social and use factors determines where species lie on a gradient of potential use (i.e. sustainable or unsustainable use) and whether they are vulnerable to harvesting (Wild and Mutebi 1996; Aumeeruddy-Thomas 1999). The method is therefore a first step in identifying which species require further research and what information gaps exist. Cunningham (2001) also calls this process of choosing priority species 'filtering', i.e. methods and predictors of vulnerability that help 'filter' species that are likely to be more resilient or more vulnerable to over-harvesting.

1.4.3 Threat Assessment

Species that are the most threatened biologically are usually considered as having high priority for management action; however, some species with low levels of biological threat may have high priorities for management action because of a perceived value (Given and Norton 1993). The difference between threat and priority is thus important (Given and Norton 1993). The IUCN Red Lists, for example, categorise threatened species. The different quantitative criteria used for evaluating the different levels of threat were developed through a wide consultation process. The criteria are used to place taxa into threat categories (e.g. Critically Endangered, Endangered or Vulnerable), and a higher threat listing implies a higher risk and therefore a higher expectation of extinction within a specified time-frame.

It is generally accepted that species on a Red List are a conservation priority (Victor and Keith 2004). Conversely, it is often assumed that species that do not qualify for Red Listing require no conservation efforts (Victor and Keith 2004). It is important to note, however, that a taxon may require conservation action even if it is not listed as threatened. As a result, the 'Orange List' was proposed that comprises taxa that require anticipatory conservation planning to avoid future Red Listing (Victor and Keith 2004). *Clivia miniata,* for example, does not meet the criteria for a category of threat in the Red Listing process and is thus classed as *Least Concern*. In terms of the Orange List, however, the species is classed as 'declining' (J. Victor pers. comm.). In terms of this categorisation, *C. miniata* has large population numbers or distributional area, but is threatened by commercial harvesting, horticultural acquisitions or is declining for other reasons.

Other methods have been developed that list or rank species in linear order of threat. These systems use multiple scoring for a range of criteria to derive total scores for each species (Given and Norton 1993). Species are then placed into risk, threat, conservation priority and/or species management categories based on their total scores. Problems with linear ranking schemes, however, include deciding on the weight of the variables and objectively deciding where the numerical cut-off is between the one category and the next. Furthermore, "*there is no objective criterion that determines when a score is sufficient to qualify a species for high-priority management action*" (Nel *et al.* 2004).

In another method to determine the threat profile for species, Given and Norton (1993) propose the use of multivariate techniques to assess the types of threats facing species and to determine priority groupings for threatened species conservation. Using agglomerative hierarchical clustering (unweighted pair-group centroid method of cluster fusion), Detrended Correspondence Analysis and discriminant analysis, species were grouped into priority clusters and redundant criteria were identified (Given and Norton 1993).

1.4.4 Setting Conservation Priorities (CP)

Assessments of extinction risks/threat and the setting of conservation priorities are two related but different processes. RA and/or threat assessment generally precedes conservation priority (CP) setting, and the latter often considers the risks of extinction in the determination of priority, but other factors are also taken into account such as: the global RL status of a taxon, the availability of financial and human resources to carry out conservation tasks, legal frameworks for the conservation of threatened species, the cultural value and significance of species and, the phylogenetic distinctness of the taxon. Hence, there are additional criteria for determining CP that are not necessarily mutually inclusive of the criteria required for RA or RVA and, priority setting is often based on factors in addition to those that actually threaten a species (Given and Norton 1993). Criteria for setting CPs for plants that are used by indigenous communities for either construction, crafts, fuel, fodder, food and medicine can be broadly classified as biological, ecological, geographic, cultural and trade/market related. In addition, RL categories are often used to ensure that species with pre-existing background threats of extinction aren't omitted from an assessment, especially if the plant is endemic.

In general, many priority lists are compiled using linear ranking techniques where each species is scored against a number of criteria and then ranked in order of total scores or integrated indices (Pfab 2002). The setting of conservation priorities with linear ranking schemes has been used for threatened medicinal plants in South Africa (Mander and Quinn 1997), within the South African provinces of KwaZulu-Natal (McKean 1993) and Gauteng (Dzerefos and Witkowski 2001), and India (Kala *et al.* 2004) for example (See Tables 1 and 2 in Chapter 10). Because of the potential problems of linear ranking schemes (Given and Norton 1993), Pfab (2002) adopted a hierarchical approach to setting priorities for RL plant taxa in Gauteng. In this approach, eight criteria, ranked from most important to least important, were used to progressively sort the species using the next most important criterion until all the criteria had been used and a final priority list was produced (Pfab 2002).

Another approach taken to identify 'flagship' species for conservation priority and action is the "Top 50" listing and action plan of the IUCN's Medicinal Plant Specialist Group (MPSG). The MPSG outlined five steps to progressively focus on and select the most threatened species (Cunningham 1996b, 1997). These steps are discussed in more detail in Chapter 10, but the approach was followed by Özhatay *et al.* (unpublished report cited in Lange 1998) to identify the top 50 native Turkish medicinal and aromatic plants most threatened by collection owing to their demand in trade.

1.4.5 A Hybrid Risk Assessment Method

The purpose of this research was to develop and recommend a hybrid risk assessment method for medicinal plants that incorporates aspects of multivariate statistical models traditionally used in ecological risk assessment, with the RVA and 'Top 50' method which incorporates indigenous knowledge and scientific data, to identify groups of species that have similar profiles of relative risk, threat and vulnerability to over-utilisation and over-harvesting by the trade. The assessment process integrates features of the trade with selected biological and ecological traits of the species being exploited. Given that some of the criteria used for assessing the risks are similar to criteria used for setting CP, the assessments of species are also partly descriptive of the priorities that should be given to their conservation. The risk or threat levels proposed for species do not specify the time-line for extinction, but they do categorise the probability of partial or total loss of a population *if current harvesting trends continue*. This process could therefore be used to support and validate the Red List RA procedure, and *vice versa*.

1.5 Thesis Structure

The thesis is structured as a set of 13 published or in press papers (except for Chapter 10, which has yet to be formatted for publication). Presenting a thesis as a collection of papers inevitably results in some repetition, particularly in sections dealing with the study area and methods. For this reason, the survey methodology, data collected and related outputs are summarised in the subsequent section (1.6). Furthermore, the questionnaires used to record the data were not published with the papers and they are included as Appendices to the thesis.

Chapter 2 describes the study area and the selection of a stratified random sample of traders for a survey of 50 *muti* shops based on information derived from municipal trade licence application records, former Regional Service Council records and information from telephone books.

Chapter 3 summarises the taxa traded on the Witwatersrand, the plant parts harvested, the sources of the harvested species, and the suppliers to the trade in 1994 [the data collection format for recording the information is shown in Appendix C(I)]. A preliminary investigation into the use of species diversity indices to analyse ethnobotanical data is also described. The success of this preliminary investigation led to the expansion of this idea in **Chapter 6**, and the development of a methodology recommended for ethnobotanical inventories. Also investigated in **Chapter 3** was the use of Spearman rank correlations, chi-squared and Fisher's exact probability tests to assess the probability of certain taxa being sold.

Chapter 4 is a lexicon of the plant names, and corresponding species, captured from the survey of 50 *muti* shops. The survey technique used for inventorying the species sold in the shops involved recording the common names (subsequently described as '*ethnospecies*' from **Chapter 5** on) of the plants. Due to the sample size and the number of plants sold per shop (82.6 ± 46, mean ± SD), it was not possible to collect voucher specimens for every plants sold, hence species identification was primarily achieved by matching the vernacular names to botanical names from previously published studies. Because of the potential for error in species identification, and the impact it would have on some quantitative analyses, succeeding chapters (e.g. **Chapter 6**) used the frequency of occurrence of *ethnospecies* as a quantifying variable rather than the frequency of occurrence of *species*. Experience with working with vendors and species lists also resulted in a more efficient data collection and species identification process in the subsequent survey of the Faraday Street market in 2001 (**Chapter 5**). The species inventories from the *muti* shops were recaptured on a database and combined with the Faraday plant inventory to produce the species lists used in subsequent Chapters and analyses. The combined list of species are in Appendices A and B at the end of the thesis.

Chapter 5 deals with the survey of the Faraday Street traditional medicine market. In 2001, I was awarded a contract from the Directorate of Nature Conservation within the Gauteng Department of Agriculture, Conservation & Environment (GDACE), to perform an ethnobotanical assessment of the market and the market dynamics thereof. The extensive quantitative study of 100 traders was written up in a 200 page report (Williams 2003) (Faraday Report 2003; Faraday Report Appendix hyperlink to the report on the CD version). Various elements of the study were incorporated into **Chapters 6–10**. In **Chapter 5**, however, I describe a subset of the original data. The chapter examines the component of woodland and forest resources that were sold, and includes a description of the methodology used to conduct the survey and the socio-economic profiles of the traders. The questionnaire designed for the survey is in Appendix C(V).

In **Chapter 6**, 22 measures of species richness, diversity and evenness are applied to the analysis of ethnobotanical data derived from the *muti* shop and Faraday surveys. Thereafter, the use of incidence-based species accumulation functions, species richness estimators and similarity measures to appraise ethnobotanical inventories is explored. These methods have the potential to be successfully applied to other resource inventories.

Chapter 7 is concerned with aspects of the relationship between bark thickness, estimated harvestable bark mass and tree stem diameter for six tree species. The research was motivated by the need to link market information on the thickness of bark sold by vendors with the condition of the resource in the wild (i.e. the availability and selection of particular stem size-classes). Also included in this chapter is a paper on the characteristics of the fluted stem of *Balanites maughamii* Sprague.

Chapter 8 describes the novel concept of ‘individual equivalents’, a means by which estimates of the volume of plant material traded annually can be translated into estimates for the number of individual plants harvested annually. The study is divided into two parts: first, estimates on the number of trees debarked; and second, the number of bulbous and perennial herbs harvested. The research also describes the prevalence of plant size-classes in the markets between 1994 and 2001. Chapter 8 also links methods developed in **Chapter 7** with market information presented in **Chapter 9**.

Chapter 9 concerns economic aspects of the Witwatersrand medicinal plant trade. The trade values for 22 species are estimated, the prices paid for plant resources are described, pricing structures relative to the mass/volume sold and the factors that influence the market price for plants are investigated. [The trade data capture format is shown in Appendix C(II-IV)]

Chapter 10 aims at developing a risk assessment method for the medicinal plant trade. The chapter incorporates data from preceding chapters and recommends the placement of species into a number of categorical risk hierarchies.

Lastly, **Chapter 11** gives the overall synthesis, conclusions and recommendations.

1.6 Outline of Survey Methodology, Data Collected and Related Outputs

The table below outlines the survey and field methodology undertaken, the data collected and the associated outputs as both papers and chapters.

Survey/Method	**Description**	**Summary of data collected**	**Output**
Pre-survey	• February – May 1994 • Examined the trade licence records of 18 former municipalities to find records of licensed *muti* shops • Searched phone book records for *muti* shops • Visited >70 traders to discuss the aims of the research and obtain consent to do survey 1	• Number of *muti* shop traders on the Witwatersrand • Geographic distribution of the shops • Trader demographics	Chapter 2: Williams *et al.* 1997: Muthi traders on the Witwatersrand
	Used information on trader distribution and demographics to select a representative sample of 50 traders for Survey 1		
Market survey 1	• July – December 1994 • 50 *muti* shop traders on the Witwatersrand • Stratified random sample of traders • Semi-quantitative survey	• Trader information and demographics • Common names ('ethnospecies') of plants sold • Plant part • Supplier/gatherer • Where harvested • Scarce/popular species	Chapter 3: Williams *et al.* 2000: the market for medicinal plants Chapter 4: Williams *et al.* 2001: lexicon of plants traded
	Selected 29 ethnospecies of varying risk levels for further study		

A

Market surveys 2a, 2b & 2c	a. April – October 1995: • 27 *muti* shops • recorded trade data for 29 ethnospecies	• Supplier and harvesting locality of species • Price paid and quantity purchased of current stock • Plant size (e.g. bark thickness and bulb diameter) • Mass and price of a typical unit sale to a customer	Chapter 9: Williams *et al.* in press 1: Volume and value Data used in Chapter 8, • Williams *et al.* in press 2 • Williams *et al.* 2007 Individual equivalents for bulbs and trees Data used in Chapter 10: Risk assessment
	b. April – October 1995: • 27 *muti* shops • Recorded trade data for 29 ethnospecies	• Estimated quantity of the species bought per trader per annum • Price per bag bought • Value and frequency of weekly or monthly sales to customers	
	c. July – September 1995: • 10 visits to the Faraday market • purchased samples of 29 ethnospecies	• Measured plant size (e.g. bark thickness and bulb diameter) • Recorded the mass and price of a typical unit sale to a customer	
Investigated novel methodology for analyzing ethnobotanical inventory data	• Used data from Surveys 1 and 3 • Species diversity indices • *EstimateS*	• Used ecological methods to analyse species prevalence, richness and diversity • Estimated the species richness of plants traded in the region	Chapter 6: Williams *et al.* 2005a Williams *et al.* in press 3
Market survey 3	• January 2001 • Semi-quantitative survey for GDACE • 101 Faraday market traders • See Williams 2003 • Used some of the data in the thesis	• Trader demographics • Plants sold • Sources and suppliers • Market networks • Volume and value • Plant size and mass	Chapter 5: Williams 2004: woodland and forest species traded in Faraday Data used in: • Chapter 6 • Chapter 8 • Chapter 9 • Chapter 10

A

	Selected 6 tree species used for bark from the 29 previously selected ethnospecies for further study		
Field survey	• March – July 1998 • Investigated relationship between bark thickness and tree stem diameter for 6 species • Visited 15 woodland sites • Total of 207 individual stems measured • 1026 circular bark samples removed (5 cm diameter) • Bark samples placed in a chamber set at a constant temperature and RH, and were weighed and measured weekly for 12 weeks	• Diameter of stem at 5 height intervals • Thickness and mass of the bark samples removed at the corresponding height intervals • Weekly changes in the mass and thickness of the bark samples • Relationship between stem diameter and bark thickness • Estimated harvestable bark mass per tree size-class	Chapter 7 Williams *et al.* 2005b Williams *et al.* in press 4 Williams *et al.* in press 5 Williams *et al.* in press 6
	Used data on 6 tree species, 4 bulb species and 2 perennial herbs		
Investigated novel methodology for estimating the number of individual plants harvested annually	• Developed the 'individual equivalent' methodology for 12 species	• Estimates of the number of individual trees and bulbs harvested annually for selected species	Chapter 8 Williams *et al.* in press 2 Williams *et al.* 2007

Data from all surveys and novel methodology results

Risk assessment methodology	• Designed a process for assessing the risk of species to over-harvesting and extinction as a result of being harvested for the traditional medicine trade • Methods based on cluster analysis and Principle Components Analysis	• Used data derived from all surveys and methods • Groups of species in similar risk clusters and hierarchies	Chapter 10

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