Exploring the past and the present in order to predict the future: herbarium specimens, field data and extinction probability for conservation managers

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DECLARATION

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ABSTRACT

Loss of biodiversity is a global conservation crisis. Environmental change is rapid and biodiversity loss is happening at rates never experienced before. Conservationists must deal with an ever growing responsibility to conserve biodiversity and in addition to this they must also meet recently recognized conservation heritage mandates. In the face of mounting environmental pressure protected areas have been identified as the primary means for saving biodiversity and heritage sites. Protected area managers are constrained by limited time to act and less available resources than in the past. Negative impacts caused by threats such as climate change or land transformation within biodiversity hotspots require research, monitoring and conservation actions to mitigate these threats and save species from extinction. Monitoring species for a trend in population reduction is particularly difficult when protected area management is faced with a large list of species under its custodianship. Exacerbating this problem is the current format of existing data and its accessibility to managers. Conservationists and protected area management now require new and innovative tools for informed decision making and a multidisciplinary approach is required to achieve their expanded mandate.

This research sought specifically to expand our knowledge on global plant species loss from both a social heritage and biodiversity perspective. The study was carried out in the context of science as a discipline and the recently recognised mandate of heritage and biodiversity conservation of protected areas. The thesis deals with the epistemology of science, biocultural heritage, extinction probability and species detection in protected areas. This thesis explores herbarium data from a number of points of view, and looks at the value of herbarium collections to plant species survival at a fine scale within protected areas. Work was carried out in national parks in the Fynbos Biome, a biodiversity hotspot in the Cape Province of South Africa, using herbarium and botanical survey data.

I draw on historical views to understand the contribution of herbarium specimens to botany. I explore herbarium specimens as objects of information and show that they make numerous contributions through the field of botany to science, in serving as the longest standing record and providing a window to the nature of the physical world at the time when collected. Early botanical collectors may have at times contributed to what are now known as common practices in science such as the practice of repeat sampling and collecting. This thesis highlights the significant value of the vast amount of work undertaken by early botanical collectors and the tremendous value of information gathered at a certain point in history, it emphasises the urgent need for an increased effort by modern explorers and naturalists to

once again embark on fieldwork and collections to advance our understanding of the natural world.

I then look at the individual narratives of early botanists in relation to extant populations and the heritage contribution of these to individual national parks. Herbarium specimens are well recognised as historic scientific objects. Herbarium specimens become part of the narrative of the collectors which are directly connected with nature and should be recognised as part of the heritage and natural conservation landscape. The localities of extant plant populations connect biodiversity, current protected areas, and the people who visited and lived there. Working in the Agulhas National Park, I located numerous localities still extant within the Park more than 100 years after collection of the herbarium specimen. I illustrate that plant populations, where historic specimens were collected, are historical scientific places with significant biocultural heritage value, they are areas that show the footprint of people on the landscape, and are spaces where society and science came together to generate knowledge. My research reveals that botany (through herbarium specimens) is consistent in its contributions to science, both social and biological, from the role of herbarium specimens in the development of scientific epistemology and practices, to the recognition of historic herbarium specimens and the sites of *in situ* extant plant populations as biocultural heritage. I recommend that these sites be included in biocultural heritage monitoring activities of protected areas, regardless of the Red List status of the locality species, and in recognition of their heritage contribution.

Tackling the loss of diversity requires an understanding of extinction risk in protected areas. I once again interrogate the value of herbarium data. I undertook a desktop quantitative assessment of herbarium data, survey data and a combined dataset. Using the Solow (1993) extinction probability equation I generated mean survival probabilities for species of four of the main fynbos families (Ericaceae, Fabaceae, Proteaceae and Restionaceae) in the Cape Floristic Region. I then interrogate this against the International Union for Conservation Red List status categories. I present results that show how the inaccessibility of the underlying data results in sparse data available to run the extinction probability model, which alters the accuracy of extinction probability results. Whilst accurately inferring the extinction status of a species is important for species conservation, arguably it is more important to determine whether species in protected areas are still there and if they are stable or declining.

Through much of this thesis I demonstrate the value of the capturing of detailed information associated with field collection and how this has been extremely useful through the ages. The modern approach to seek swift insights in light of time and budget constraints does not lend itself to the accumulation of usable, reliable data. Modelling may work in data rich situations, but that is not the case here as I show in testing the extinction probability on the flora of Table Mountain National Park. It is currently not feasible to monitor all IUCN Red List species within a protected area given the economic climate most protected areas find themselves in. Pressure on protected areas to monitor all species with a Red List threat status can be reduced by targeting high-priority species for monitoring and those which have the greatest return on investment for the conservation of the species. To achieve this, an increase in financial support for botanical monitoring based on sound fieldwork practices is needed.

The work done in this thesis by exploiting current resources for data such as herbarium and survey records found that an indication of extinction risk could not be determined using the data in its current form. The survey data in particular had significant shortcomings in its curation and management, which in turn restricts its use to conservation science. What appears to be needed is better synergy between herbarium and survey data to determine extinction probabilities. The next step is to investigate new practical methods of data collection, collation and storage such as remote sensing, citizen science, and making use of new technologies as they become mainstreamed. The results of my work contribute to our understanding of the current state of data and floral species in case study national parks in South Africa, and provide a basis for using quantitative approaches to inform conservation decision-making.

Lastly, I adapt and develop methods for in-field detection of threatened plant species for the finer scale landscapes of protected areas to inform conservation management decisions. The combination of herbarium and survey data did provide for a clear in-field status to be obtained and it was possible to verify a species as extant at its known subpopulation localities, but more importantly whether a reduction in species subpopulations had occurred. I found no correlation between the Red List status of a species at a broad scale and the actual status of that species in the Table Mountain National Park. I demonstrate that although a species may occur in a protected area it is not necessarily secure if its subpopulations are being lost. Therefore, species that are declining in a protected area should be monitored and action taken to prevent loss irrespective of their Red List status. This thesis articulates the degree to which the IUCN Red List does not align with extinction predictions or in-field survival of species within a protected area. I suggest that the next

stage of the Red List development is in setting small scale limits on how to prioritise actions and monitoring in small geographically defined areas. This work highlights the importance of selecting an in-field detection method that is suitable to meet the multiple needs of conservation management (resources and capacity) and to help prioritise which Red Listed species may not necessarily be under immediate threat and can survive with less regular and intense monitoring whereas others with lower Red List rankings may require immediate attention.

Herbarium data clearly speak to the wider conservation mandates that have recently emerged. My work shows the multi-layered contribution of herbarium data from global scientific practices and epistemologies, to local heritage contributions in national parks, to informing and guiding species detection and in-field work. Broadly the work shows that this is a highly valuable source of data, which should be fostered and grown. There is a need to revive the role of the field-biologist, to reinitiate a period of collection, data gathering and knowledge generation. Current herbarium and survey data provide a present temporal scale, by employing both of these data, species declines can be found and possibly future extinction can be forecast, enabling conservation actions to be put in place. My work highlights the current situation protected areas find themselves in, with recognition of the biodiversity crisis, fiscal constraints, and data limitations imposed on them. One of the biggest benefits in using herbarium data is the long-term history of the records, coupled with accurate vegetation survey data, this combined dataset could hold unknown potential for use in conservation planning and assessments. By combining in-field survey data, long-term and historic data accurate predictions may be obtained and result in conservation efforts maximised and implementation by protected area management where it counts.

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GLOSSARY

Biocultural heritage	Biocultural Heritage (BCH) refers to the knowledge and practices of indigenous people and their biological resources, from the genetic varieties of crops they develop, to the landscapes they impacted upon. Biocultural heritage is a holistic concept, where knowledge, biological diversity, landscapes and culture are inter-connected and inter-dependent.
Biome	A large naturally occurring community of flora and fauna occupying a major habitat
Biomedical	Relating to both biology and medicine
Bio-prospecting	The search for plant and animal species from which medicinal drugs and other commercially valuable compounds can be obtained
Botanical collection	Is the gathering of plant specimens for the purposes of research or cultivation and at time as a hobby
Botanising	The study of plants in their natural habitat
Encyclopedic	A comprehensive, complete, thorough and exhaustive, in-depth investigation and collection of a wide-range of information. The storage of which is generally done alphabetically and systematised.
Endemic	Of a plant or animal that is native and restricted to a certain place
Epistemology	The theory of knowledge, especially with regard to its methods, validity, and scope, and the distinction between justified belief and opinion
Extant	Still in existence or surviving
Extinction risk	Is a measure of the potential for a species to become threatened
Field botanist	An expert in or student of the scientific study of plants who does this in the natural environment and is not restricted to a laboratory or herbarium
Fynbos	A distinctive type of vegetation found only on the southern tip of Africa. It includes a very wide range of plant species, particularly small heather-like trees and shrubs
Georefencing	To associate something with locations in physical space. The term is commonly used in the geographic information systems field to describe the process of associating a physical map or raster image of a map with spatial locations.
Global scale	The geographical realm encompassing all of Earth

Herbarium	A systematically arranged collection of dried plants
In situ	In the original place where it was found or is occurring
Local (fine) scale	Used to describe the geographical realm of things which relate to a particular area in a protected area
Metapopulation	A group of populations that are separated by space but consist of the same species. These spatially separated populations interact as individual members move from one population to another
Niche habitat	The role a species plays in the ecosystem is called its niche. A habitat is the physical environment in which a species lives
Nomenclature	The devising or choosing of names for things, especially in a science or other discipline
Phenology	The study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life
Phytogeography	The branch of botany that deals with the geographical distribution of plants
Probability	The extent to which something is likely to happen or be the case
Protected area	A legally declared area managed for conservation
Provenance	The place of origin or earliest known history of something
Red List	A list of threatened animal or plant species
Regional scale	Used to describe the geographical realm of things which relate to a particular area of a country or of the world.
Spatial	Relating to or occupying space
Specimen	An individual animal, plant, piece of a mineral, etc. used as an example of its species or type for scientific study or display
Subpopulation	A subset of a larger population
Taxonomist/herbarium botanist	An expert concerned with classification, especially of organisms and systematics and generally works indoors

Temporal	Relating to time
Threat status	indicates whether the group still exists and how likely the group is to become extinct in the near future
Thresholds of concern	A set of operational goals that together define the desired spatial and temporal variation in ecological conditions
Type specimen	The specimen, or each of a set of specimens, on which the description and name of a new species is based

Definitions according to the Oxford English Dictionary Online 2018

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CHAPTER 1: Introduction

Prologue[*]

This thesis is about the past, present and future collection of botanical data collection in aiding management of protected areas to conserve floral biodiversity. It is a multidisciplinary study drawing on different fields and methods to investigate the conservation of botanical assets, historical and biological, within protected areas. I use the Fynbos Biome in South Africa, as a study area and investigate the contribution of botanical collections to the evolution of scientific thinking through the collection of herbarium specimens in the Cape Colony, which I explore in the second chapter. I examine a herbarium dataset in relation to the concept of biocultural heritage as historic records and heritage items in my third chapter. I then seek to investigate, in the fourth chapter, whether herbarium and survey datasets can be used as a tool to determine extinction probability at a finer scale within protected areas in conjunction with the global scale International Union for the Conservation of Nature (IUCN) Red List. I apply the results of the extinction probability to the herbarium data and survey data, to establish the presence of extant plant populations in a South African National Park in the fifth chapter. The research is intended to explore whether herbarium plant collection records can act as long-term datasets to inform management activities to assist in conserving heritage and biodiversity within protected areas.

[*] The function of the Prologue Box in multidisciplinary studies is to provide the reader context for a chapter and situate it which the

1.1 Context

South African National Parks is the national organisation mandated to manage the 21 declared national parks in South Africa. My role within South African National Parks (SANParks) is as Regional Ecologist in the six Cape Cluster parks. This position is relatively new to Scientific Services in the national park organisation and was initiated in 2008, I joined SANParks in 2010. Historically scientists in SANParks conducted research in their field of expertise and park management ran the park operations which focused on infrastructure and tourism needs without much interaction between the two. It has since been recognised, both nationally and internationally, that there is a need for science to inform management practices and scientists have had to align their work to park requirements. SANParks created positions for Regional Ecologists to be the interface between scientists and managers, to ensure that wherever possible science could inform management. My role is to take scientific outputs and translate them into management recommendations and actions, and in turn to take management observations and needs and, translate these into robust research questions and projects. The overarching goal is to achieve SANParks' vision of 'a sustainable National Park System connecting society', and mission, which is 'to develop, expand, manage and promote a system of sustainable national parks that represents biodiversity and heritage assets, through innovation and best practice for the just and equitable benefit of current and future generations' (SANParks 2014). SANParks recognises that we work in complex systems (Roux and Foxcroft 2011) and that the challenges facing the long-term conservation of national parks is best addressed through multidisciplinary contributions from scientists, funders and stakeholders (Roux et al. 2010, Esler et al. 2016). Multidisciplinary projects are novel and the implementation of such has to be monitored. Concomitantly SANParks has experience in the practice of adaptive management which ensures that learning is consistent through continuous feedback to parks and scientists (Biggs and Rogers 2004, Keith et al. 2011, McGeoch et al. 2011). I therefore, work in a multidisciplinary environment with a wide range of topics (biodiversity conservation and heritage), needs (academic and operational), and people at various levels in and outside of SANParks. Although the needs frequently change, many agree that the current loss of biodiversity integrity through species loss is one of the most significant challenges to protected areas.

As the outcomes of this study are aimed at addressing real-world problems concerning conservation of heritage and biodiversity in protected areas, a different approach, set of research skills and reasoning was required. This thesis straddles the research topics of cultural heritage and biodiversity conservation, it is multidisciplinary in the scope of work that is covered (Stember 1991, Esler et al. 2016). In order to address the complex problem of biocultural heritage, as a result of the interactions of humans (botanical collectors) and the environment (plant collection), as well as the complex multi-layered process of species extinction risk, the thesis draws on a several different bodies of research, weaving together different disciplines which have mutually complementary interests but which are not traditionally considered together.

1.1.1 Protected Areas, South African National Parks and threatened species (Red List)

Protected areas, defined here as legally declared areas managed for conservation (Andreone 2000), are a cornerstone for the conservation of biodiversity and heritage (Davis et al. 1994, Phillips 2002). Biodiversity is the full range of life on Earth and the ecological processes that support it (Noss 1990, Sutherland et al. 2011). The main purpose of protected areas globally is to protect and nurture biodiversity within their boundaries and mitigate the negative effects of external pressures to ensure the functioning of ecosystems and the continuation of natural ecological processes (Leroux and Kerr 2012, Pimm et al. 2014).They also aim to conserve heritage and natural sites of value such as archaeological landscapes, biological or geological formations (Lockwood 2010).

Protected areas in the form of national parks are mandated to conserve both biodiversity and heritage elements within their borders (Yui 2014). In the South African context, SANParks is governed by The National Environmental Management: Biodiversity Act (10 of 2004) (NEMBA), the National Environmental Management: Protected Areas Act (57 of 2003) (NEMPAA) and the National Heritage Resources Act (25 of 1999). The NEMBA aims to establish a framework within the National Environmental Management Act (107 of 1998) for the management and conservation of South Africa's biodiversity so that it can be suitably governed. This act seeks to achieve the protection of biodiversity in South Africa through effective and efficient management, by amongst others; protecting species and ecosystems and ensuring fair and sustainable use of biological resources. The Act specifies the identification of priority areas for conservation and an integrated, uniform approach to the management of biodiversity in protected areas. The NEMPAA relates directly to the protection and conservation of ecological areas that represent South Africa's biodiversity, and it provides for the establishment of a national register of all protected areas and the management of protected areas for the conservation of biodiversity and cultural heritage of the country. The NEMPAA aims to develop national norms and standards for protected area management through intergovernmental collaborations and public engagement. The state is recognised as the custodian of protected areas and is to adhere to NEMBA and other relevant legislation. The National Heritage Resources Act, aims to achieve an integrated and interactive system of management for national heritage resources within South Africa. It further aims to foster a nurturing culture in civil society for the conservation of heritage resources in order that they may be given to future generations to appreciate and conserve.

Lastly it seeks to have an integrated system for identifying, assessing and managing heritage resources.

In order for protected areas to assess whether conservation objectives are being achieved, an assessment of the management effectiveness is regularly conducted (Hockings 2003, Hockings et al. 2006). The Management Effectiveness Tracking Tool (METT) commissioned by the World Commission on Protected Areas WCPA (Hockings et al. 2006) and used by SANParks, has had both positive and negative feedback from protected area custodians (Dudley et al. 2004). While the METT tool has assisted governments to rapidly evaluate whether protected areas are well managed, the METT does not look at the successful conservation of actual objects, be it heritage, species or ecosystems (Boitani et al. 2008). To address this shortfall the METT has been updated and other tools developed to assess how effective both the management and conservation of protected areas are (Cook and Hockings 2011). Information and knowledge of the state of biodiversity within protected areas is required to inform these assessments. In order to develop such knowledge protected areas are required to undertake research and monitoring of species and ecosystems under threat. Addressing such monitoring needs is key to this study both for heritage and biological diversity conservation.

There have been many criteria suggested and used to determine which areas should be protected (Rouget et al. 2003b) including species ranges, richness and/or rarity, and habitat diversity (Margules 2000, Pressey et al. 2007, Kukkala and Moilanen 2012). The majority of protected areas established since 1990 have been selected using biodiversity hotspots as the main means to determine which areas to protect (Myers et al. 2000, Kuper et al. 2004). Prior to the establishment of formal protected areas, areas were set aside for use by the wealthy elite for activities such as hunting and recreation, such examples include deer parks in the United Kingdom and Russia, and Hluhluwe-Imfolosi as the Zulu King Shaka's domain in South Africa (Carruthers 2004). The first formally declared national park (protected area) was Yellowstone National Park established in 1872 by the United States government (Chape et al. 2005). The fundamental reason was to prevent the rich geological features and abundant diversity of fauna and flora from being exploited by individual people, but rather conserved for public recreational use (Yui 2014). Since 1872 countries all over the world have declared protected areas for various purposes of protecting landscapes (Desmet 1999), heritage sites (Phillips 2002), or wildlife and natural areas with high scientific value (Chape et al. 2005). In South Africa this included areas not fit for agriculture or areas prone to disease.

South Africa’s first national park, the Kruger National Park, was declared in 1926 (SANParks 2008). To-date there are 21 parks forming the South African National Parks Estate (Figure 1.1), the majority of which were declared for the conservation of large mammals and their associated habitats. The original rationales for the establishment of national parks appear in contradiction to the fact that plants are both such a large taxonomic group and now recognised as fundamental to informing animal and insect diversity (Joppa et al. 2013). This is testament to the state of knowledge at the time when more was known about large and medium mammals and hence they formed the focus of conservation efforts. The oldest park declared for floristic conservation was the Tsitsikamma National Park (1964) which was established to protect the remaining indigenous forests. It should be noted that currently five of the six floral informed national parks occur in the Fynbos Biome due to the high proportion of endemic or niche plant taxa in this biodiversity hotspot (Cowling et al. 1994, Linder 2005, Linder et al. 2012). It is now SANParks’ responsibility to ensure that these are managed appropriately for the larger ecosystems and natural heritage they presently encompass.

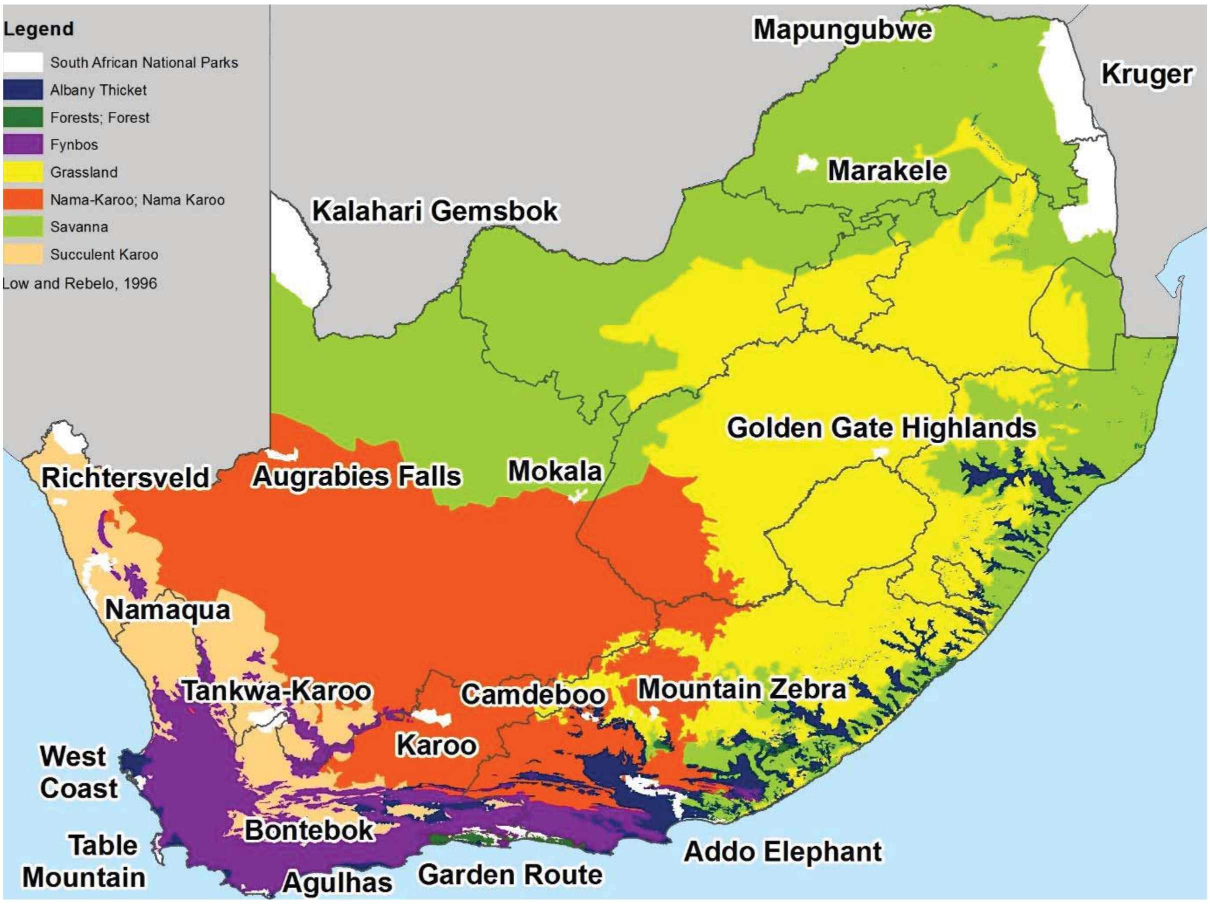

Figure 1.1. South African National Parks and the respective Biomes in which they are found.

1.1.2 Threatened species identification and protection

Climate change, habitat fragmentation and alien species introductions have been listed as major threats to conservation at a global and local scale (Pimm and Raven 2000, Malanson 2008, Moncrieff et al. 2015, Slingsby et al. 2017), and are resulting in the extinction of species at an extreme rate (Dirzo and Raven 2003, Ceballos et al. 2017). The view that extinction risk is an important aspect to consider when undertaking biodiversity conservation did not fully gain momentum until the end of the 21st century (Kuussaari et al. 2009). It is now seen as one of the greatest challenges for present day conservationists (Cousins and Vanhoenacker 2011). Research looking at plant species extinction in the light of habitat conservation found that recognising extinction risk was a priority when developing conservation strategies based on spatial patterns of species richness (Fahrig 1997, Pimm and Raven 2000, Adriaens et al. 2006, Cousins 2009, Piqueray et al. 2011).

In excess of 840 extinctions across all taxa have been documented since 1500 AD (Collen et al. 2010). The need to define extinction for species around the world has been a priority of conservationists for several years, yet determining the difference between extinct, almost extinct and functionally extinct has been a major challenge. A robust method was needed that could distinguish species at risk of extinction and be comparable between species and taxa (Collen et al. 2016). This made the task of developing such a method extremely difficult. The International Union for the Conservation of Nature (IUCN) was designated the task of developing a standardised system that could assess taxa according to a scientific method of extinction risk (Robbirt et al. 2006). Theoretically such a system should be used to compare threats to varying taxa and aid in setting conservation priorities, by highlighting where conservation is needed most urgently. The IUCN Red List was developed over a number of years and has been continually re-assessed as our knowledge and understanding of species and systems improves (Pimm et al. 2014). The Red List has been utilised to inform national and international conservation policies and report on the state of the environment (Lamoreux et al. 2003). It has also been used to; a) influence legislation to regulate development and strengthen conservation planning, b) foster research and monitoring of species, habitats and biodiversity status, c) identify areas for conservation and facilitate resource allocation and d) generate public awareness of the plight of threatened species (Possingham et al. 2002, Robbirt et al. 2006).

The IUCN have been criticised because the Red List is a global assessment tool and that at a regional or even local scale a species may be under threat but currently this is not flagged (Gärdenfors 2001, Seminoff and Shanker 2008). Small isolated subpopulations face greater extinction risk, and if evaluated individually may inflate the threat status possibly rendering the global assessment useless or less accurate. Both of these factors may have unintended consequences for conservation management. To resolve this the IUCN established Regional Guidelines with adapted criteria for subpopulations at the regional scale (Gärdenfors 2001). As a result the IUCN Red List criteria are applied at a finer scale and a regional and national status obtained. The criteria are then run against the global population and a global status obtained for a species (Miller et al. 2007). Another criticism is that scientists and conservation managers are sceptical of the assessments which are often based on poor data when assessing the population range and size. This has caused major contradictions in the Red List status of a species and its actual extinction risk (Robbirt et al. 2006), which this thesis illustrates in Chapters 4 and 5.

In 2003 the IUCN recognised that these data used in the assessments contains major uncertainty, this could take the form of insufficient data on species numbers, temporal and spatial data, subjectivity of collections and errors in measurements (Lamoreux et al. 2003). Finding adequate data on species to conduct Red List assessments is time consuming and often impractical requiring capacity, resources, and extensive field work (McInerny et al. 2006). Botanical collections from herbaria have been recognised as a valuable source of readily available information on floral species and have been used in assessing threats to species (McCarthy 1998, Roberts et al. 2005, Skarpaas and Stabbetorp 2012). The Red List does not use models or equations in its assessments at present due to the lack of data on many species (Gonzalez et al. 2010). Collen et al. (2016) contend that employing other avenues of data gathering such as citizen science, social media and remote sensing will help increase the reliability of data and thus relieve the uncertainty regarding the Red List assessments.

1.2 Objectives of the Study

This research is multidisciplinary and draws on different methods and fields to better establish the value of botanical collections to science, conservation and protected area management.

The objectives of this study are:

To explore the contribution of botanical science in terms of recorded knowledge of the environment, using herbarium collections, as objects of information and knowledge, made by early plant collectors and botanists.

To establish the value of historic herbarium collections as potential biocultural heritage assets by determining whether historic localities are still extant in areas which are now national parks.

To determine the relative value of herbarium collections and botanical surveys as long-term datasets, using an extinction probability equation in establishing baseline floral biodiversity information to assist conservation management.

To use in-field detection methods to establish the value of herbarium data and/or survey data by determining anticipated and actual extant status of selected plant species.

1.3 Methodology

In this study I used desktop analysis, archival research, extinction risk modelling and in-field surveys. I used the herbarium and survey data from the South African National Biodiversity Institute (SANBI). The National Herbarium database and Vegetation Distribution dataset of SANBI were the most comprehensive for both herbarium specimens and botanical surveys in South Africa at the time of my study. All spatial data was obtained from SANParks Data Repository System, an internal data archive. This study focussed on two national parks, Agulhas and Table Mountain National Parks found within the Fynbos Biome, as case studies in biocultural heritage and extinction probability and in-field detection, respectively. Agulhas National Park was selected for the study on biocultural heritage as this park has the best performing heritage portfolio within SANParks (SANParks 2009) with a comprehensive database of the history of the farmsteads which now make up the current park. The Agulhas Plain is also known as a biodiversity hotspot and much botanising has been known to occur in the area (Mouton 2007). Table Mountain National Park was chosen for the testing of extinction risk and in-field detection as this park is tightly bounded by the metropolitan area of the City of Cape Town on one side and the ocean on the other. Species that occur naturally within the park have few avenues for dispersal and are heavily impacted by anthropogenic activities. In addition to this the park has a large number of endemic, rare and threatened species (Rebelo et al. 2011a, Rebelo et al. 2011b), and is thus a priority for predicting which species may have a higher extinction probability.

This study is reflexive in that it searches past clues to assist in future predictions. It provides a background for the gathering of botanical herbarium specimens. My research seeks to understand the herbarium specimens in a contemporary setting, in order to determine the contribution these records can make to our scientific understanding and present day conservation management. It looks forward in time to establish the probability of the extinction of species within protected areas. Being able to fill the gaps in our knowledge, via desktop study and field work, it contributes to informed decision making by protected area managers. It also attempts to highlight the additional value of these collections to conservation and contemporary understandings of heritage management (Soberon et al. 2000, Ahrends et al. 2011, Joppa et al. 2011, Bacher 2012).

This thesis sets out to understand the usefulness of herbarium specimens; their contribution to the evolution of botany and science and to the current conservation of floral species in protected areas. The focus of this thesis is the dire need for conservation and particularly protected area management, as the mechanism for conservation, to prevent the loss of natural-cultural heritage and biodiversity. I do this by firstly looking at the global contribution of botany to science through the history of botanical recording and documenting of herbarium collections. I then explore the concept of historic herbarium specimens and the associated *in situ* plant populations as biocultural heritage at a local scale. Further in this thesis I look at the use of herbarium and botanical information as long-term data to assist in making conservation management decisions.

1.4 Research Limitations

Table Mountain National Park, was the case study park for the work executed in Chapters 4 and 5. The timeframe of the study coincided with a large wildfire in the Table Mountain National Park and as a result the full suite of targeted species from the extinction risk analysis, performed in Chapter 4, could not be found or used in the field work. While the effect of this temporal limitation was a disappointment to the researcher, it reflects the dynamic state of the ecosystem under consideration and that these data is not always available.

1.5 Literature

1.5.1 The epistemology of science and objects as information

The first part of this study looks at the contribution of botany to science and defining biocultural heritage in reference to historic plant collections. Calvert-Minor (2014) recognises the epistemic importance of objects, and reconceptualises the idea of objects relating to the evolution of a field of study. On this basis I look at the evolution of botany and science through the collection of natural objects in the form of herbarium specimens. Many scientists and philosophers believe that what lies at the heart of knowledge production is not individuals or communities, but practices such as mathematics, medicine and science (Calvert-Minor 2014). This is seen as a rational and logical way of viewing and understanding the world through applying distinct methodologies (Herrada 2011). Science represents a body of knowledge, often obtained through empirical observations and experiments, which have been peer reviewed and validated. As knowledge of the natural world has improved, so the epistemology of science has evolved with particular world views and philosophies (explained in Chapter 2). Science is one of the most mature and advanced disciplines, illustrated by the use of theory in its scholarly work, and has a long history of such work (Pettigrew and McKechnie 2001). That science has come to be recognised as robust, rigorous and thorough may be partly as a result of the work of historic collectors of natural and scientific specimens (Browne 2001, Gaukroger 2006). In my second chapter I show how in describing and defining the nature of objects early collectors contributed to the basic scientific rules, techniques and procedures for the collection and recording of specimens (Buckland 1991, Parsons and Murphy 2012). The passion of the early scientific collectors for understanding the form and structure of our world enabled them to build a coherent discipline of collecting which helped inform science (Bates 1999). This disciplined collection of specimens and records was adopted by colleagues based at international institutions and probably played a major role in the development of robust scientific practices.

Natural history museums, including herbaria, initially emerged in response to the processing needs for scientific collections. The aim was to collect objects for storage, study and curation so that knowledge could be developed and advanced. Knowledge is generated by humans through their experience with information as objects. Bates (2006) describes information as ‘a thing in a world full of objects needing to be discovered and described’. Information resides in the physical entities of nature, yet it is not exactly the same as those entities, it is the understanding of the entity not the entity itself. Thus all information is natural information as it originates in the natural world. It is created, kept and interacted with in various subjective ways (Bates 2006). Various forms of information are recognised in the discipline of information science, these are represented, encoded and embodied information and are considered in depth in the second chapter of this thesis.

As collections grew so an organised system of recording and curating was needed. Here the techniques developed by collectors in the field, such as those described in Chapters 2 and 3, filtered into the stored collections and the scale of the collections meant a more substantive process was required. Museums and herbaria now house natural history objects, along with associated records in the form of field observation notes and sketches, which continue to grow today as conservation adds new collections and findings. Scientific published information is housed in libraries and, in the present day, more and more is available electronically. Living collections are kept at zoos, arboretums and botanical gardens (Bates 2006). Yet these resources are underused and undervalued by science in present times, particularly by conservation management.

Given that herbarium collections date back to the first western visitors to South Africa circa 1592, it may be possible to establish the presence of plant populations within present-day national parks that link directly to these original collections and as a result would have significant natural heritage value as sites of initial documentation. The third chapter of this study establishes a connection between historic herbarium collections, associated narratives of early collectors and whether the plant populations (from which historic specimens were taken) are extant within current protected areas. The present extant plant populations constitute historical scientific sites and may serve to address recently acknowledged legislative heritage mandates in South African protected areas, as stated in the NEMPAA and in the National Heritage Resources Act of South Africa. A gap has been identified in the knowledge of historic botanical collections in protected areas. In terms of the heritage mandate there is also a gap in the finer scale information of species localities. This provides an opportunity to identify risks and threats to plant populations, and their survival, which I investigate in Chapters 4 and 5.

1.5.2 Herbarium data and botanical survey data

Herbarium specimens, the focus of this study, are pressed and dried samples of living plants, preserved for future reference. In the region of two and a half billion herbarium specimens are thought to be housed around the world (Robbirt et al. 2006). To date herbarium specimens have not been used as long-term datasets to aid management at the scale of actual species survival in the fynbos, which is addressed in my fourth chapter. They have primarily been used to establish presence or range. Herbarium specimens have also not been used as a source of heritage information to highlight the value of historic locality plant populations as biocultural heritage assets (Davidson-Hunt et al. 2012), which is investigated in Chapter 3. This study seeks to open a dialogue on how historic plant localities and specimens can be biocultural heritage assets. Due to the scientific method established in the process of collecting these specimens an associated collection record for each exists (Daston 2004). Even for the very oldest specimens the date and location of the collection is captured (examples can be seen in Figures 1.2 and 1.3). A type specimen is a sample of a plant species collected and seen as ‘typical’ of that species which is then used to describe and name the species by the scientific community (Stevens 2002, Dayrat 2005). Historic herbarium specimens are considered to be scientific heritage objects in their own right as objects of information (Clavir 2002) and their associated *in situ* plant populations may carry a heritage value which is as yet unrecognised in the South Africa context.

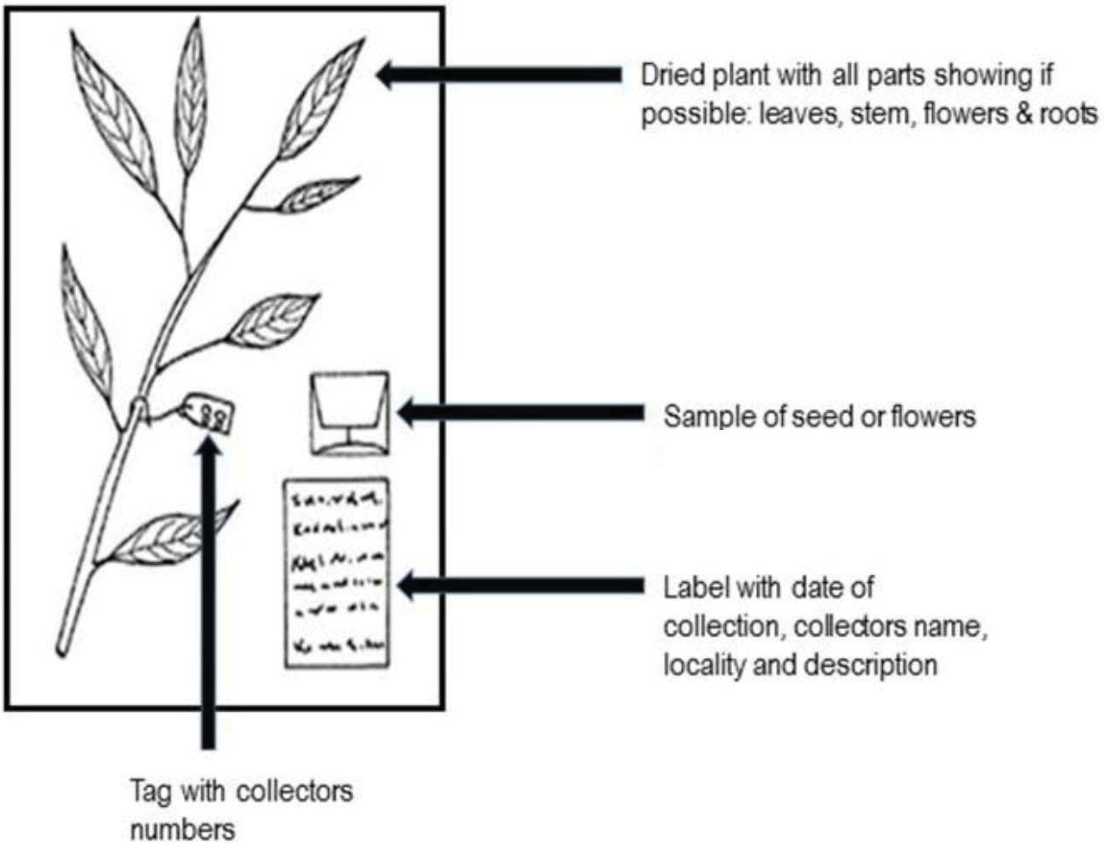

Figure 1.2. Basic standard mounting layout of a herbarium specimen.

Figure 1.3. Type herbarium specimen of *Restio calcicola* (Mast.) H.P. Linder (syn. *Calopsis fruticosa)* collected on the Agulhas Plain in 1896 and designated the type specimen later. This specimen shows the typical layout of a mounted herbarium specimen with the relevant labels and bar coded for identification and recording of observation data.

In 1969, Stanwyn Shetler, a curator of the Smithsonian Institute, noted his concern that herbarium collections were undervalued as a resource for conservation research (Lavoie 2013). The idea of using herbarium collections to inform and assess biological conservation issues has only recently been mainstreamed (Roberts et al. 2005, Lee and Balick 2007). Since the early 1990s the use of herbarium collections and survey records for biodiversity research and ecological conservation has gained momentum. Work in the early part of the 21st century used herbarium collections to analyse and illustrate the temporal and spatial dynamics of phytogeographic patterns across the continents (Linder 2003, Linder 2005). Further examples of the use of herbarium data in science and particularly in the field of conservation are provided in the fifth chapter of this thesis. The term *survey data* in this study refers to vegetation data obtained from formal botanical surveys which do not have associated herbarium specimens. These data contain lists of species and locality information occasionally accompanied by a description of the plant or a sketch. It must be noted that the identification of the species is completed in the field during the survey and relies on the expertise of the field botanist, this is explained in more detail in Chapter 4. More recent records often contain photographs and Global Positioning System (GPS) readings of the species locality. Herbarium and botanical survey records have been used by scientists around the world for many purposes (Lindborg 2007, Soubiran 2011) including environmental awareness programmes (Lourenco and Gessner 2012), Environmental Impact Assessment mitigation recommendations (Morrison-Saunders et al. 2001) and monitoring species of concern in protected areas (McGeoch et al. 2011).

Reflections by staff of SANParks have indicated that at a more local level national parks have not fully embraced the potential of these datasets. SANParks have been using broad lists of plant names without any fine scale locality data to serve as species lists for the national parks. Long-term monitoring and in-field surveys are expensive, both in time and capacity, neither of which is abundantly available to conservation management (Tomović et al. 2015). A large resource such as historical herbarium and contemporary survey data could provide a practical way to distinguish which species are present in a protected area and their extinction risks, providing conservation managers and scientists a way to determine which species to prioritise for monitoring. Central to this thesis is the idea that large datasets, such as historic herbarium collections and botanical survey records have the potential to aid in answering fundamental conservation questions such as (and in particular to this research) whether a protected area is fulfilling its mandate in conserving a species and biocultural heritage assets (Maffi and Woodley 2012).

Even though many studies have been undertaken on the use of herbarium records the focus is strongly on the Northern Hemisphere and island ecology. This study thus complements a much needed perspective from a biodiversity hotspot in the Southern Hemisphere and its protected areas. I aim to validate whether the two datasets can be utilized to inform the conservation of floral species in protected areas in order to support SANParks' obligation to manage and monitor areas of conservation risk as specified by national and international legislation.

In light of the literature it is clear that there is a gap in the knowledge regarding the botanical heritage of SANParks and whether herbarium and survey data can assist in fine scale species monitoring. My intention is to identify whether historical herbarium collections and botanical surveys have a place as long-term datasets to assist in the conservation and heritage management of protected areas (Baldi and Voros 2006).

This thesis is comprised of six chapters, an introduction (Chapter 1), four data-informed chapters (Chapters 2, 3, 4 and 5) and a conclusion (Chapter 6) (Figure 1.4). Each of the chapters is guided by the research objectives listed above. Each of the chapters builds on the overview given in this chapter and has its own literature review. The focus of the first two chapters, Chapters 2 and 3, is in the field of natural-cultural heritage. Chapters 4 and 5 are positioned in the field of biodiversity conservation situated within protected areas. In the interests of keeping the reader informed as to the relevance and position of each chapter in the greater context of the thesis and a multidisciplinary study, each chapter is prefaced with a short prologue, presented in a text-box, which aims to guide the reader through the thesis.

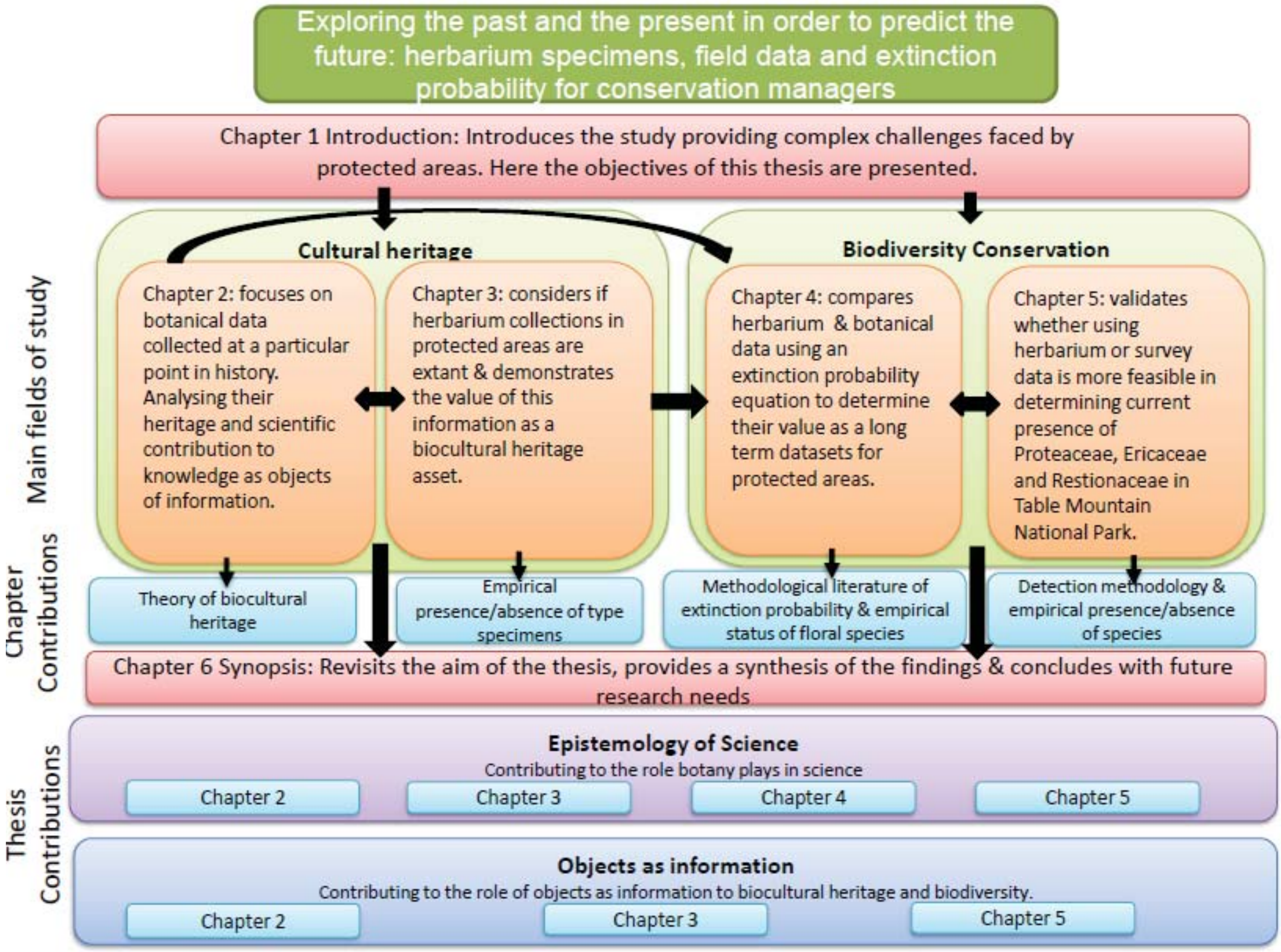

Figure 1.4. Structural layout thesis, showing linkages between chapters and contributions.

CHAPTER 2: The historical contribution of botanical collections to science and modern day conservation management practices

Prologue

In this chapter I consider the historical development of science and botany's possible contribution to the concept of science and the material scientific procedures practiced globally today. The early botanical collectors, their collections and the means by which they were able to acquire vast numbers of herbarium specimens are used to situate and provide a foundation for this thesis. The value of herbarium collections is known by those working closely with them, such a taxonomists. However, the greater worth of herbarium specimens and their role in the development of science and scientific practices today, is not entirely recognised. An overview of the universal contribution of botany to science, in the form of herbarium specimens is provided here.

2.1 Introduction

2.1.1 The history and epistemology of science

Human knowledge of the world is ever evolving and our advancement as a species is reliant on understanding the world we live in (Gaukroger 2010). In the last quarter of the 20th century, science has become one of the dominant discourses in the world. Science is a collective notion of enquiry and is conceptualised as a way of knowing the world by seeking answers from objects to explain the unknown. Today science is omnipresent however its origins and the processes through which it has evolved are often not easy to see (Serres 1995). Nature has always played a pivotal role in the expansion of human knowledge (Verschuuren 2010, 2012) and this study seeks to explore the role that botany and botanical collecting played in the development of science (Berlin et al. 1973). Botanical collecting is the gathering of plant specimens for the purposes of research or cultivation and sometimes as a hobby. I chose to focus this study on western science and western culture, with a view to understanding a particular moment in modern western science (Manktelow 2010). While I acknowledge the earlier role of eastern scientific thinking, the thesis is mostly confined to recent European colonisation and plant collecting in the past few hundred years in the Cape Flora of South Africa.

From the 9th to 13th centuries the quest for knowledge was mainly in the fields of astronomy, medicine and mathematics. These early fields of study formed the foundation of science and can be seen in the hieroglyphics of Egypt, cuneiform tablets in Babylon, and ancient texts in Greece. Among the first great theorists of western science were Pythagoras, Hippocrates and Archimedes who were mainly concerned with medicine and mathematics (Manktelow 2010). These philosophers questioned the working of the world and drew explanation from a diversity of fields (Uekoetter 2010, Herrada 2011). Science as a standalone academic field did not exist during this period and its character was as yet undefined, sitting either in esoteric thinking or in mathematics. During the crusades (1095-1291), western culture underwent a profound transformation when Europeans came into contact with other ways of thinking (Berlin et al. 1973, Smith and Nothling 1992) prompting a revolution in science in the west.

For nearly 900 years there has been a pursuit of knowledge which developed into western science (Huff 1995). This pursuit began with the ideas from spiritualism and the occult and grew into the notion that man is a rational creature in an ordered universe and should be able to describe this order. In the 17th and 18th centuries new concepts were developed within the field of natural philosophy (Pancaldi 2003). The mathematician and philosopher René Descartes, in the 17th century, expounded man's ability to understand the elements in nature, as moving matter (Pickstone 2000). Descartes attempted to distil a single, coherent narrative of the formation of knowledge using the overlapping of natural history and man's place in the world. Around the 18th century an encyclopedic way of thinking emerged that sought to establish a comprehensive and exhaustive collection of knowledge, and encyclopedic works began to be developed. Epitomising this is the classification work of Carl Linneaus (Metz 2009). In the 19th century, science and philosophy began to separate into their own pursuits. At this time the term 'science' was not readily used and two routes through which knowledge was sought emerged, these being natural history and natural philosophy (Laudan 2003). Descartes' theory was later echoed by the French philosopher Foucault in the 1970s, when he expanded on the double emergence of man as a knower and observer from the outside, and the social aspect of man as part of nature. According to Foucault knowing is not something that happens from a distance but it is a direct interaction with an object, things had meaning and not only substance, it was about possession and owning things and finding ones place in the world (Pickstone 2000). This formulation of knowledge is relevant to this study as it speaks to collection and data gathering as ways of knowing in the 20th century.

Building on Descartes and Foucault’s approach to man’s place in nature, and at the same time embracing an encyclopedic view of knowledge, philosophers and scientists began to develop categories (which became known as disciplines) as a means of grouping information and processing it into knowledge. Early disciplines such as physics, chemistry, botany, and mathematics, were embraced as ways to organize knowledge. Broadly the literature on early botany depicts the discipline as only a collective of expeditions and collections of plants and it does not highlight the contribution botany made and still makes to science (Huff 1995, Serres 1995, Pickstone 2000, Laudan 2003). Through the knowledge gathered in botany other scientific disciplines have been improved by means of the concepts of fertilization (agriculture), anatomy of plants (plant pathology), and carbon fixation (climate change) (Henry 2008, Uekoetter 2010, Buchanan 2015). Botany it could be argued has formed and informed the foundation for many scientific disciplines. The broader role played by botany in the form of botanical collections has not been wholly recognized. The history of botanical collections is closely bound with the development of modern science (Naylor 2003) and botanical expeditions could be argued to be relevant forces in the shaping of science as we know it today (Petitjean and Jami 1992). Botanical collections include herbarium specimens and living parts of plant species. Botanical collections can be argued to have directly and indirectly helped inform the evolution of scientific practices in the past and continues to do so. While evidently relevant and a pre-cursor to a number of modern scientific fields, I argue that botany has specifically influenced science in two ways: a) in the process developed for collecting herbarium specimens, through the co-development of scientific practice of sampling and collecting (Alberti 2005), and b) in the physical material collected, being the herbarium specimens. I will address the first here and the second is examined in detail in Chapters 3, 4 and 5.

To expand on the academic discussions of scientific epistemology and the contribution of botanical collections to science more broadly, I look at objects in the form of botanical collections providing information in a variety of forms; represented, encoded and embodied (Bates 2006) (Table 2.1). This is achieved through the gathering of objects as information and processing it into knowledge (Henry 2008). Aimé Césaire (poet, author and politician 1913-2008) contended that colonisation was a reframing of the world as objects and not processes, it was ‘thing-ification’ (Green 2014). In this chapter I take a theoretical approach to information and view information as a ‘thing’ (Buckland 1991, Bates 2006). I use the colonial project of European expansion (Petitjean and Jami 1992, Pyenson 1993) and look at herbarium specimens as objects that hold and impart knowledge as types of information given in Table 2.1. This study views herbarium specimens as embodied information which have informed science and enhanced scientific knowledge and culture.

Table 2.1. Types of information and its definition (Adapted from Bates 2006)

Types of information	
Represented information	Represented information can only be found in association with living organisms. It is observed information that is distinctive and can be encoded or embodied. E.g. Herbarium specimens
Encoded information	Natural information that has symbolic, linguistic, and/or signal-based patterns of organization. E.g. botanical sketches and field notes
Embodied information	The physical manifestation of information previously in encoded form. It is the evolution of one form of information into another being actual, or potential. In the genetic, neural, and biochemical information of living organisms, and in information produced by living organisms. E.g. Herbarium records

The Greek word ‘episteme’ means definitive knowledge over opinion, and in turn study of knowledge and how it is acquired is known as epistemology (Gale 1979, Pickering 1992). Information exists in the physical objects of nature, as explained in Chapter 1, it is the understanding and interpretation of the physical object and not the object that becomes the information respectively. Information can have a double character with embodied and encoded information existing in the very same object (Table 2.1) (Witcomb 1997). Herbarium specimens are a part of a larger collection which involves not only the plant material but also the associated narratives and articles in the form of maps, letters, diaries and sketches that accompany these collections (Browne 2001). When viewed together they constitute scientific records, a form of embodied information as described by Bates (2006) in Table 2.1, and sources of data, the value of which is still to be fully understood and recognised (Chapman 2005). In Chapters 3, 4 and 5 I highlight and discuss the value and worth of herbarium data. Botanical collections hold all three types of information in one (Table 2.1); representational, encoded and embodied information, where herbarium specimens are represented information (Chapters 3 and 4), and the sketches of such collections along with field notes are encoded information (Chapter 3). Knowledge generation is complex emerging from inseparable engagements across all types of information and any interrogation of knowledge and its origins will require a multidisciplinary approach (Pickstone 2000). Knowledge, therefore is developed from by information when it is interpreted and leads to the understanding of a subject (Bates 2006). The generation of knowledge is not a static practice but ever advancing and the current and future contribution of botanical collections to the growth of knowledge is an example of a source that provides continuous contributions and which warrants better recognition.

This chapter seeks to provide a commentary on collection practices that may have informed the evolution of science in part by botanical collections in the Cape Colony, in South Africa as an illustrative case. I will attempt to show the role of herbarium collections as scientific objects continually contributing to the culture of science and worthy of preservation, persistence and study (Zytaruk 2011).

2.2 Methods

In order to determine the full value of herbarium records and build an argument of their value beyond their immediate current use. I scoured a number of sources for all information I could find in order to demonstrate a contribution of herbarium specimens to botany and modern day conservation practices. I drew from a wide range of philosophical, scientific, environmental and historical literature. This included books, letters, journals, maps, herbarium specimen records and drawings. Due to the diverse scope, the records and literature had to be obtained from national and international sources both published and unpublished. Herbarium records were sourced from the Brahms database of the South African National Biodiversity Institute (SANBI) and the JSTOR Global Plants online resource (http://plants.jstor.org, accessed 5 September 2014). The timeframe of the case study was from the establishment of a European settlement at the Cape of Good Hope (1652) to 2014. Data was filtered and only records pertaining to the collection of plants in the Cape Colony of South Africa were extracted. All literature sources were read for any additional and relational information associated with the plant species collected in this period.

2.3 Results: Early botanical collecting

In his attempt to document plants Greek philosopher Theophrastus (371-287 BC) began one if the first written botanical records (Manktelow 2010). This resulted in a written account of all known plants in the ancient world. Very little additional information was added to these written texts until the mass exploration of the world through the colonial projects of expansion which played a significant role in defining and developing the natural sciences into what is known today as botany. Early botanical expeditions provided a significant contribution to knowledge of over one million original herbarium collections. These specimens and their associated field datasheets, comments and observations recorded in the journals of the intrepid botanists who collected them, have greatly advanced the field of botany and by proxy aided in the development of western scientific tradition. This was made possible by the contentious undertaking of European colonisation.

The notion of acquiring land for expanding territories (Stewart 2000) has been described as a global act of geographic violence where new countries and territories are explored, exploited and subjected to economic dominance[1]. The colonial literature abounds with reasons why the European countries engaged in colonisation (Weaver 2006). These include that Europe acquired its taste for goods from the Far East during the struggle against Islam (Smith and Nothling 1992). When Constantinople fell to the Ottoman Empire (1453) trade to the East was restricted, which halted the supply of these goods (Weaver 2006) and required the European countries to establish alternate routes for commodities such as gold, silk and spices (Smith and Nothling 1992). Simultaneously, new sources of materials were needed for a rapidly urbanizing Europe (1517-1760) (Fara 2003, Weaver 2006). European capitalism further fuelled this colonial project (Weaver 2006). By the end of the 15th century European countries were embarking on adventures to find new land with rich resources, all aimed at expanding their empires (Fara 2003). The race for resources resulted in strong competition between European countries, particularly Spain, Portugal, France, the Netherlands and Britain.

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[1] Although many experienced colonisation as a harsh treatment by an oppressor and were hurt and harmed in the process, there were many positive outcomes of the colonial project. For instance, colonies were provided with resources to build infrastructure such as roads, schools and hospitals. Colonies were given preferential trading rights with mother countries. Advanced knowledge from the mother countries was shared with the colonies in the form of healthcare, agricultural practices and schooling standards.

The need to explore and expand empires resulted in an increase in maritime expeditions, here analytical knowledge and practice were important for navigating and surveying new lands (Pickstone 2000). Surveying was embraced by the military who included botanical scholars (amongst others) on their voyages to assess the new lands being sought and surveyed. Associations such as these greatly benefitted the development of botany. A classic example of the inclusion of a scholar on a military vessel is Charles Darwin, famous evolutionary biologist, who took passage on the British Admiralty hydrological survey on the HMS *Beagle,* to South America. On this voyage he observed elements in nature (finches) which generated the development of his theory of evolution (Brockway 1979, Musgrave et al. 1998). Following Darwin's discoveries and work, the practice of the collection of duplicate specimens began in earnest. Auguste Comte (1798-1857) the positivist philosopher stated that science developed spontaneously through questioning of man and his environment and his place in it as a complex network of overlapping ideas, discoveries and events. Exploration challenged the ways of knowing as described by the classic scholars in Europe and was encouraged by those supporting new discoveries. European governments sent explorers to gather information about new lands for colonisation. Overtime the value of science became recognized in its own right and specialized scientific fields of study undertook expeditions for their own needs and not as part of exploratory voyages. Thus one way that science probably developed was through botanical exploration, which saw a sudden increase during the European colonial project (Pyenson 1993).

2.3.1 Recent European Colonialism 1500-1800

Following the establishment of trade posts and routes, a race to acquire natural resources along with new and exciting natural specimens began, with particularly fierce competition between France and Britain (Musgrave et al. 1998, Parsons and Murphy 2012). The French sent an expedition in 1785 to continue the work started with James Cooks' V*oyage of Knowledge*, and in quick and competitive response the British sent George Vancouver on a voyage around the world in 1790. With the opening up of new territories an intense rivalry ensued between countries for the prestige associated with the discovery of new scientific objects. Collection methodologies were developed during this period and these in turn fuelled the need for more expeditions as better collections could be made and stored more reliably (Merton 1957, Jacobs 2010). Such voyages of discovery stimulated interest in the natural world, and with the growth of major cities, such as Paris and London, scholars met and shared ideas, this scholarly exchange was the first form of scientific study as a stand-alone faculty.

Changes to the educational systems in Europe, from the very early systems restricted to churches and monasteries (11th and 12th centuries) to a more broad based education system (1517-1648), bought about important consequences for the part played by science in society. The infusion of science and technology in everyday life resulted in more people being educated and embarking on further study (McNeely 2009). An emphasis on applied field practice encouraged scholars to get into the field and undertake fieldwork, and this was particularly evident in botanical studies at the time (Pickering 1992). An example of this was the numerous botanical scholars who visited the Cape Colony in South Africa.

Societies for the educated elite (Serres 1995) emerged, these consisted mainly of lawyers, doctors, clerics and landed gentry who were engaged in academic study (McClellan 1985). These societies were largely focussed on the social aspects to do with society, rather than science and learning. Such societies later evolved into scientific societies with the aim to discover new information and generate knowledge, and one of the functions of universities at the time was to distribute this knowledge. The Royal Society of London (Figure 2.1), one of the oldest scientific societies in the world, was officially founded on the 28 November 1660 (Bradlow 1994) and soon became known as ‘The Royal Society for the Improvement of Natural Knowledge’. The Royal Society, the Royal Botanic Garden at Kew, the American Philosophical Society founded by Benjamin Franklin in America, and the Muséum national d'histoire Naturelle in France, all supported the collection of plant specimens for scientific study (Desmond 1995, Spary 2010, Egerton 2012).

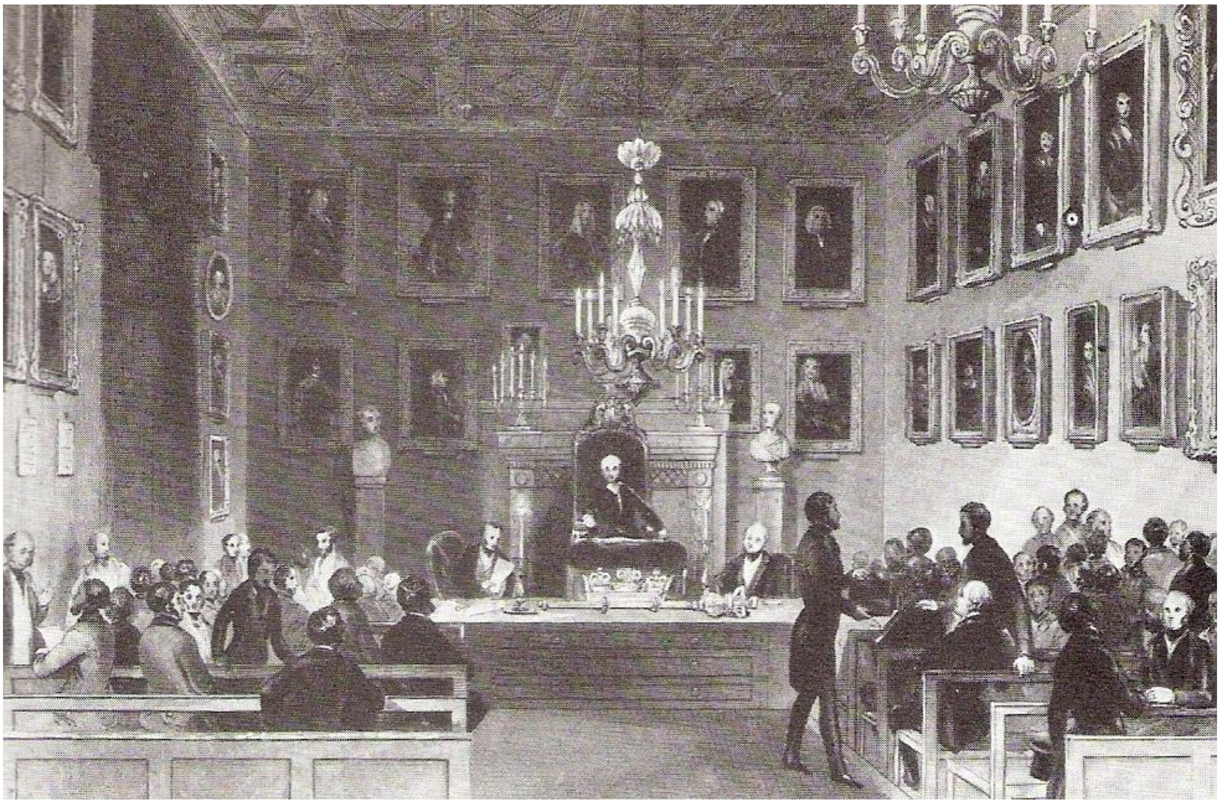

Figure 2.1. A meeting of the Royal Society at Somerset House in the Strand. Engraving by H. S. Melville, 1844, after F. W. Fairholt, 1843.

Further impetus for botanical collecting was gained when colonial governments established natural history museums as core networks for the collection of botanical items and gathering of knowledge (Pyenson 1988, Grove 2010). Scientific societies (Figure 2.1) played advisory roles to governments who gave them access to these museums and state funding for expeditions (Biagioli 1996). The societies established and maintained networks of people both internationally and locally in colonies, and facilitated the collection, exchange and dissemination of specimens and information (McClellan 1985, Storey 2006). Such societies helped maintain the scientific power and dependence of the colonies on the home country (Biagioli 1996, Storey 2006), resulting in large herbarium collections generated by botanical explorers sent to botanical gardens and museums some of which are still in existence today (Pyenson 1988). The explicit value of such long-term data is interrogated in Chapters 3 and 4. The appointment of Kew Gardens' first Director in 1842 ushered in a collection policy based on the idea of a *hub and spoke* system (Musgrave and Musgrave 2002) aimed at making Kew the centre of a web of knowledge (Beinart and Middleton 2004). This system required all botanical specimens collected in the British colonies to be sent to Kew for identification and storage. France and America then followed suit with their own systems established along similar lines. Through networks of botanical gardens and societies, botanists were able to exchange specimens and practices (Beinart and Middleton 2004). As a consequence of this exchange intellectual ideas were shared and this refined botanical collection and curation methods which have now been incorporated in the field of natural sciences (Margocsy 2010).

One such example is when the famous North American explorers Lewis and Clark received instruction in botanical and zoological skills prior to their *Expedition of Discovery* across north-western America. With the help of indigenous tribes who showed them species, they found and described more than 200 plant and animal species new to western science (Fritz 2004). The faunal and floral discoveries by Lewis and Clark drew the attention of the America Philosophical Society who funded more expeditions and requested that all specimens be sent directly to them for identification and housing, once again following the *hub and spoke* system of Kew Gardens (Ott 2007). Botanical explorers in all colonies followed the same type of system until the early 1900s when local patriotism grew stronger than loyalty to the colonial empire and collections were retained within the individual colonies (Van Sittert 2003, Storey 2006). The motivation and funding for these early collection expeditions, as noted above, highlights how botanical collections were originally bound up in political dogma in order to obtain support for expeditions and the testing of scientific theories. Although science strives to be objective, it can be seen that here in order to obtain funding the early botanists had to align with certain ways of thinking at the time (colonial expansion) even though they may not have fully supported the ideals of the project. The changing political climate in foreign territories had a direct impact on botanical collections as collectors originating from a certain country with which the colony was fighting were not allowed to explore or collect (Bradlow 1994). This was the case in South Africa, when Britain wished to take control of the Cape Colony from the Dutch in 1795 (Table 2.2).

From the early collections mentioned above, emerged a very systematic approach to collecting and methods to knowledge gathering. The collected herbarium specimens themselves became embedded in a greater representational knowledge of the natural world when they were curated in museums and university herbaria. I use the Cape Colony, a historically well-known botanical collection site and current day biodiversity hotspot in South Africa in order to examine the contribution of botanical collections to science. In the next section I elaborate more on the collections made in the Cape and on the botanical collectors who botanized there and thus contributed to the global wealth of natural and scientific knowledge.

2.3.2 Early Plant Collectors in the Cape Colony

Cape Town, South Africa, is an exemplary case of botanical specimen collection and its role in the development of modern botanical knowledge (Brooking and Pawson 2007, De Vos 2007). Empirical science was limited in pre- and colonial Africa as oral and spiritual ideologies were practised with little replicable or recorded results (Smith and Nothling 1992). Scientific development rested with the colonial governments until independence was gained by each country. South Africa was the only country to develop independent schools of research (Royal Observatory in 1820) on the African continent during the colonial period. Lying along a major trade route between Europe and the East (Cory 1910), South Africa has featured in much of the colonial literature (Van Sittert 2003, Ferro 2005, Grove 2010). The Portuguese were the first European explorers to record landing along the South African coast in 1488 (Smith and Nothling 1992), followed by the Dutch, who established a replenishment station at the Cape of Good Hope in 1652 (Fraser and McMahon 2011) (Table 2.2). The Dutch held the Cape for approximately 150 years until they surrendered it to the British in 1795 (Fraser and McMahon 2011). The number of botanical collectors in the Cape was extensive (Table 2.2) and the collection period during the time under consideration was fairly continuous making for a substantial and substantive contribution to botany.

Table 2.2. A chronology of early collectors' visits and key historical events in the Cape Colony from 1488 to the outbreak of World War I in 1914. The time periods that collectors stayed in the Cape are given in the left column and key historical events are provided in bold.

Date	Collector
1488 Bartholomeu Dias rounds the Cape	
1608	Gouarus de Keyser
1652 Settlement of the Cape by Jan Van Riebeeck	
1679	Simon Van der Stel
1687	Paul Hermann
1692	Hendrick Bernard Oldenland
1751	Rijk Tulbagh
1763	Carl Gustav Ekeberg
1771	Joseph Banks & Daniel Solander
1772 Cape Colony expands and more foreign shipping at Cape Town	
1772	Anders Sparrman
1772-1774 & 1778	Carl Peter Thunberg
1772-1774	Francis Masson
1775-1776	Anders Sparrman
1777-1780	William Paterson
1786-1797	Francis Masson
1786	Francis Boos and Georg Scholl
1795 Dutch surrender to the British	
1798-1812	James Niven
1806 England begin rule of the Cape Colony	
1810-1815	William Burchell

1812 Budget cuts in Europe and the death of Monarchs leads to fewer collecting expeditions	
1816-1823	James Bowie
1826-1834	Johann Franz Drége
1862-1905	Peter MacOwan
1864-1899	Francis Guthrie
1865 Bolus Herbarium, oldest functioning herbarium established in Cape Town, South Africa	
1865-1908	Harry Bolus
1883-1931	Rudolf Marloth
1891-1895	Rudolf Schlechter
1911-1959	Thomas Stokoe
1914 World War I is declared in Europe	

One famous botanical expedition was that of James Cook on the *Endeavour* in 1768, who was accompanied by Joseph Banks, a wealthy aristocrat whose passion for natural history led him to spend his fortunes on expeditions to uncover new species and sponsor other collectors (Brougham 1872, Fara 1997, 2003, Lamb 2009). Also on this voyage was Daniel Solander, an apprentice of Carl Linnaeus who is often called the *father of modern taxonomy* due to his development of the binomial classification system for plants (Fraser and McMahon 2011). Together Banks and Solander collected numerous plant specimens on their many stops throughout the voyage including a stop at the Cape Colony (Table 2.2). Following this there was an increase in the number of ships stopping at Cape Town in 1772 and this bought with it an increase in visiting plant collectors and botanists (Bradlow 1994), many of whom sent herbarium specimens to Linnaeus for classification. Encouraged by Banks, the British took a keen interest in South African flora (Buchanan 2015). Banks sent a young gardener by the name of Francis Masson, to Cape Town with Captain James Cook on the *HMS Resolution* to botanize and collect new plant specimens for Kew Gardens in 1772 (Musgrave et al. 1998). Although Masson collected in the Canary Islands, the Azores and the Antilles, his main love was the Cape flora in South Africa and he spent a total of 12 years studying plants in this region (Table 2.1) (Fraser and McMahon 2011). Masson was often asked to accompany fellow collectors in the Cape due to his knowledge of the area and was joined on numerous expeditions. During his stay in the Cape from 1777 to 1780, Masson collected with other well-known botanical collectors such as Franz Boos and Georg Scholl, German botanists sent by the Emperor of Austria in 1787 (Bradlow 1994). Masson, like so many of the plant collectors who set out from Britain and Europe, returned with, or shipped, collections back to botanical gardens and museums for curation following an increasingly recognised systematic approach to the collection of botanical material and the generation of botanical knowledge (Desmond 1995).

At the same time as Masson disembarked from the *HMS Resolution* in Cape Town (1772), another famous botanist boarded the ship. Anders Sparrman was a qualified doctor and pupil of Swedish botanist Carl Linnaeus. He had been collecting in the Cape for seven months (Sparrman 1786, Hansen and Wagner 1998, Fraser and McMahon 2011) when the *HMS Resolution* took him to the Pacific Islands. He returned three-years later to continue collecting in the Cape (1775). On his return to the Cape Sparrman collected with Carl Peter Thunberg in 1810, another of Linnaeus's pupils and a professor of botany at Uppsala University (Musgrave et al. 1998). As pupils of Linnaeus, Sparrman and Thunberg sent their specimens back to Sweden for identification and categorisation by Linnaeus, feeding into the development of his binomial classification system (Silvey 2012). It was fortunate that just as Linnaeus had developed his new classification system, the botanical collecting in the Cape was at its peak and this momentous amount of information contributed to Linnaeus' population, testing and refining his binomial classification system as a globally recognised system to describe plant species.

A prime example of the sharing of knowledge through herbarium specimens can be seen in the collections of William Burchell. A prolific collector in the Cape, William Burchell arrived in Cape Town from St Helena in 1810 and spent five years traversing the country in search of new and interesting natural specimens. During his time in South Africa Burchell collected over 50 000 natural specimens and made 499 known sketches (Buchanan 2015). He also made detailed maps, sketches, journal entries and published two volumes on his journeys in South Africa. Burchell was one of the first collectors to venture into the heart of a relatively unexplored South Africa, often finding his life in jeopardy from hostile groups and later in his travels even more hostile anti-British Boers (Buchanan 2015). He returned to England with 48 crates of specimens, the bulk of which were sent to Kew and the Oxford University Museum (Buchanan 2015). It was another 200 years before botanical collecting was established in the central and northern parts of South Africa and early journeys into these areas mainly relied on Burchells' maps, drawings and notes to guide their expeditions to the interior of South Africa (Skead 2009).

Due to political instability and budgetary cuts in Europe very few botanical expeditions were undertaken in the 1800s. Certain collectors like Burchell were self-funded, while other collectors who did make it to the Cape shores did not venture far and collected specific plant families or wants of their patrons who still had funding available (Fraser and McMahon 2011). Francis Niven (Table 2.2), a skilled collector and enthusiastic botanist, collected in the mountains of the Cape, however his collection time (1798-1812) was cut short by the withdrawal of funding from his sponsor in Europe. In the late 1800s Harry Bolus, an Englishman living permanently in Cape Town, began his collecting career. He was the first botanist to collect solely in South Africa and made 40 collection trips across the country. He initiated contact with overseas experts and established collaborative partnerships in Kew and Berlin, to share information and herbarium specimens. Over the course of his career Bolus undertook a total of 28 voyages to visit Kew Gardens, on some he lost specimens and almost his life (Liltved and Johnson 2012) (Figure 2.2). Fortunately he followed the botanic system of replication and left duplicates in Cape Town. The German botanist, Rudolf Schlechter, also collected in the Cape and sent many of his specimens to the Berlin-Dahlem Herbarium in Berlin, which was destroyed by Allied bombing in March 1943. Luckily, he had sent duplicates to his mentor Bolus (Chapter 3), and these have survived at the University of Cape Town through two world wars in Europe (Desmond 1995). Botanical exploration of the Cape Colony was undertaken by diligent, brave and curious men willing to risk their lives on perilous voyages travelling to and from the Cape (Figure 2.2), and thus advanced the understanding of the natural world (Bush 2012). From the mid-1800s botanical collectors in South Africa were mainly permanent residents with a passion for botany and a loyalty to the Cape Colony. They followed the protocols and procedures for the collection of herbarium specimens the same as their European predecessors and therefore strengthened the role of botany and science in the new countries outside of Europe by maintaining the Cape collections as part of a larger global system.

Figure 2.2. Artist's impression of a storm in Table Bay Harbour of the Cape Colony in the 1800s. Published Nov. 1st, 1805, by James Cundee at the Albion Press, Ivy Lane, London.

Early plant collection records provide little information on the local people who were employed as guides and whose local knowledge was no doubt imperative to the success of expeditions. Many of the plant species collected were given names in honour of the European collectors (e.g. *Thunbergia capensis* for Carl Thunberg) while the names of the local people remain absent from historical records (Browne 2001). Early European collectors received much assistance from the native people in the colonies (De Vos 2007), who negotiated safe routes across the landscapes and provided knowledge of the flora to the collectors, such as Lewis and Clark in America.

The collections of Bolus and Schlechter on the Agulhas Plain in the Cape Colony are an example of this reliance on local guides, which is looked at in more depth in Chapter 3, where I provide the routes and number of collections made by these early botanists. Guided by Reverend Lemmertz, of Elim a small Moravian Missionary village, Schlechter discovered a new species of pincushion growing flat along the ground and named it after the Reverend (*Leucospermum lemmerzianum*). This initial species name so clearly captures the historical presence of circumstance and moment. The name has since been revised and changed to *Leucospermum heterophyllum* (Germisthuizen and Meyer 2003).Yet most names of guides and assistants were seldom recorded and are now lost to history. It is important to our current understanding of the history of science to reflect that this was a function of the structure of society at the time. The herbarium specimens collected during this period highlight the absence of information about local guides, but from the collection notes local people and their involvement is written back into history. Assuredly the colonial project was not a positive experience for many. Historic collections and records made by Europeans, foreigners to the lands they explored, and their written history has all the consequent biases of the time (Browne 2001). This falls beyond the scope of my research, which explores the role of these botanical collections as objects contributing to the growth of science (Daston 2004). Both nature and human history can be viewed as facts and/or as values. Biocultural heritage, as discussed in the next chapter, encompasses both of these (IUCN 2010, Harmon 2013).

2.4 Discussion: The Contribution of Botany though herbarium specimens

2.4.1 The physical collections

Science has evolved over the decades and the current definition of science is the everyday process of the logical completion of thoughts via inference of facts obtained through calculated experiments (Gale 1979, Herrada 2011). In the 17th century what is known as science today was part of philosophy (Laudan 2003) and the Latin word *Scientia* was used in reference to knowing and not the discipline of science itself (Pancaldi 2003). The term ‘scientist’ (and ‘science’) was accepted in general use and officially recognised in 1833, as a term that brings together ‘knowing’, ‘philosopher’ and ‘artist’. This is based on the fact that many early natural history collectors sketched their subjects and were considered artists of the natural world (Gale 1979, Stein 1994). One such artist was Burchell who contributed over 400 sketches of specimens found on this journeys many of them botanical drawings (Buchanan 2015). In this way it can be argued that botany had a role in the contemporary understanding and naming of science. The contribution botany has made to the epistemology of science has many forms. Firstly, in the form of the actual discoveries made during historic expeditions and the physical species themselves. Secondly, in the co-development of practices that evolved into an information gathering and knowledge producing exercise with practices lasting throughout the centuries (Suarez 2004). Lastly, in historic herbarium specimens as biocultural heritage assets which are further explained in Chapter 3, where I show their relevance to science and protected areas in achieving conservation mandates. Botany therefore had an influence on science, it is possible that without it the name ‘science’ would be different. Gaukroger (2006 & 2010) argues that possibly some of the current values that embody scientific knowledge and explain the natural world, including both the descriptive method and philosophical approach also have been influenced in part by botanical collections.

The early botanical collectors were educated men who often wrote very detailed explanations and descriptions of the specimens they collected as well as comprehensive text books and field guides on plants and places they had visited, thereby bringing new information to universities and broader society (Skead 2009). Botanical scientific specimens carry information as objects themselves (Table 2.3) and can inform science via analysis of these objects and information. To maintain an orderly system of botanical names, botanists put together a set of laws in 1867, with the aim to govern the application of plant names. In 1906, such a code was first adopted internationally. Herbarium collections are core products of botany and provide a window to the nature of the physical world when collected. Historic botanical records are scientific memory and have been used by scientists for many purposes (Soubiran 2011) including environmental awareness and education programmes (Lourenco and Gessner 2012). Large datasets, such as historic herbarium collections, could answer fundamental heritage and conservation questions, and this is taken up and clarified in Chapters 3 and 4 in this thesis. The contribution of botanical collections to the understanding of the natural world includes aspects of both pure analytical science and, in keeping with the more complex recognition of what modern science entails (Cochrane 2014), the more multifaceted layers of social and heritage knowledge presented through the associated drawings, journals and field notes. Basic botany has since diversified and current biogeography and ecology are testament to the constant evolution of botany and science (Raven and Axelrod 1974, Linder et al. 2012). Botanical information provides science with a way of knowing what something is and where it came from. As one of the oldest and leading historic sciences, botany is now being used to develop detailed models on plant species movement in regards to predicted climate change.

Botanical taxonomy originally focused on identifying plants for food and medicine (Cain 1959, Knapp et al. 2004) and later on, capturing a representative collection of the natural world (Gaukroger 2010). Herbarium specimens began as ad hoc collections and drawings of new and interesting plants made mainly by gardeners and horticulturalists, such as Francis Masson and Rudolf Schlechter (Chapter 3), who travelled to the Cape to work in the colony gardens in Cape Town (Fraser and McMahon 2011). Botanical collectors collected more than just the specimens alone, they made maps, drew the specimens and habitats, and even captured anthropological data that added yet a further layer of embodied and encoded information to the basic object of a herbarium specimen (Table 2.3). As colonisation (and in particular modern western science) gained momentum, plants were collected around the world in the form of dried, pressed specimens in an increasingly systematic manner (Fraser and McMahon 2011). The historic herbarium specimens and their more recent additions are used for pure taxonomy (Berlin et al. 1973), such as monographs and floras, but also in more advanced taxonomic analyses using DNA sequencing techniques for identification (Ames and Spooner 2008, Andreasen et al. 2009). These new techniques address the limitations of traditional taxonomy by identifying genetic shifts in relation to spread and selective forces (Table 2.3). Historic herbarium specimens provide the means for current research into genetics and highlight the importance of expanding our knowledge of the geographic range of germplasm data (Lister et al. 2010).

Table 2.3. Types of information as described by Bates (2006) and presented previously, and annotated here to show the contribution of herbarium specimens to science in the form of each information type.

Types of information	Contribution of herbarium specimens
Represented information **(in association with living organisms. E.g. Herbarium specimens)**	Invasive alien species identified, DNA available for sequencing, plant pathogens identified and available for testing, historic pollution levels can be obtained, genetics research made possible, new medicinal compounds discovered, extinction probabilities (Chapter 4 and 5)
Encoded information **(has symbolic, linguistic, and/or signal-based patterns of organization. E.g. botanical sketches and field notes)**	Pathways of alien species invasion, spread of plant diseases, protocol of field surveys (Chapter 5) and collection techniques from field notes, extinction debt and land use change, insight to original habitats for restoration of species
Embodied information **(information produced by living organisms. E.g. Herbarium records)**	Biogeographical areas defined, global distribution of flora, identification of climate change threats, temporal scale of species evolution, biocultural heritage of historic localities (Chapter 3)

Herbarium collections represent the vast history of the state of knowledge on the distribution of floral species (Feeley 2012). The huge areas explored for collection now provide science with a spatial knowledge of what plant species occurred in specific areas over a period of time. Distribution information generated from herbarium collections were the start of biogeographical regions on which current understanding of the flora across the world is now based (Raven and Axelrod 1974, Chapman 2005, Linder et al. 2012). Herbarium specimens provided the first spatial data and aided in the development of the field of spatial analysis (Rhoads and Thompson 1992). Additionally, precise locality descriptions on herbarium labels were used to test spatial resolutions when developing GIS systems which are widely used today (Rhoads and Thompson 1992). Recently herbarium distributional data has been used to ground-truth and validate MODIS (or Moderate Resolution Imaging Spectroradiometer) satellite imagery through comparison of the data produced from the satellite imagery and what herbarium records show is in an area (Park 2012). Although unknown at the time of collection, the accurate recording of the provenance of the specimens is now used to locate the historic ancestors or close relatives of, amongst others, domestic food crops (Lister 2010). Herbarium collections, as embodied information, are also being used to identify possible new candidate medicines via biomedical surveys and bioprospecting assessments (Table 2.3).

The collection of botanical specimens also currently aids in the identification and impact of threats such as climate change, habitat fragmentation and alien species invasions (Table 2.3). Investigations into the spread and impact of alien species using herbarium data assists our understanding of the dynamics of alien species ranges (Delisle et al. 2003). The spread of alien insects and herbivores is being monitored using herbarium specimens (Lees et al. 2011) and has made a significant contribution to the combatting of invasions. Using historic herbarium specimen localities of alien species occurrence, ecologists have been able to predict where new invasions will occur and inform conservationists and land managers to put measures in place to prevent new invasions. Herbaria also aid in the identification of historic plant pathogens and their ecology. This has helped to prevent spread and potential economic impacts (Jeger and Pautasso 2008). This is particularly relevant given our current need to understand how climate change will affect plant diseases and production. Herbarium data provide insights to historic pollution levels, capturing a snapshot of atmospheric pollution levels in the past (Table 2.3), for a comparison to current levels and aid the development of adaptation and mitigation measures (Pyke and Ehrlich 2009).

Herbarium specimens address the problem of short-term ecological studies in systems that require long-term data (Bromberg and Bertness 2005) such as protected areas. The temporal and spatial data generated by the historic collections enables current conservation concerns to be addressed. Using this information, long-term analyses have been undertaken to determine population dynamics to identify declining abundances and species migrations (Feeley 2012). A recent study using similar records for vertebrates looked at the decline of populations as an indicator for population shrinkage and ultimately population extinction (Ceballos et al. 2017).

Updating the Red List status of species (Rivers et al. 2011) is accomplished by using occurrence data from herbarium specimens (Skarpaas and Stabbetorp 2012). Herbarium data have been used to calculate extinction probabilities (Sutton and Morgan 2009) (an aspect taken up Chapters 4 and 5 to follow) and to infer extinction for whole plant communities and vegetation types (Piessens and Hermy 2006). Hence data play a major part in enabling multi-species conservation efforts and are highly valued in modern conservation research. Restoration ecologists use data from herbaria to determine the habitat preferences and associated species of extinct in the wild species, giving practitioners an impression of the habitat and community in which the species originally grew (Bromberg and Bertness 2005) and providing possible alternate sites for restoration. As scientific knowledge grows, basic collection information is still recorded together with other required information including: habitat type, geology, soil type and threats to the plant population at the time of collection (Bridson and Forman 1998). The scientific method for organising large collections[2], datasets, or a group of test subjects into a systematic and logical way provides a means to trace a specimen and ideally ensures its provenance is maintained. Tracking the provenance of a specimen enables researchers to locate the sites where collections were made and are explained in Chapter 3, where I search for historic specimen localities, and in

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[2] The invention of moveable type and printing enabled large numbers of specimens to be kept in collections and classified according to a set system. Development of printing was another parallel development of science that allowed objects to be quickly documented when compared to hand-copied script or verbal communication (Winston 1999).

Chapter 5 where I look for subpopulations of species. With the use of modern technology such as GPS devices, electronic recording units, digitising and online systems, this information has become globally accessible (Pimm et al. 2014) and it is imperative that accurate information on the labels is maintained (Häuser et al. 2005).

2.4.2 The evolution of scientific practices

Studying nature and one's natural surrounds was the easiest and most logical way to acquire knowledge (Browne 2001). For example the methods for collection, processing and shipping of herbarium specimens, from the colonies to the mother countries informed the standards of herbarium specimen preparation used in current herbaria (this is elaborated in the next chapter). Botany offered insights to how nature could be studied, analysed and represented. A considerable amount of our current understanding of the elements in and functioning of the natural world results from the contribution of botany through the collection process of natural history specimens. Herbarium collections it could be argued contributed towards the tailoring of scientific methods and standards used today (Henry 2008) and may indeed constitute scientific memory as stated by Nicolson (1991).

Early mankind undertook botanical 'studies' by testing and selecting plants for their value as food or medicines (Kenrick and Crane 1997, Knapp et al. 2004). The ancient Egyptian, Greek and Roman scholars practiced selective breeding and mass crop production, and this developed into the fields of agriculture, forestry and horticulture (Manktelow 2010, Meyer et al. 2012). Botany originally had two main foci: taxonomy (listing and classifying plants) and medicinal applications (Gaukroger 2010). Getting the name of a plant right was at times a case of life or death. Between the 17th and 20th centuries, how knowledge was classified changed rapidly, and this was influenced greatly by natural history and natural philosophy, now known as botany, geology and zoology. The collection of natural specimens stimulated new ways of thinking about nature such as Darwin's theory of evolution and Linnaeus' binomial classification system (Manktelow 2010). Resulting from Darwin's work on evolution it was clear that duplicate specimens had to be collected from within a single colony so as to document the differences within and between species. His work therefore truly began the scientific practice of not only duplicate collections of a single species but also the need to collect many different collections of the same species from different populations for comparison. In defining the natural world the early botanical theorists (Locke 1602-1704 and Linnaeus 1707-1778) concerned themselves with an encyclopedic way of thinking and while striving for an exhaustive knowledge base they established a rational classification system to assemble similar living organisms in groups (Anstey and Harris 2006). The result was a universally accepted language with a simple and practical structure of classifying objects into categories, Linnaeus then based his philosophical principles of science in his binomial classification system on this way of thinking and categorising. Linnaeus’ classification system also moved science out of the realm of the elite academics to the broader community as it was easily understood by both scholars and non-scholars. The method used was simple and the terminology for much of the system was fairly colloquial, this was embraced by society who felt they could even contribute to the botanical collections (Koerner 2009). An example of this can be seen in the increase in amateur botanists and the associated increase in collections, which still occurs today through citizen science programmes such as the California Native Plant Society (this is taken up in Chapter 5). The colonial project inadvertently aided in the aligning of standard ideas and practices with regards to herbarium collections globally, through the communications networks established between mother countries and colonies and between colonies themselves (Petitjean and Jami 1992, Pyenson 1993). The binomial classification system once established was reinforced and validated through the donation of species collections to it from botanical collecting such as the vast amounts of new species collected in the Cape. This in turn strengthened the encyclopedic way of thinking and the development of classification systems in other fields of science and the field of chemistry, metallurgy and geology, which have, over the years, adopted similar classification systems that are easy to memorise and use for discussion.

Due to the European colonial endeavour being at a global scale a universal system for the collection of specimens emerged. Although some early collectors had good records, the majority made poor recording and incomplete information was kept. Over time the information recorded pertaining to each collection was improved through standard botanical collection practices. Huge collections built-up over time in botanic gardens or natural science research institutions such as the Muséum national d'histoire Naturelle in France and Uppsala University in Sweden (Duckworth et al. 1993, Spary 2010). To keep results uniform, standard shipping and storage protocols developed in order that the herbarium specimens became a permanent and more systematically managed record in scientific archives and used in scientific studies (Suarez 2004).

There are four key stages to herbarium collection: 1) collection, 2) pressing and preservation, 3) mounting and labelling, and 4) databasing including digitisation (Bridson and Forman 1998). Early botanists discovered new species and found the ideal specimen was a whole plant with all the growth stages present (buds, flowers and seeds). This made describing and examining specimens easier on returning to their respective home countries. Collecting guidelines for herbarium specimens now list all the parts required when making a collection and how these should be taken and displayed. This exhaustive list was arrived at through trial and error. Early collectors realised in order to preserve the exact physical state of the plant they must be pressed immediately (Bridson and Forman 1998). As collections and collecting skills grew, so collectors wrote guidelines on how to press and preserve certain groups of plants. Specific groups, such as ferns, orchids and aquatic plant specimens then had their own guidelines written. Set guidelines and protocols now exist that herbaria are required to follow when preserving specimens to maintain the quality of the specimen (Bridson and Forman 1998).

Given the harsh environments such as those experienced in the Cape Colony regarding transport (horse, cart, ship) and travel routes (Chapter 3), some collectors for practical purposes made multiple collections of one species from a single locality to prevent an individual specimen being destroyed by the elements, accidents or contamination (fungi) (Bridson and Forman 1998, Parsons and Murphy 2012). It also saved many valuable specimens from being lost during the destruction of Europe in World War II as duplicates were kept safe in herbaria in the colonial countries such as the Bolus Herbarium in Cape Town (Chapter 3).

Early collectors ensured localities of botanical sites were recorded with precision so they could be passed from collector to collector enabling repeat visits to sites. This can be seen in the encoded information in the form of the journals of Bolus, Masson, Sparrman and Thunberg who often retraced collection routes taken by others and returned to exact populations for further collection or study which I expand on in Chapter 3 (Fraser and McMahon 2011). Pioneering botanists perfected the recording of locality details, such as the country, region, local area and site-specific particulars. Globally recognised practices developed using botanical and other natural specimens to record basic information such as the scientific name of the specimen, the collectors name and date of collection and a brief description of the collection locality (Bridson and Forman 1998). Natural specimen collections have contributed to advances in databasing such as the systematic storage of herbarium specimens, nevertheless if these data recorded are not thorough, accurate and reliable, the use and potential value of the collection diminishes.

As stated in the preceding sections, through hard experience early botanists most likely learnt that duplicates of an individual collection of a species from one locality had to be made of their specimens, as insurance against loss in transit or to pests (Parsons and Murphy 2012), and in order to share their findings with other researchers and institutions. Certainly following Darwin’s work on evolution the collection of multiple specimens was recognised and embraced. These multiple collections are themselves now useful replicates that can be used for current scientific study, using constants such as species or locality. This represented information can be used to test other variables like phenology and aid in informing conservation about threats like climate change (Table 2.3). This collection of multiples may have informed the culture of science in the form of repeat sampling as studies using replicates could not be refuted. Replication is now a core scientific method accepted worldwide (Applebaum 2000), to the test results and to safeguard against loss as well as to find an average within a group of specimens.

Herbarium specimens have the potential to shed light on current day conservation management of protected areas to conserve flora. The methods followed in observing a species habit and habitat by the early botanists as can be seen in Burchell's and Bolus' journals, which may have led to the establishment of survey techniques (Burchell 1819, Bolus 1894). These techniques were shared between collectors and may have resulted in standardised scientific field survey protocols (Applebaum 2000). The collection of herbarium specimens subsequently influenced the rigorous and robust protocols of the scientific knowledge gathering system on which current monitoring, data accumulation and conservation management decisions are based (Lourenco and Gessner 2012).

Botany may thus be a greater role-player in the development of science than previously acknowledged, as the first real collection of herbarium specimens occurred at the same time as some scientific practices and protocols were being developed. Early botanical collection and observation laid the foundations of ecology as we currently know it (Storey 2006). Through trial and error (Parsons and Murphy 2012) the process of collecting, documenting and storing specimens and records was established. Herbarium collections have arguably contributed to scientific practice, and while historic insights are harder to validate, but can none-the-less be argued for, herbarium specimens most certainly contribute to science in an on-going way in the establishment and fostering of various sub-disciplines and scientific pursuits such as information technology, GIS spatial systems and climate change predictions (Browne 2001). Indeed the presence of herbarium specimens in scanned electronic format, and online availability, has made research more streamlined and knowledge generation faster (Pimm et al. 2014). Whole countries and researchers are now able to share knowledge and develop new ideas with greater ease. Herbarium specimens have been and continue to be a substantial contributor to the development of science.

2.4.3 The heritage contribution to science

Over the centuries the empirical way of thinking has dominated scientific theory, this includes for example Darwin's theory of evolution (Del Valle 2013). Botanical collecting is the epitome of traditional empirical scientific study as recorded data is verifiable and repeatable. During the 20th century the notion of evidence-based science was bought into question by theories from Freud and Einstein (Herrada 2011). This initiated the study and acknowledgement of cognitive knowledge, and the need to acknowledge and include elements of sociology in science (Giere 1988). Science is now described as having a complex and compound character, whereby it seeks strategic empirical solutions to problems, whilst recognising that knowledge is also generated by perceptions and culture (Giere 1988, Cochrane 2014). Academics have come to realise that there is a heritage contribution to science made by botanical collections and botanical collectors, which has a social science aspect to it and should be recognised too.

2.5 Overview

Expeditions to far-flung places were challenging endeavours where botanists encountered difficult terrain and suffered extreme deprivation and loss. Early explorations into unfamiliar environments were gruelling with no guarantees of food, clean water or success. Many collectors faced unknown threats from disease, hostile terrain and resistant local populations and only had their travel companions to rely on. The men embarking on these expeditions had to have a passion for the natural sciences in addition to a tolerance for hardships, and a love of adventure and exploration (Biagioli 1996). The many dangers, trials, tribulations and friendships forged, along with anecdotal stories of the botanists are part of the materiality of the herbarium specimens. Indeed the objects collected during the colonial project embody more than the physical specimen as their stories are a unique and an irreplaceable slice of history (Beinart and Middleton 2004). One of the many contributions that botanical collections make to knowledge is in the authenticity of its collections (represented information) and the associated maps, notes and sketches (encoded information) which results in embodied information as historic specimens. The wealth of spatial data and the temporal scale of data has multiple benefits to current scientific and conservation questions.

All the elements that constitute a herbarium record are objects of information and should continue to be used together, to advance scientific understanding of the natural world. The material object of a herbarium specimen embodies more than just the information recorded on the specimen sheet, it has value as an object of information itself, enabling knowledge generation broader than only the specimen (Alberti 2005). Herbarium specimens could have a major influence on science (Suarez 2004), in serving as the longest standing record and giving insights to plant species and populations in a set time and context as I discuss in later chapters in this thesis. As we discover new technologies and ways that we can use herbarium specimens to answer questions about our world, so their value increases.

This work on both the colonial project and epistemology of science has touched on the influence by the early botanists to protected area management. In the next chapter I will further elaborate on the contribution of botanical collecting to biocultural heritage and its role in current protected area management.

CHAPTER 3: Historic herbarium specimens as biocultural assets: An examination of herbarium specimens and their *in situ* plant communities of the Agulhas National Park, South Africa

Prologue

This chapter arises from the need to recognise that globally protected areas have a mandate to conserve both biodiversity and heritage. Drawing on the rich history of science and botany in Chapter 2, this chapter aims to articulate the conservation and heritage value of herbarium specimens. Historic specimen localities, although significant to botanists, were not known or recognised under the global heritage umbrella yet they form an important component of the protected area landscape. Historic specimen localities link the past with the current and future management of a protected area. Historic specimens and their associated *in situ* localities are valuable to both ecological study and conservation around the world and this chapter highlights an emerging facet to science of the influence of people on the natural landscape. I found this to be the case not only in an ecologically transformative way, but from a heritage aspect regarding the social nature of botanising and discovering. The work of the Regional Ecologist for SANParks reaches beyond park management to biodiversity conservation and includes heritage conservation. Often one cannot be managed without acknowledging and managing the other.

3.1 Introduction

The period of European colonisation (1500-1800) was a time of acquisition and nature was seen as an assembly of objects, as discussed in Chapter 2. Such objects in the natural world are specimens of living and non-living things and have been listed according to their contributions to science (Knapp et al. 2004). These objects contribute to our state of knowledge in the form of encoded and embodied information, contributing to the advancement of human and scientific knowledge. In botany these take the form of plants that were collected and dried, and kept as herbarium specimens, and remain as a permanent record that can be returned to at any point (Daston 2004). A herbarium specimen is a sample of a plant, dried and pressed, identified by an expert, and stored in a climatically regulated environment for examination and research purposes in perpetuity (Knapp et al. 2004, Culley 2013). Plant collections date back to some of the first exploratory voyages from Europe and many of these have been designated as type specimens. Certain of these specimens are the first recorded collections of a species and with or without type status they hold historic value. In 1905 the Vienna Code of Taxonomy accepted type specimens in principle, but it was not until 1935 in the ‘Cambridge Rules’ Article 18 that types were formally recognised (Nicolson 1991, Winston 1999, Knapp et al. 2004, Manktelow 2010, McNeill et al. 2012). The recognition and acceptance of type specimens in nomenclatural codes has a complicated history, although the term ‘types’ was already in use in 1867 and the method of using types was well known in Europe by 1910 (Daston 2004) it was the American Botanists who first formally accepted their use in 1904 (Philidelphia Code). In 1905 at the first dedicated nomenclature code meeting in Vienna the type method was proposed by the American botanists but was declined. Persistence by American and later British botanists finally had the type method accepted in 1935. Even though they have been retrospectively denoted as type specimens, meaning can be drawn from these early and first collections as they are relevant today where they carry a certain scientific status and purpose, thus lending additional value to their role in the biocultural heritage argument.

A type specimen status is an objective foundation to which a plant name is permanently linked (Knapp et al. 2004). One of the key rules of scientific taxonomic practice (Pyenson, 1993), based on Linnaeus' binomial classification system, is that every scientific name must be validly published, and form part of an accepted nomenclature based on a type specimen preserved in a collection (Mears 1981, Price and Fitzgerald 1996). This constitutes the ultimate scientific reference for any species and establishes a lasting nomenclatural standard for taxonomy (Daston 2004, Knapp et al. 2004, Dayrat 2005). While not designated as types at the time of collection, the specimens used in this study were awarded the status more recently when this system was initiated and therefore have the status of type specimens.

Herbarium specimens hold significant scientific value as objects of information of the living world that is, as yet, unmatched over time (Suarez 2004, Häuser et al. 2005). Historic botanical records are generally the longest standing record of a species occurrence used by scientists for many purposes and are not restricted in providing information on plant species alone (Lindborg 2007, Soubiran 2011). Usually given a collection number by the collecting botanist, they are issued accession numbers by a herbarium in order for them to be tracked as they provide verifiable proof and credibility to biological and ecological science (Culley 2013). These exactly curated historical datasets can be used to investigate environmental history and answer fundamental conservation questions, which I explore in relation to extinction of species in protected areas (Chapters 4 and 5).

Herbarium specimens are well recognised in the academic literature as scientific records in their own right (Clavir 2002, Dosmann 2006, Dargavel et al. 2014). I argue that their associated *in situ* plant populations carry heritage value, similar to archaeological artefacts and their associated excavation sites (Purdie et al. 1996). Literature in the environmental humanities and human geography supports a view that objects and places can and do hold more than a purely scientific value (Kroeber 1963, Schwandt 1994, Argumedo 2013, Ryan 2015). Historic collections sites where plant populations still exist are a living heritage, and cultural relict plants are already recognised (Solberg et al. 2013). Examples of biological and cultural sites include Cahokia in Illinois, USA (Brown 1994, Billington 2004, Verschuuren 2010) and Linnaeus' Hammarby in Sweden (Van Der Aa 2000, Worley and Josefsson 2010). Such aspects of cultural and biological heritage speak directly to the core mandate of SANParks which '…is the conservation of South Africa's biodiversity, landscapes and associated heritage assets, through its system of national parks.'(SANParks 2014).

3.1.1 Scientific Biocultural Heritage

The United Nations Education, Scientific and Cultural Organisation (UNESCO) World Heritage Committee defines 'historic' as an object or site that must be a minimum of 100 years old. Natural heritage is defined in Article 2 of the UNESCO charter of 1972 (UNESCO 1972) and was ratified by 187 countries in 2011 (Rodwell 2012, Gfeller 2013). The concept of biocultural heritage, was first used in the Declaration of Belem in 1988 (Posey 1999, Davidson-Hunt et al. 2012) and thereafter occurred with increasing frequency in the literature (Gokhale 2003, Wilkes and Shen 2007, Argumedo and Stenner 2008, Gavin et al. 2015). However, the concept had been alluded to in earlier studies such as Berlin et al. in 1973, where the authors discussed 'prescientific mans' naming and classification of important plants. Biocultural heritage appears in the UNESCO charter for the first time in 2011. It is defined as the knowledge and practices of indigenous people and their biological resources, from the genetic varieties of crops they develop, to the landscapes they impacted upon. Biocultural heritage is a holistic concept, where knowledge, biological diversity, landscapes and culture are inter-connected and inter-dependent (Mackenzie and Dilts 2013). Biocultural heritage is the interwoven relationship between the natural environment (biodiversity) and a culture, it identifies objects making a contribution to human understanding of a specific culture (Price and Lewis 1993, Gavin et al. 2015). In this study biocultural heritage is used to identify plant populations viewed in a historic context where human interactions with nature has added value to the development of scientific knowledge (Hill et al. 2011a, Yiching and Jingsong 2011, Harmon 2013). Historic localities aid in our understanding of times past through their inclusiveness of communities (human and plant). Thus I align my argument with Verschuuren (2012) that plant populations from which historic collections were made should be viewed as objects similar to historic sites. Historic plant populations constitute markers of the intersection of culture and biological heritage. Plant populations, where historic specimens were collected over 100 years ago, may be able to provide insight to research questions pertaining to the state of the environment and ecosystems at the time of collection, highlighting how these have changed over time.

Type status has been retrospectively formally designated and assigned to historic herbarium specimens. On the Agulhas Plain type specimens were used as a means to reduce the very large number of specimens collected in the area to a more workable number given the time for this study. Herbarium specimens, including type specimens, are used for comparative purposes, such as the prevalence of pests and diseases (Malmstrom et al. 2007), monitoring temporal changes in climate (Primack et al. 2004, Loiselle et al. 2008) or phenology (Lister et al. 2010, Park 2012). Often living plant populations can provide information not obtainable from the dried herbarium specimen and, as stated by Rautenberg, (2014, p.2), and in support of my argument:

‘…there is a unique scientific value in plants and animals around the world that live on the sites where they were first discovered, or where they have previously been studied.’

Biocultural heritage, as it is used here, has both a practical and a theoretical aspect (Maffi 2005), it identifies and defines plant populations that have an associated historic value through their contribution to the development of scientific knowledge (Hill et al. 2011, Yiching and Jingsong 2011). Here I argue that historic herbarium specimens and their original collection sites are biocultural heritage assets and a new recognition of the social human role and contribution of botanical collecting should be applied to conservation. Historic plant populations should be seen in the same way as historic sites, when compared to more immediately mobile objects such as animals. The term ‘cultural geography’ has also been applied in similar cases (Price and Lewis 1993). In this chapter, the suggestion is put forward that historic plant populations older than 100 years should be recognised as biocultural heritage assets, as they are sites where scientific (social and biological) knowledge was and is generated (Zytaruk 2011).

The most commonly studied aspect of biocultural heritage is the value humans have placed on plants, animals and sites for economic purposes (Cocks and Dold 2006) and the geographic development of linguistics (Maffi 2001, 2005). However, there is far more to biocultural heritage than the link between human needs and nature. Few studies have looked at the idea of objects of nature influencing the culture of a discipline such as botany and science, as discussed in Chapter 2, where I provided examples of the literature that does exist on this topic. The notion of biocultural heritage has traditionally been used to describe the link between indigenous peoples and the environment as a means to retain their cultural identity (Hill et al. 2011b). Here I aim to extend the notion of the value of biocultural heritage beyond indigenous people to all citizens according to a recognition of our collective biocultural and cultural identity rooted in the land. I argue that historic plant collection sites and populations are biocultural heritage.

Biocultural heritage has attracted interest in disparate fields of the humanities and social sciences (Maffi 2005, Puig de la Bellacasa 2010), and as time passes and societies grow and change, the application of biocultural heritage should follow suit (Price and Lewis 1993, Cocks and Dold 2006).

South Africa is known globally as a mega-biodiverse country having extremely high levels of floral endemism and animal genetic diversity (Thuiller et al. 2008). South Africa has been the destination of botanical explorers for centuries, as illustrated in Chapter 2, with herbarium specimens featuring in botanical publications since the 1700s (MacOwan 1890, Glen and Germisthuizen 2010) . The link between the collections made by early botanists and the scientific and historic value of these collections has not been closely examined in the South African context. In drawing together the multifaceted thinking of numerous historical figures and authors in Chapter 2, regarding the history of botany and its contribution to science, I now describe the historic botanical collecting that took place on the Agulhas Plain in the Cape Colony of South Africa. My aim is to explore the value of historic herbarium specimens as biocultural heritage assets, as established by a growing set of literature (Maffi 2001, Pretty et al. 2009, Solberg et al. 2013, Gavin et al. 2015), so that a new discourse may be engaged to recognise the joint value of natural sites and cultural sites to science and conservation. In this chapter I make the links between people, botanical culture and nature explicit in order to argue the case that historic specimens and their associated *in situ* plant populations are biocultural heritage assets. I attempt to bridge the gap between biodiversity conservation and culture and my research aimed to establish the presence of historic plant localities in the Agulhas National Park, from collections made prior to 1914. Once confirmed extant they could then be included into the South African National Parks (SANParks) conservation management and heritage portfolios and thus ensure a continued contribution to knowledge generation through conservation of these historic sites. For this reason I will first provide an historic account of the botanising that took place on the Agulhas Plain and the farmsteads present in what is now the Agulhas National Park. I will then give an account of my search for extant plant populations of historic collections, my findings and recommendations.

3.2 Methods

3.2.1 Study Area

My case study is in the Agulhas National Park, a protected area in the Western Cape Province of South Africa. Proclaimed in 1999 to conserve the exceptional floristic diversity and endemism of the fynbos found on the Agulhas Plain (Euston-Brown 1999, SANParks 2013a) it is currently 21 149 hectares in size. Fynbos is a Mediterranean-type vegetation that consists of evergreen shrub lands with the majority of species relying on fire for regeneration (Kraaij and Van Wilgen 2014). The park is managed by SANParks, the national conservation arm of the government of South Africa. The park lies at the southernmost tip of the African continent, with the coastal towns of Pearly Beach (34º 35' S, 19º 21' E) and Struisbaai (34º 49' S, 20º 03' E) at the western and eastern boundaries respectively. It is a linear park running approximately 45 km from east to west and 25 km inland from the coast. The Agulhas National Park has many historic sites within its borders, such as ship wrecks and shell middens along the coast and original Cape Dutch farmsteads inland. It has a comprehensive heritage management plan for the park when compared to other parks in the Fynbos Biome so was chosen as the case study protected area for investigating the potential of historic herbarium specimens and the original plant specimen collection sites as biocultural heritage assets. As such the inclusion of biocultural heritage sites in the heritage management plan for Agulhas National Park would be relatively easy.

3.2.2 Data analysis

I used the online database of the Global Plants Initiative, JSTOR Plant (http://plants.jstor.org/), to search for type specimens collected on the Agulhas Plain more than 100 years ago to reduce the number of total specimens collected in this botanically rich area (Knapp et al. 2004). Search fields included country (South Africa), locality (Agulhas), date from (1600) and date to (1914), allowing for the 100 year heritage rule (Gfeller 2013). I then georeferenced the herbarium records (Wieczorek et al. 2004) and combined the data to produce a single GIS layer of plant collections. This was overlaid onto the Agulhas National Park boundaries with ArcView software (ESRI ArcView Version 10.3). The map was used to select only those collections made in the current Agulhas National Park as this was the case study area for this research. Figures 3.3 and 3.4 in the results section show the regional situation of the Cape of Agulhas in South Africa, and the Park boundaries and type collection sites.

As the most prolific collector on the Agulhas Plain in the given time period, the daily journal entries in Harry Bolus' collection register were cross referenced with historical literature regarding the Agulhas Plain and the Cape Colony (Theal 1905, Hall 1984, Heydenrych 1999, De Kock 2011). Although Bolus died before type were formally recognised by the Vienna Code his type specimens, and those of Rudolf Schlechter, were used as a subset to develop the theory of biocultural heritage of historic botanical collections sites in Agulhas National Park.

Botanical collection in the 1700 and 1800s was part of a particular colonial endeavour, and reflective of the social structures of that period. The material sought and used is thus colonial and European in origin. While I acknowledge the presence and importance of other parallel indigenous histories at the time, these were largely excluded from the botanical records and are therefore not taken up here. This in no way reflects the views of the author, who is acutely aware of the national and cultural value of indigenous plant species beyond their recordings in the colonial scientific literature. However, this area of interest falls beyond the scope of this particular research endeavour.

The routes taken, farmsteads visited and the type specimens collected were located on the type specimen map for Agulhas National Park (Figures 3.3 and 3.4). By determining the habit and habitat requirements (Goldblatt and Manning 2000) of the plant species that were collected and later designated as type specimens, it was possible to predict where plant populations would most likely occur in the areas noted on the specimen labels. Certain specimen labels included brief habitat descriptions and, at times, listed a particular feature such as limestone outcrops or marshy wetlands. Taking into account the occurrence of wildfires over the intervening years (Midgley et al. 2006), a localized target area with a 1 km radius was determined. Three transects of 100 m were placed within the 1 km area of predicted collection locality, each transect was 4 m wide with markers placed every 20 m. Two observers worked side-by-side in 2 m strips and spent 8 minutes per 20 m section looking for the target plant species (Alexander et al. 2012). Field visits were undertaken between April 2014 and December 2014, to establish if the historic plant populations were still extant in the areas of what is now the Park. In order to allow the best possible chance of finding the species extant, sites were visited at the same time of the year as that on the specimen label and also during the peak flowering periods of the plants as these time periods may no longer coincide (Tingley and Beissinger 2009).

3.3 Results

3.3.1 The Agulhas Plain

By way of a brief historical detour, and providing relevant historical context, I give a background on the Agulhas Plain and botanical collecting that took place there. Cape Town, like many early colonial coastal towns, was the gateway to the terrestrial interior (Hume 1943). The major wagon routes used for passage along the Cape coast and the interior started as game trails and subsequently developed into travel routes used by indigenous South African people. The major route from Cape Town to the southern Cape coast was over the Hottentots Holland Mountains and onto the warm water baths at Caledon (Figure 3.1) (Rookmaaker and Svanberg 1992). Figure 3.1 shows the main wagon route to the eastern boundaries of the Cape Colony and the frontier territories beyond the Sundays River (Skead 2009). Famous botanical explorers such as William Burchell, Anders Sparrman and Francis Masson passed through Caledon, along the foothills of the Riviersonderend and Langeberg Mountains to Swellendam from where they proceeded to explore the frontier regions of the Cape Colony (Bradlow 1994). These famous botanists did not collect on the Agulhas Plain as it was largely inaccessible with few roads to isolated farmsteads. Exploration of the Agulhas Plain took place from the mid-1700s onwards when people began to deviate from the main route to larger farmsteads, continuing south of Caledon, via Oudekraal and through the Klein River valley, to the Agulhas Plain (Figure 3.1). The Moravian Mission Station of Elim (34° 35’ S, 19° 45’ E) was established in 1825 (Mouton 2007) and formed a central locale where travellers could rendezvous, find accommodation and hire guides[3] and equipment, to explore the surrounding areas. A journey generally took three days by horse and wagon from Cape Town to Elim, weather permitting (Bolus 1894). The main farmsteads visited by botanical explorers on the Agulhas Plain which are now within the Agulhas National Park were: Ratelriver, Rietfontein and Renosterkop.

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[33] Early plant collection records give little recognition to the native guides, who were important to the success of the collecting trips (Chapter 1), and focus primarily on the European collectors (Lustig 2001) with many of the specimens collected bearing European names. Botanical collection trips provided employment for many guides and some even volunteered in order to share their passion and knowledge of the flora with foreign visitors. Although their names were seldom recorded and are now lost, it is important to protected areas to recognize not only the contribution to scientific botanical knowledge of physical specimens but also the myriad of collectors, men and women, to whom this knowledge is owed both the botanical collectors and the native guides (Hume 1943, Barker and Barker 1990). The presence of biocultural heritage is evident in the collections and the stories of the people who made them.

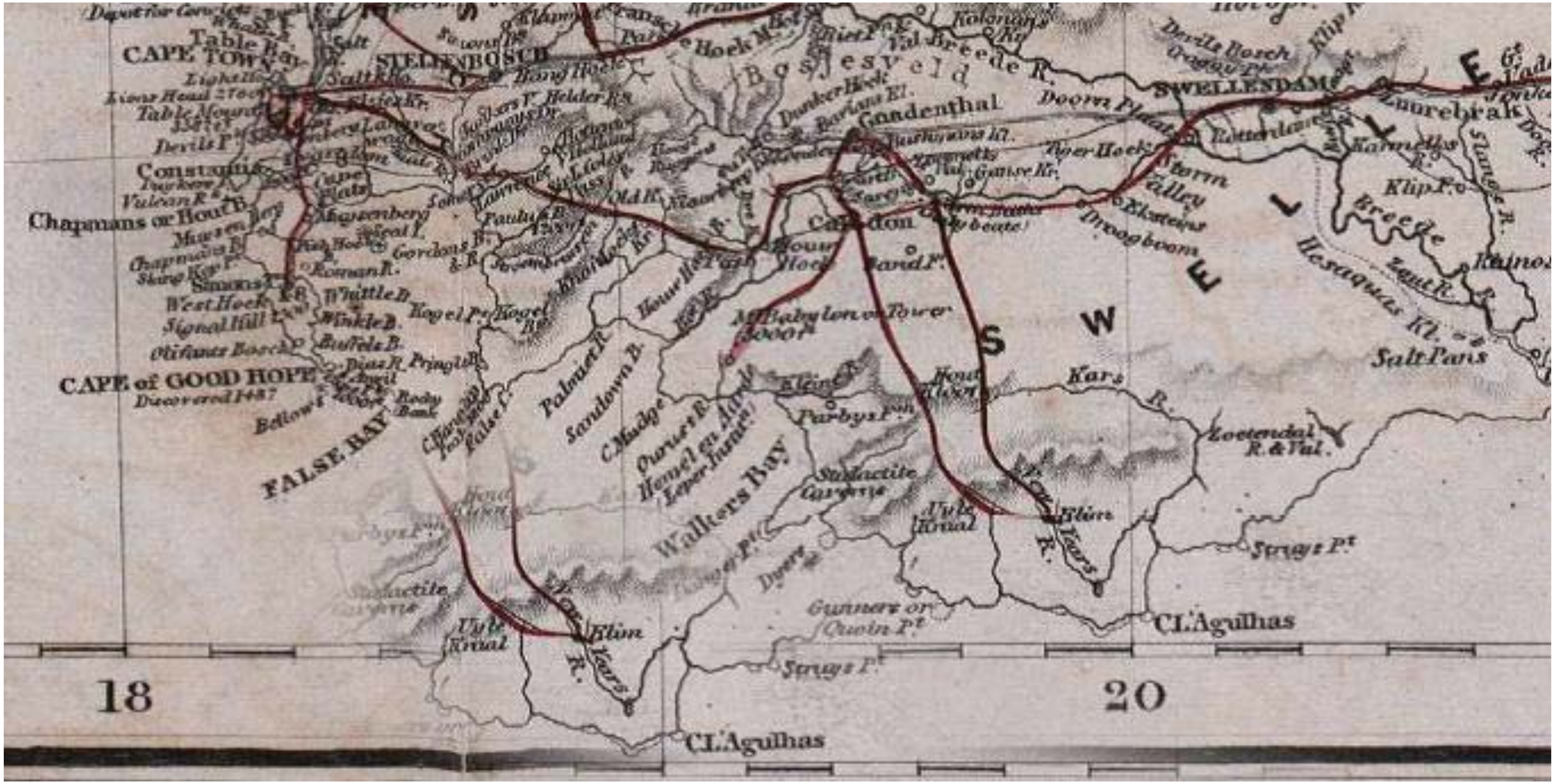


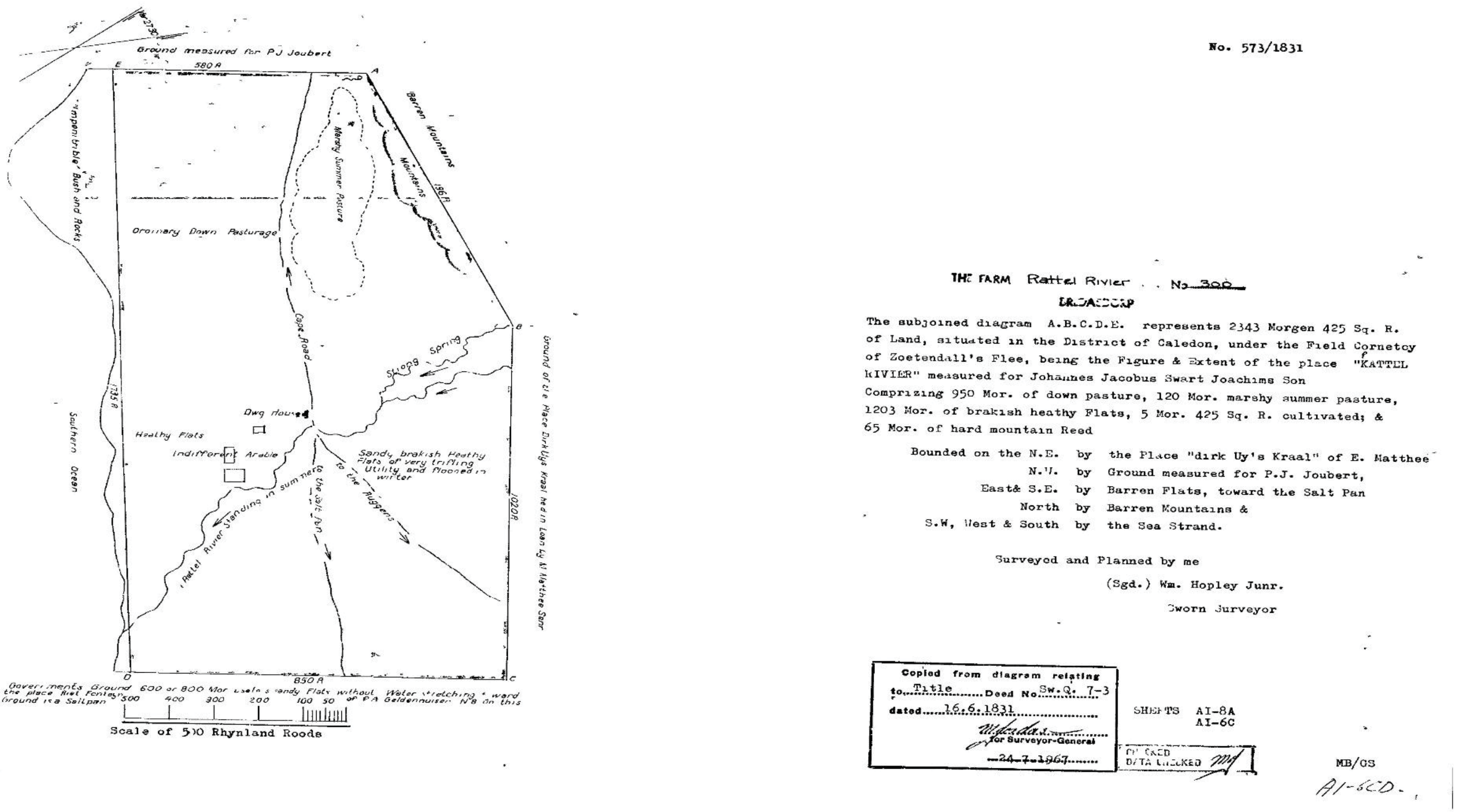
Figure 3.1. Section of historic map of the major wagon routes (in red) showing the Agulhas Plain in 1844 (Surveyor-General 1844).

3.3.2 History of the farmsteads in Agulhas National Park

While contemporary focus is on the Agulhas National Park, early collectors collected on and around private farmsteads owned by Dutch settlers in the early to late 1800s. A brief history of the three main farmsteads of Ratelriver, Rietfontein and Renosterkop, which now form part of the park, is given below.

Ratelriver

The first European owner of Ratelriver was Matthys Lourens in 1745. The farm was sold in 1831 to Hans Swart, who consolidated it with other land, making it one of the largest farms on the Agulhas Plain at this point in time (Figure 3.2) (Mouton 2004). Hans died in 1835 and his widow, Catharina Swart, continued to run the farm until it was sold to Dirk Van Breda in 1860. The widowed Catharina Swart had a reputation for abusing her slaves, and one story relates how she buried a slave in the sand dunes on the coast with only his nose sticking out. She promptly forgot about him and shortly after being retrieved, he died, but not before allegedly cursing the lady and her farm (Mouton 2004). While the story is noted in the records socially as one of interest, there was evidently no formal justice system at play at the time, and life in the southern Cape was typical of the period, being somewhat off the beaten track, it had a Wild West feel to it.



No. 573/1831

THE FARM Rattel Rivier . . No 300

BREDASDORP

The subjoined diagram A.B.C.D.E. represents 2343 Morgen 425 Sq. R. of Land, situated in the District of Caledon, under the Field Cornetcy of Zoetendall's Flee, being the Figure & Extent of the place "KATTEL RIVIER" measured for Johannes Jacobus Swart Joachims Son Comprizing 950 Mor. of down pasture, 120 Mor. marshy summer pasture, 1203 Mor. of brakish heathy Flats, 5 Mor. 425 Sq. R. cultivated; & 65 Mor. of hard mountain Reed

Bounded on the N.E. by the Place "dirk Uy's Kraal" of E. Matthee
N.W. by Ground measured for P.J. Joubert,
East& S.E. by Barren Flats, toward the Salt Pan
North by Barren Mountains &
S.W, West & South by the Sea Strand.

Surveyed and Planned by me

(Sgd.) Wm. Hopley Junr.

Sworn Surveyor

Copied from diagram relating
to Title Deed No Sw.Q. 7-3
dated 16.6.1831
M.Jordaan
for Surveyor-General
24-7-1967

SHEETS AI-8A
AI-6C

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AI-6CD.

Figure 3.2. 1831 Boundary map of the Farm Rattle River, showing the conditions of the surrounding veld, listing marshy pastures, down pasture, brakish heathy flats and hard mountain reeds (Agulhas National Park Archives).

When Dirk Van Breda purchased the farm from Catharina Swart, the curse is thought to have held true when his eldest son shot and killed his wife on the 21 March 1871 at Ratelriver. The farm remained in the possession of the Van Breda family but was managed by a Mr Hughes until 1902 when it was sold to William Fletcher, a wealthy Cape Town businessman who bred horses on the farm (Mouton 2005b). SANParks purchased the farm in 2003 from the Fletchers. Numerous records from the owners of Ratelriver mention the extensive fields of fynbos flowers around the farmstead (Mouton 2004, 2005b, a), and the records of herbarium specimens, verify that the Ratelriver farm was an exceptional site for plant collection.

Rietfontein

In 1746 the farm Rietfontein, originally known as 'Rietfontein aan Zandberg', entered the colonial land registry as a stock post. Matthys Lourens of Zoetendalsvlei purchased it in 1755. The farmstead was formally registered by the Cape Government in 1839 to the same Dirk Van Breda who went on to buy Ratelriver. Rietfontein was rented to tenant farmers by the Van Breda family. The last tenant farmer was Piet Lourens who, for 52 years, was a shepherd on the farm until SANParks acquired it in 2003. Fortunately, the nature of the seasonal wetlands that surround the farmstead were not suitable for agricultural crops and minimal grazing took place. This has left the natural veld relatively undisturbed and thus able to recover naturally after wildfires (Gaertner et al. 2007). An assessment by the Agulhas Biodiversity Initiative (ABI) found that the fynbos on the farm is still one of the most diverse on the Agulhas Plain (Cole et al. 2000). Historic and current herbarium records list a number of collections made at Rietfontein.

Renosterkop

Initially established as a stock post for grazing in 1742, Matthys Lourens was awarded formal farming rights at Renosterkop in 1757. The homestead on Renosterkop was small in comparison to Ratelriver and Rietfontein, and consisted of structures built in the typical style found on the Plain in the 1800s. Being immediately adjacent to a notoriously wild coastline which during this period (1815-1849) was the site of a number of shipwrecks meant many homes on the Agulhas Plain were made with timber from the shipwrecks, and Renosterkop was no exception (Mouton 2009). Situated between the foothills of the coastal dune fields and the inland salt pans, crop farming and grazing were limited. Again, this has benefitted the natural vegetation which has remained relatively intact in undisturbed pockets (Gaertner et al. 2007). The ABI botanical assessment notes the unique diversity of veld on the farm and in particular the limestone fynbos and that of the salt pans to the north-west of the farmstead (Euston-Brown 1999).

3.3.3 Biography of three botanists in Agulhas National Park 1894-1897

It was found that between 1600 and 1914 only three collection trips were made from 1894 to 1897, from which type specimens have been designated in retrospect. These historic collections were made by three botanists, Harry Bolus, Rudolf Schlechter and Francis Guthrie (Table 3.1). A total of 127 type specimen records were obtained from the search of JSTOR Plant online database. There were 31 type specimens collected within the current Park boundaries, 82 in and around Elim and 27 in other areas outside of the Park currently known as the buffer zone (Figure 3.3). This was a workable number of localities to try and source as a pilot project in this area of numerous botanical collections. The following description of the collectors and their collections is an example of historic collections on the Agulhas Plain but is by no means necessarily the first or all of the historic collections made in this area.

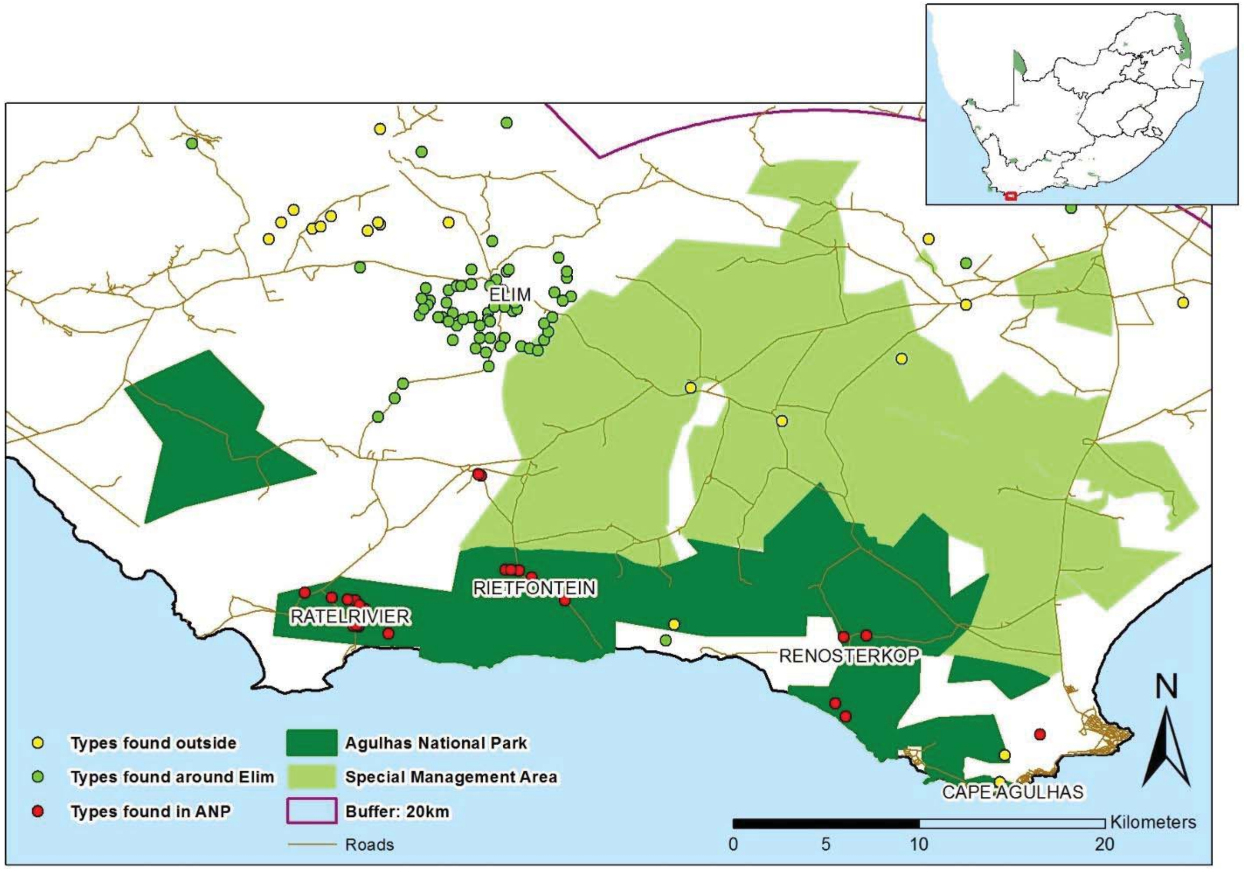

Figure 3.3. Map of the Agulhas Plain in the Western Cape Province, showing the Agulhas National Park, the Nuwejaars-Wetlands Special Management Area and the buffer zone of the Park in purple. Type localities are shown inside and outside of the Park. Insert in the top left corner of the map shows the position of the Agulhas National Park in red within the country of South Africa.

Figure 3.4. Map of the Agulhas National Park, showing the type localities found (in black) and not found (in red) within land managed by the Park.

Harry Bolus

Harry Bolus travelled to South Africa from England when he was 15 and settled in Graaff-Reinet, he became the first botanist solely based in the Cape Colony, as previously explained other botanical collectors had visited the shores of the Cape but returned to their home countries (Chapter 2). In 1864 he lost his six year old son and at the suggestion of his friend Francis Guthrie, took up botanising to help him grieve. In 1865 he moved to Cape Town and took up a post at the South Africa College (now the University of Cape Town) founding the Bolus Herbarium in Cape Town. Botanising became a passion and in 1895 he started fulltime botanical collecting. Bolus was a philanthropist, organizing expeditions and helping fellow collectors financially (Liltved and Johnson 2012). Similar to Linnaeus he mentored other botanists, one of whom was Rudolf Schlechter, working with them in the herbarium and also taking them on field expeditions to collect herbarium specimens. Bolus shared his knowledge of the area and his botanical skills as well as teaching other collectors the correct collection procedures for herbarium specimens, which is mentioned in Chapter 2 as one of the key outcomes of colonial botanical collecting and its possible influence on scientific practices. Figure 3.5 is a photograph of Bolus, Rudolf Schlechter and his brother Max Schlechter on one such collection trip in 1896 to the Agulhas Plain.

Rudolf Schlechter

Rudolf Schlechter was born in Berlin in 1872, studied horticulture and worked as a gardener for the Berlin University Garden. He left Europe in 1891 for a botanical expedition to the Cape and worked as a gardener in the Cape Company Gardens and later as an assistant to Bolus, where he joined collecting trips on the Cape Peninsula (Glen and Germisthuizen 2010). In 1892 Schlechter started collecting on his own, or with his brother Max, in the southern and Eastern Cape regions. Schlechter also collected in German New Guinea, Indonesia and Australia, and returned to Germany in 1921 where he wrote and described many new orchid species, having developed a love for this plant family while in the Cape.

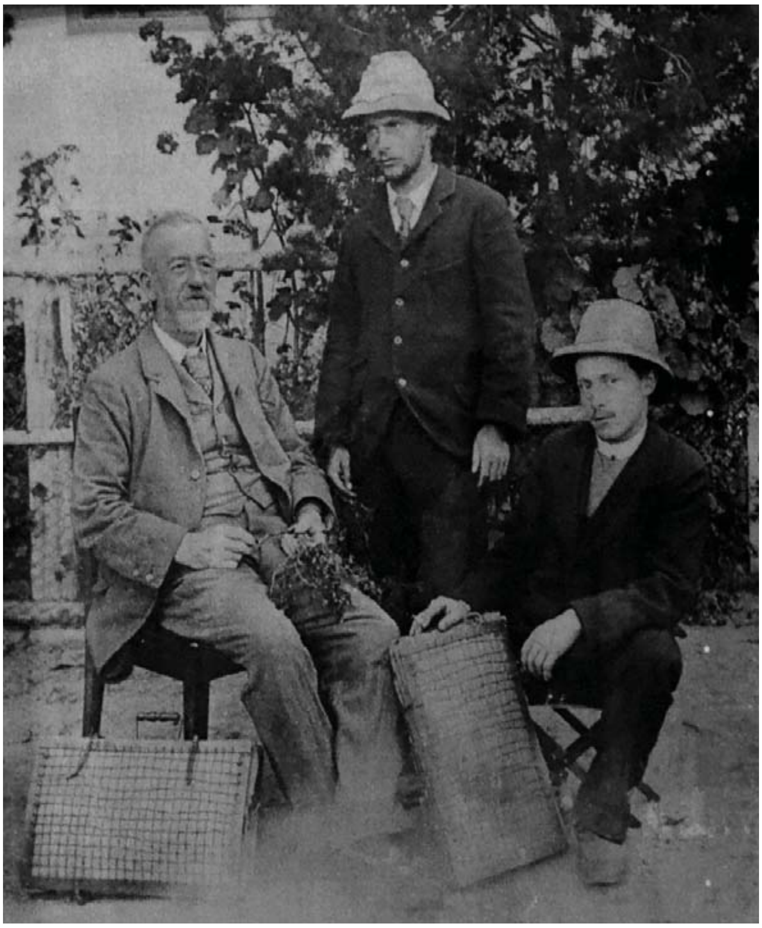

Figure 3.5. Harry Bolus (seated left), Max Schlechter (standing) and Rudolf Schlechter (seated right) on a collecting expedition in 1896.

Francis Guthrie

A lifelong friend of Bolus, Francis Guthrie, arrived in South Africa in April 1861 from London. Along with Bolus, Guthrie was employed at the Graaff-Rennet College and in turn followed him to Cape Town in 1875. He became professor of mathematics in 1876 at the South African College. Although he mainly collected around the Cape Peninsula, he did join Bolus on expeditions to the southern Cape. Guthrie retired and died of cancer three months after his last collecting expedition to the southern Cape with Bolus. The strength and depth of relationships forged through botanising and collecting in the wilds of the Cape is apparent in Bolus' diary (Bolus 1894, p91) where he wrote:

> 'Oct 19. F. Guthrie, my dear old friend, counsellor teacher, companion and close intimate died at about 11.30pm this night…, from cancer of the stomach- an illness borne with wonderful courage, patience and resignation…'

Table 3.1. Type collections in Agulhas National Park between 1600 and 1914, Taxon, Family, collector, Red List status, original collection date, and presence provided.

Taxa	Family	Collector	Red List Status	Date of collection	Extant in 2014
Acrolophia micrantha (Lindl.) Pfitzer.	ORCHIDACEAE	Schlechter	Least Concern	1896/12/10	No
Adenocline pauciflora Turcz.	EUPHORBIACEAE	Bolus	Least Concern	1896/12/10	Yes
Agathosma dielsiana Schltr. Ex Dümmer	RUTACEAE	Schlechter	Least Concern	1897/04/27	Yes
Argyrolobium harmsianum Schltr. Ex Harms	FABACEAE	Schlechter	Endangered	1897/04/27	No
Cassine peragua L.	CELASTRACEAE	Schlechter	Least Concern	1897/04/28	Yes
Erica accommodata Klotzsch Ex Benth.	ERICACEAE	Bolus	Least Concern	1895/13/07	No
Erica aghillana Guthrie & Bolus	ERICACEAE	Schlechter	Endangered	1897/04/28	Yes
Erica filipendula Benth. subsp. filipendula	ERICACEAE	Bolus	Rare	1895/16/07	Yes

Erica filipendula Benth. subsp. parva E.G.H.Oliv. & I.M.Oliv.	ERICACEAE	Guthrie	Least Concern	1895/16/07	Yes
Erica gracilipes Guthrie & Bolus	ERICACEAE	Bolus	Critically Endangered	1896/12/10	Yes
Erica plukenetii L.	ERICACEAE	Schlechter	Least Concern	1896/12/12	Yes
Erica propinqua Guthrie & Bolus	ERICACEAE	Bolus	Least Concern	1894/04/10	Yes
Erica radicans (L.Guthrie) E.G.H.Oliv. subsp. schlecteri (N.E.Br.) E.G.H. Oliv.	ERICACEAE	Schlechter	Endangered	1897/04/27	Yes
Erica saxicola Guthrie & Bolus	ERICACEAE	Schlechter	Least Concern	1896/12/10	Yes
Ficinia latifolia T.H. Arnold & Gordon-Grey	CYPERACEAE	Schlechter	Endangered	1897/04/30	Yes
Gladiolus carneus D.Delaroche	IRIDACEAE	Bolus	Least Concern	1896/12/12	Yes
Gnidia linearifolia (Wikstr.) B. Petersen	THYMELAEACEAE	Bolus	Least Concern	1896/12/09	No
Leucospermum cordifolium (Salisb. ex Knight) Fourc.	PROTEACEAE	Bolus	Near Threatened	1896/12/09	No
Leucospermum heterophyllum (syn. Lemmerzianum) (Thunb.) Rourke	PROTEACEAE	Schlechter	Endangered	1896/12/09	Yes

Limonium scabrum (Thunb.) Kuntze var. avenaceum (C.H.Wright) R.A.Dyer	PLUMGABINACEAE	Bolus	Least Concern	1896/12/12	Yes
Mimetes saxatilis E. Phillips	PROTEACEAE	Schlechter	Endangered	1897/04/25	Yes
Ornithogalum dubium Houtt.	HYACINTHACEAE	Schlechter	Least Concern	1896/12/10	No
Protea aspera E. Phillips	PROTEACEAE	Bolus	Vulnerable	1894/04/10	No
Restio calcicola (Mast.) H.P. Linder (syn. Calopsis fruticosa)	RESTIONACEAE	Schlechter	Least Concern	1896/12/12	No
Restio dodii Pillans	RESTIONACEAE	Schlechter	Vulnerable	1897/04/28	Yes
Roella arenaria Schltr.	CAMPANUALCEAE	Schlechter	Vulnerable	1896/12/10	Yes
Roella compacta Schltr.	CAMPANUALCEAE	Schlechter	Least Concern	1896/12/12	Yes
Senecio pillansii Levyns	ASTERACEAE	Bolus	Threatened	1896/12/09	Yes
Tetraria brachyphylla Levyns	CYPERACEAE	Schlechter	Least Concern	1897/04/28	Yes
Thesium capituliflorum Sond.	SANTALACEAE	Bolus	Least Concern	1896/12/10	Yes
Thesium sertulariastrum A.W.Hill	SANTALACEAE	Bolus	Data Deficient	1896/12/10	Yes

3.3.6 Results from revisiting sites in 2014

Between them Bolus and Schlechter collected 81 specimens including 17 previously undescribed species. I found that 31 historic specimen collections made between 1600 and 1914, are still extant at their localities (Table 3.1) in what is today the Agulhas National Park. On the first expedition to the Agulhas Plain, 4 October 1894, Bolus collected two specimens (which now have type status). Returning to the Ratelriver farm, in 2014, I found that the historic population of *Erica propinqua* collected on this first trip, is still extant. The next historic excursion to the Agulhas Plain was in July 1895 and on this trip three type specimens were collected. In looking for these three in the Park, I found that only one, *Erica filipendula subsp. filipendula* was extant (Figure 3.6). I was unable to locate *Erica filipendula subsp. parva* and *Erica accommodata* in the flats near the Ratelriver homestead as referred to in Figure 3.2. Twelve of the 17 designated type collections made in December 1896 by Bolus and Schlechter, were found to be still growing at their historic localities. The habitats of *Restio calcicola* and *Leucospermum cordifolium*, a popular cut flower and garden plant around the world (Littlejohn et al. 1993, Leonhardt and Criley 1999) were completely transformed and the populations are no longer extant. The 1896 trip was to be the last trip to Agulhas for Bolus, yet throughout his later writings he continues to make reference to his trips and his longing to return to Agulhas (Bolus 1894).

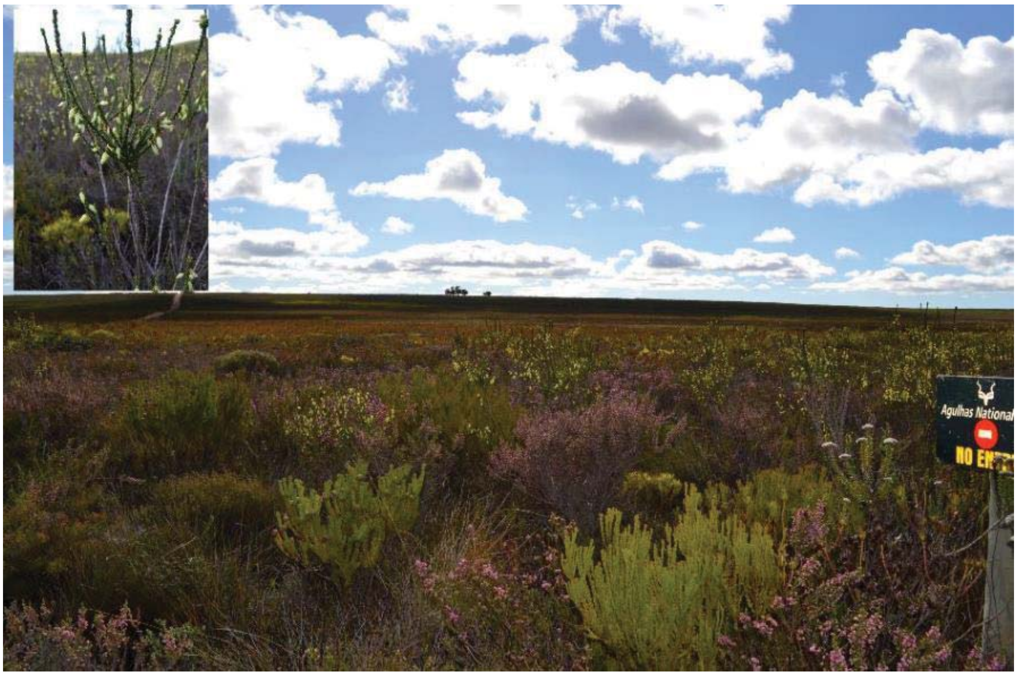

Figure 3.6. Historic locality of *Erica filipendula subsp. filipendula* in Agulhas National Park. Insert is a close-up of the individual yellow flowered erica first documented in 1895 (C. Cowell 2014).

Rudolf Schlechter undertook a trip to the Agulhas Plain at the end of April 1897. Schechter's trip is recorded in Bolus' journal from a letter written to him by Schlechter. Venturing further than Bolus, he visited the farm Renosterkop and the Cape of Agulhas. Schlechter arrived at Agulhas from Bredasdorp and collected on the limestone hills and dunes around the southern point of Africa from the 25th to 27th April 1897. On his first day he found the iconic *Mimetes saxatilis* now listed as endangered on the IUCN Red List (Raimondo et al. 2009). Schlechter resided at Renosterkop while he collected around Cape Agulhas, on the 28 April he collected *Cassine peragua subsp barbara,* a current day favourite amongst gardeners and landscapers making its future fairly secure from total extinction (Archer and Van Wyk 1997, Coates Palgrave 2002). From Renosterkop he made his way along the coastal foot slopes of the Soetanysberg to Rietfontein, where once again he botanized at Rietfontein Poort. Evident here is a pattern of returning repeatedly to a favoured site, a process further instilling these sites with a depth of historic engagement. On this occasion he only documented one species to his collection records at the Poort, *Ficinia latifolia* and collected seven other specimens. Schlechter sent Bolus 1115 specimens, including duplicates for the Royal Botanic Gardens Kew according to the practice at the time (Chapter 2). Closely following Schechter's 1897 collection route

117 years later in 2014, it was found that eight of the nine specimens collected on this trip are still extant at their localities within Agulhas National Park.

All but two of the historic localities of species with Red List status (Raimondo et al. 2009), that I searched for in the study period (1600-1914), were eventually located. The flat fertile field where *Protea aspera* (Vulnerable), once grew, was ploughed at the turn of the century and the historic population was likely lost at that point (Heydenrych 1999). *Argyrolobium harmsianum* (Endangered) was not found as it is a post-fire species requiring fire for growth and flowering. This species will be looked for following the next fire in this area of the Park. These findings are a prime example of Red List species within a protected area not being imminently under risk of loss as I discuss in Chapter 4 and 5.

3.4 Discussion

During this period of particular scientific interest and a colonial project of accumulation, naming, and possession (Green 2014), the encoded and embodied information, that is explained in earlier chapters, and the resultant knowledge gained through hard earned experience, frustration and frequent setbacks on botanical expeditions, should be recognised for the historic scientific endeavour it was (Parsons and Murphy 2012). Only Bolus' collection journals have been preserved intact and these were used in the study. What is evident from reading the collecting journals is the emergence of a network of knowledge-sharing and sense of community between botanical collectors. This is something seen more easily today, enabled by the availability of electronic identification tools and data (Chapter 5).

A reason for the lack of exploration to Cape Agulhas prior to the late 1700s was the scarcity of settlements in this area and not a lack of interest to explore and collect (Heydenrych 1999). The Moravian Church established the Elim Mission Station which played a major role acting as a central hub in this remote environment and enabled explorers to meet the local residents. Bolus noted in his journal that on one occasion he hired a cart and driver at 16 pence per day from Tilus Von Graan, the local blacksmith in Elim. In his collection register, he mentions the collection of several species from his explorations of the veld around the village and on his trips to the farmsteads of Ratelriver and Rietfontein (Bolus 1894). On his last trip to the Agulhas Plain, Bolus attended service in the large church in Elim and spent the day with the people in the village. Throughout his writings he makes reference to Elim and the Agulhas farmers he visited, acknowledging the role that the Agulhas community played in the advancement of botanical knowledge (Bolus 1894). This is an example of the biocultural heritage embodied in herbarium specimens and their historic localities.

Economic needs resulted in stock stations being established on the Agulhas Plain (Gaertner et al. 2007) and access routes opening that connected these remote and far flung farmsteads. Even then farming was relatively marginal and the large farms resulted in limited disturbance to small areas with low stocking rates of domestic sheep that had little impact on the veld (Hydenrych, 1999). The remaining natural areas on the old farmsteads of Ratelriver, Rietfontein and Renosterkop are testament to this rather marginal agricultural engagement (Figure 3.2). The ownership of farmsteads by a few key families (Lourens and Van Breda) also resulted in the farms being managed in a similar manner reducing intensive use of individual farms. My research found that the wetlands around Ratelriver homestead were drained in the early 1900s when a canal was built to channel the Ratel River away from the homestead (Mouton 2005b). The field data gathered in this study suggests that this caused a decline in species reliant on the seasonal inundation of the wetlands along with an increase in invasive alien Acacia species densities over time, possibly in response to the ‘gap’ provided by the decline of the indigenous species. The scarcity of *Gladiolus carneus* in the wetland is a case in point and although the historic localities of *Erica plukenetii* and *Roella compacta* at Ratelriver were in good condition, the majority of the Ratelriver wetland habitat has been negatively affected by this disturbance and requires interventions to ensure these species persist. By identifying the human cultural impact on the wetlands (i.e. draining of the wetlands for a horse breeding farm) a greater understanding of the decline of the wetland species is gained. Here is a prime example of how biodiversity and culture (biocultural heritage) can influence the current understanding and future management of a wetland in a conservation area.

Humans are creatures of habit, returning to a place again and again (Sellars 1963, Marchette et al. 2011), and on closer examination of the collections made by Bolus and Schlechter, it was found that they had often collected in or around the same spot on different occasions. This kind of repeat sampling by botanical collectors provides science with a temporal and spatial knowledge as to what plant species occurred in a specific area (Rietfontein Poort) over a period of time (Chapters 2 and 5). Using this information, long-term analyses and studies can be undertaken to determine population dynamics including impacts of land transformation, alien species (Higgins et al. 2001, Rouget et al. 2003a) and climate change on floral populations at a landscape and individual species scale such as the analysis and in-field detection of subpopulations conducted later in Chapter 5 of this thesis. Bearing in mind that history is subjective and the writers often recount their stories selectively according to his or her own perspective (Nicandri 2004), the mentioned written accounts of the botanical explorers provide only a glimpse of the original abundance of floral species and how things may differ in the present day. Nonetheless, the collection notes accompanying the herbarium specimen of the common garden pincushion, *Leucospermum cordifolium*, evoke images of an abundant species dominating large patches of the veld. The historic locality has been completely lost because of land transformation for wheat and other crops (Heydenrych 1999). I would like to note that its biocultural heritage contribution has been lost to science. Yet this species is prolific across the Agulhas Plain in remnant pockets of natural vegetation and is secure from global extinction as a garden plant through the horticultural efforts of botanical gardens in promoting this species (Maunder et al. 2001, Walters et al. 2013). In contrast, the perennial shrub, *Senecio pillansii*, discovered close to the Ratelriver farmhouse was described by Bolus as a common sight both on the farm and on the Agulhas Plain. It is still extant at its historic locality but no longer abundant on the Agulhas Plain also a result of land transformation, which is discussed in Chapter 5, and shown to be one of the most common threats to species survival (Kew 2017).

Historic herbarium specimens have the potential to shed light on current day conservation management of protected areas to conserve plant populations and their habitat (Pimm and Raven 2000). However, without the narratives associated with these collections the unique perspective provided is lost. Early botanical collectors took time to observe and capture the details of the areas they found themselves in and the species that they were collecting. Collectors of the herbarium specimens discussed in this chapter followed the strict protocols of botanical collecting, making detailed records, duplicates of the specimens and sharing the collections amongst institutes as stated earlier in the thesis. Together the narratives, herbarium specimens and localities have an historic value for scientific heritage and should be used to structure current nature conservation in terms of a site’s historic and biodiversity significance (Ott 2007). Using this information to highlight the importance of conserving an area for its intrinsic biological or natural worth as well as its biocultural heritage to government agencies and conservation organizations, will safeguard this biocultural heritage in order for people to continue learning and studying it. Ensuring the persistence of original texts, specimens, and *in situ* localities, will contribute to the advancement of scientific knowledge and will aid protected areas in achieving their mandate to conserve not only the biodiversity of a region but the heritage of an area (Andreone 2000, Phillips 2002, SANParks 2013b). This research argues for the education of scientists, conservators and the public regarding the value of biocultural heritage. This will entrench the idea of conserving historic populations as important heritage assets, not only in protected areas but within surrounding communities. While the history and original data presented are colonial and steeped in European history and western scientific practice, the specimens themselves and the extant plant populations, are the property of all South Africans today.

The herbarium specimens, as described in Chapter 2, enable us to determine exactly which plant species were collected by whom, and where along the expedition route collections occurred. , My research has shown that it is possible to locate the historic populations and assess their health (Feeley 2012). *Erica gracilipes* found at Rietfontein Poort in 1896 and now Critically Endangered, was found still growing on the limestone rocks mentioned in the original herbarium labels (Figure 3.7). The extant population has healthy numbers and this information will be used to update the Red List of Plants (Raimondo et al. 2009). Biocultural heritage status of plant populations can also highlight populations that may be threatened at a local level but not at a regional or global level and thus not be known to a protected area to conserve (Solberg et al. 2013).

Two of the species collected at Rietfontein Poort flower prolifically following fire, suggesting that there had been a wildfire in the area within the two flowering seasons (Summer of 1894 or 1895) prior to collection of these specimens. Using historic collection notes, the fire history of an area can be determined and used to inform scientific research on fire and fynbos regeneration (Marais et al. 2014). The continued existence of these historic localities allows monitoring for changes in population vigour, phenology and abundance. It is suggested that the use of distribution models (Zhang et al. 2012) be investigated to estimate population movement in response to changes in climate (Loiselle et al. 2008). All this is potentially possible through linking the original historic specimens to the extant populations in the field, similar to linking fossil plants with living specimens (Crane et al. 2004). My findings will aid in informing Agulhas National Park conservation management of its threatened species, and enable them to conserve the site as a biocultural heritage site, fulfilling the full heritage and conservation mandate of SANParks (Wilkes and Shen 2007, Rautenberg 2014, SANParks 2014).

Figure 3.7. Rietfontein Poort in Agulhas National Park, the original wagon track ran between the two hills on the left of the picture, the current management road runs to the right of the hills. The insert is of *Erica gracilipes* (CR) growing *in situ* in the limestone rocks (C. Cowell 2016).

3.5 Conclusion

Biocultural heritage represented in herbarium specimens informs modern scientific epistemologies and the social character of science via narratives, sites and the extant plants (Cocks 2006, Zytaruk 2011). The presence of historic specimens and extant populations highlights the spaces where knowledge of the natural world was documented (Rautenberg 2014). This enables us to focus our attention on these areas, continuing to generate knowledge and understanding of changes over time that no other records can achieve (Crane et al. 2004, Suarez 2004). Biological and cultural diversity is inextricably linked by the botanical collections on the Agulhas

Plain. However, the continued observation and collection of data and specimens is still required, and this is discussed further in Chapters 4 and 5, where I demonstrate the value of continued fieldwork to biodiversity conservation. There is a great need for committed well informed naturalists, ecologists and botanists to be out in the wild collecting the same types of data, so diligently collected by the early explorers. Students and scholars need to be encouraged and supported in fieldwork and expeditions where knowledge, such as biocultural heritage, is generated and can be conserved and used by science such as the work done by Crane et al. (2004) with fossil and living plants. Concurrently a system needs to be developed that supports the capture, collation and curation of the data that is collected, so that it may be made available to those looking to research aspects of biocultural heritage and biodiversity.

The grounds for park management to recognize the biodiversity and biocultural value of historic herbarium specimens and their associated *in situ* plant populations is evident, as it aids in the success of nature conservation (IUCN 2010). Historic herbarium specimens are hugely valuable in our future understanding of the environment. The value of historic populations can only be realised when the information regarding their collection and conservation is shared with local and scientific communities. This provides these communities a means to engage, participate or contribute to the recognition of biocultural heritage (Ryan 2015). Once society realizes the value of the biocultural heritage and the conservation-worth of historic populations, the value to protected areas increases (Crouch and Smith 2011). The combined stories and narratives give depth to the collections and provide a fundamental knowledge that looks to the past whilst taking us forward. The understanding of historic herbarium specimens, *in situ* populations of plants and the collectors' narratives as being inextricably enmeshed, highlights that they are indeed biocultural heritage. Together, they provide a unique perspective where the environment is viewed as historical evidence, going beyond merely seeing the biological but locating human experience and learning in a natural-cultural environment. Historic herbarium specimens provide a glimpse of what the past state of a species (and possibly the veld) was like and also enables research to take place using this as a foundation.

Further study should be done on the biocultural heritage aspects of the South African plant collectors who worked with and followed Bolus' botanical work ethic, which included being less reliant on the Kew *hub and spoke* method for identifications, as explained in Chapter 2, which was a product of the colonial project of the documenting objects and places (Van Sittert 2003). These collectors markedly increased the numbers of known flora in the country during the late 19th and early 20th centuries. Men such as Thomas Pearson (TP) Stokoe, Robert Harold Compton, Selmar Schönland and John Muir along with many others all made great contributions to the taxonomic records of South Africa. After the First World War women emerged in the early 20th century as some of the most successful botanical collectors. It took some character to develop a name in botanical collecting in what was then a male-dominated profession and took a unique woman to achieve this (Rudolph 1982). Collectors in the Cape included Margaret Levyns, the first woman to receive a Doctorate of Science Degree from the University of Cape Town, and Elsie Esterhuysen who accumulated over 36 000 specimens from 1936 to 1992 for the Bolus Herbarium (Oliver et al. 2007). Augusta Duthie, who completed a flora for Stellenbosch, and Harriet Margaret Louisa Bolus, daughter of Harry Bolus, who continued the legacy of collecting left by Harry Bolus and was an expert South African botanist (Glen and Germisthuizen 2010).

In looking to the future, park management should also concern itself with the conservation and persistence of other subpopulations of plant species within its borders not only those that historic specimens were collected from. Conservation management activities such as alien clearing, erosion control and the use of prescribed fires is essential for the conservation of biodiversity but also important biocultural heritage plant population sites. The value of all herbarium specimens (type and non-type) may indeed be able to assist in determining whether species are at risk of going extinct. When looking at the conservation of all plant populations within a protected area, the use of more recent survey records may also help determine extinction risk. In the following chapter I address the value of all herbarium specimen data by comparing it with botanical survey records in South Africa using an extinction probability equation. In order to determine the extinction probability of species, in terms of expected extinction date and survival probability, I use Table Mountain National Park as a case study protected area under the management of SANParks (Chapters 1, 4 and 5).

CHAPTER 4: Are herbarium data useful for predicting extinctions?

Prologue

Having noted the historical and biocultural value of herbarium collections in the second and third part of the thesis, in this chapter I take a forward-looking approach and look at the usefulness of herbarium data and that of botanical survey data to inform conservation management in protected areas. Protected areas have to report on both national and international conservation targets and it rests with management to gather data that will be used in reporting. Conservation organisations have witnessed the systematic reduction in budget and staff capacity over the years. This has resulted in a triage system being implemented where only priority actions can at times be applied. A source of good baseline data is required to identify and prioritise species for monitoring. Yet many protected areas lack even these data. A core part of my role in SANParks is to plan and implement monitoring within the six parks that I am responsible for. I have identified herbarium and survey data as such a potential source for the Cape Parks. In this chapter I test these data with a known extinction probability model to determine its usefulness to park management in prioritising species for monitoring.

4.1 Introduction

Biodiversity is defined as the full range of life on Earth and the ecological processes that support it (Sutherland et al. 2011). While biodiversity appears rich, it is diminishing rapidly around the world (Collen et al. 2010). Major challenges for society are combating this loss of biodiversity, and that conservation doesn’t recognise the importance of biocultural heritage (Mackenzie and Dilts 2013). Biocultural Heritage is defined as the knowledge and practices of indigenous people and their biological resources, in this study I focus on the landscapes upon which botanical collection took place (Chapter 3). Yet monitoring of both is expensive, being time and labour intensive. The present loss of biodiversity is unprecedented in human history and preventing extinction of species has become a fundamental goal of conservation (Dirzo and Raven 2003). One of the main drivers of biodiversity loss is habitat destruction through land use transformation and fragmentation (Pimm and Raven 2000, Dirzo and Raven 2003, Krauss et al. 2010, Ceballos et al. 2017). Further drivers of loss that are less obvious and require greater understanding include climate change, impacts of alien species invasions and resource harvesting, which are expanded on in the following chapter in relation to protected areas. If left unchecked the end result for individual species is extinction, where a species ceases to exist at a local, regional or global scale (Kuussaari et al. 2009).

Protected areas are geographically delineated areas which may constitute representative habitats of species lost elsewhere in their range and actual habitat of threatened animals and plant species of universal value for science and conservation (Chapter 1). Protected areas are a cornerstone for the conservation of biological diversity (Andreone 2000). This is done through management actions, and observing and monitoring population health. However, basic plant population data on size, health and distribution is often lacking (Akmentis 2011), making the management and monitoring of protected areas for faunal and floral survival extremely difficult (Pereira and Cooper 2006, Joppa et al. 2013). Protected area management is required to evaluate the effectiveness of the protected areas using tools such as the METT which I explain in the first chapter of this thesis. In order to effectively measure performance, data both for and from monitoring is required. Herbarium data have been proven useful for a myriad of ecological studies an overview of which is presented in Chapters 1, 2 and 5. In this chapter I look at their value for conservation management. I examine the value of herbarium record data and combine it here with contemporary botanical survey data, exploring the value of both individually and combined, as tools for predicting extinction within a protected area. In order to establish effective monitoring by conservation authorities.

A lack of detailed data poses a management challenge for SANParks’ park managers in the Cape Floristic Region (CFR), which is home to a particularly high proportion of endemic (± 6000) and niche plant species (Cowling et al. 1994, Linder et al. 2012). The Cape Parks are relatively new parks in the SANParks estate and as a result there is very little long-term monitoring data and sparse baseline information to inform effective monitoring and management (West et al. 2012). Monitoring of species survival is a mandated requirement for SANParks and is urgently needed to prevent biodiversity loss. Table Mountain National Park, one of the Cape Parks, is considered one of the most diverse parks in the fynbos (Helme and Trinder-Smith 2006, SANParks 2015) and due to its location close to the City of Cape Town has been the site of numerous botanical studies and surveys. This has resulted in a greater amount of botanical work undertaken in this park than other protected areas in the CFR under SANParks management. The Cape Peninsula flora has been recognized as one of the richest within a small geographic area in the world (Helme and Trinder-Smith 2006). The Table Mountain National Park has extremely high numbers of plant species (± 1900) coexisting in a relatively small area (25 000 ha), 544 of which have an IUCN Red List status (Raimondo et al. 2009, Rebelo et al. 2011b). Many of these species are threatened by climate change and although Table Mountain has topographic variation, certain species have reached their altitudinal migration limits and are now having to adapt or die due to a changing climate (Rutherford and Bond 2008, Gonzalez et al. 2010, West et al. 2012, Moncrieff et al. 2015, Pecl et al. 2017, Slingsby et al. 2017). In essence Table Mountain National Park has become an island surrounded by urban landscapes outside of the Park boundaries as a result of the expansion of the city due to population growth (Brown et al. 2014, Crist et al. 2017). Urban and industrial infrastructure and their related impacts from a consumer driven population, are hostile to species survival, these include invasive species, vehicles and pollution (Kuper et al. 2004, Pyke and Ehrlich 2009). Table Mountain National Park can thus make a significant contribution to conserving species on the South African Red List (Table 4.1).While detailed species data is critical to all protected area management and monitoring, in the case of a conservation island placed in a complex environment such as an urban centre, it is vital that we know which species are predicted to go extinct first, so that we might maximise biodiversity at the local scale and then the global scale (Pollock et al. 2017).

Fine scale data on at-risk species is particularly critical to make informed management decisions for the best conservation returns in the face of considerable threats and pressures. As with most protected areas Table Mountain National Park has budgetary constraints and insufficient resources to monitor all species all the time (Rout et al 2010). The Park is not a contiguous area but a compilation of fragments broken up by private land ownership. The topography is diverse from flat coastal beaches to rugged cliffs and mountains. Access to many parts of the Park is difficult and this results in greater time and expense to monitor in the Park. Detailed species population size and survival data would help SANParks to prioritise which species to allocate resources to for monitoring of species survival.

Table 4.1. Total number of Red List plant species nationally and those found in Table Mountain National Park with the Park contribution as a percentage shown in brackets.

IUCN RED LIST CATEGORY	TOTAL NUMBER OF SPECIES NATIONALLY 22402	TOTAL NUMBER SPECIES IN TMNP 544
CRITICALLY RARE & PRESUMED EXTINCT	236	10 (4%)
CR	373	55 (15%)
VU	1341	113 (8%)
EN	775	82 (10.5%)
NT	440	46 (10%)
DDD/DDT	1360	54 (4%)
RARE (INCLUDING DECLINING)	1359	60 (4%)

4.1.1 IUCN Red List

In addition to the history of the IUCN Red List that is covered in the first chapter of this thesis, I will now provide a further explanation of how the Red List pertains to protected area conservation. The IUCN developed what is now known as the Red List by assessing species for extinction risk, in order to provide species lists to highlight the plight of species and give an estimation of global extinction risk (Pimm et al. 2014). It formulated a set of criteria (Table 4.2) by which to evaluate species extinction risk across an entire global population (Gärdenfors 2001). Extinction risk for species are determined by using quantitative criteria which address population size and range, and the rate of decline of both respectively. These criteria aim to increase the objectivity of the evaluations. The Red List categories are aimed at reflecting likelihood of extinction under prevailing circumstances. The categories assigned to species are according to quantitative thresholds used in the criteria when assessing species (Table 4.2). The IUCN has regularly revised its assessment system to make the classification of species more objective, rigorous and comparable (Rodriguez et al. 2007).

Table 4.2. The five criteria used in the IUCN Red List to evaluate the threat status of a species in either the Critically Endangered, Endangered or Vulnerable category (IUCN 2012a).

Criteria	Critically Endangered	Endangered	Vulnerable
A Declining population (past, present and/or projected)			
A1	≥90%	≥70%	≥50%
A2, A3 & A4	≥80%	≥50%	≥30%
A1 Population reduction observed, estimated, inferred or suspected in the past where causes of the reduction are clearly reversible AND understood AND have ceased, based on and specifying any of the following:			
(a)	Direct observation		
(b)	An index of abundance appropriate to the taxon		
(c)	A decline in the area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality		
(d)	Actual or potential levels of exploitation		
(e)	Effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites		
A2 Population reduction observed, estimated, inferred or suspected in the past where causes may not have ceased OR may not be understood OR may not be reversible, based on (a) to (e) under A1			
A3 Population reduction projected or suspected to be met in the future (up to a maximum of 100 years) based on (b) to (e) under A1			
A4 An observed, estimated, inferred, projected or suspected population reduction (up to a maximum of 100 years) where the time period must include both the past and the future, and where the causes of reduction may not have ceased OR may not be understood Or may not be reversible, based on (a) to (e) under A1			

B Geographic range size, and fragmentation, decline or fluctuations			
B1 Extent of occurrence (EOO)	<100 km^2	<5000 km^2	<20000 km^2
B2 Area of occupancy (AOO)	<10 km^2	<500 km^2	<2000 km^2
C Small population size and decline	<205	<2500	<10000
C1 An estimated continuing decline of at least:	25% in 3 yrs. or 1 generation	20% in 5 yrs. or 2 generations	10% on 10 yrs. or 3 generations
C2 A continuing decline AND (a) and /(b):			
(ai) Number of mature individuals in each subpopulation	<50	<250	<1000
(aii) % individuals in one subpopulations =	90-100%	95-100%	100%
(b) extreme fluctuations in the number of mature individuals			
D Very small population or very restricted distribution			
Number of mature individuals	<50	<250	D1 <1000 AND/OR
VU D2 Restricted AOO or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time			**D2** typically: AOO <20 km^2 or number of location ≤5
E Quantitative analysis of extinction risk (e.g., Population Viability Analysis) **To list**			
Indicating the probability of extinction in the wild to be:	≥50% in 10 yrs. or 3 generations (100 yrs. max)	≥20% in 20 years or 5 generations (100 yrs. max)	≥10% in 100 yrs.

The Red List is a globally recognised tool for setting priorities for conservation (Lamoreux et al. 2003, Rodrigues et al. 2006, Miller et al. 2007), yet it has a number of significant challenges both theoretical and practical (Robbirt et al. 2006, Skarpaas and Stabbetorp 2012). It is not the purpose of this study to criticise or defend the Red List merely to highlight some of the positive and negative aspects of it as it relates to this study. For instance, many conservationists still do not understand the difference between extinction risk and the definition of conservation priorities, and use the Red List to set conservation actions such as monitoring (Collen et al. 2016). There are many misconceptions regarding the Red List and its uses (Possingham et al. 2002). The Red List has unfortunately been used for purposes for which it was not designed, such as initiating conservation advocacy (Possingham et al. 2002), prescribing conservation actions for rehabilitation of wildlife, and prioritising species for conservation in a triage approach (Bottrill et al. 2008, Collen et al. 2016). One of the central criticisms is the use of extinction risk as opposed to rarity (Brummitt et al. 2015, Collen et al. 2016). Although rarity may not necessarily result in a high extinction risk, it has been omitted as a main measure in the Red List but is alluded to within the criteria. An example of species that are naturally rare and have very restricted ranges but can persist long-term, if anthropogenic climate change is not a factor, are the endemic species of the Fynbos Biome with their niche habitats (Linder 2008). However, it is recognised that climate change is a major factor making rare and endemic species more prone to extinction and that areas of high endemism and rarity may experience higher rates of extinction as threats (climate change, increased land cover change in response to population growth, pollution etc.) are more readily realised at a local scale (Joppa et al. 2013).

Collen et al. (2016) state that assessments are based on a range of information sources and that expert committees assign listings accordingly. Yet due to a lack of data the listings are still largely based on expert opinion and although probabilistic models, which are objective and measurable, have been developed to determine threat, they are not actively used in assessments. The use of these models in conjunction with the Red List criteria can strengthen the precision of the overall final status of a species (Robbirt et al. 2006). Nonetheless, this is often not done and the Red List criteria (Table 4.2) still rely on imprecise data to determine the extinction risk status of a species (Skarpaas and Stabbetorp 2012, Tomović et al. 2015, Collen et al. 2016). As a result of using expert opinion rather than empirical evidence the decisions made regarding the extinction risk status of a species can be inconsistent and subjective and have been taken up in a number of publications challenging the Red List (Willis et al. 2003, Vie et al. 2009, Wulff et al. 2013, Tomović et al. 2015).

The IUCN have acknowledged these short comings and future research into methods that can use poor and uncertain data has been called for in the literature (Brummitt et al. 2015, Collen et al. 2016).

Assessing species for extinction risk should precede the setting of conservation priorities and actions. Therefore, the Red List is only of use to protected areas like SANParks in that they can evaluate their performance towards global and regional conservation targets. It is not designed to provide a priority list for conservation monitoring and actions on the ground. Golding (2004) advocates that conservation actions should be set only in conjunction with social, logistical and cultural parameters, which are also noted in Chapter 5 when discussing in-field detection and monitoring in protected areas. Despite the lack of data and uncertainty regarding many species, the Red List is still one of the best tools available to conservation at present.

The Red List is an excellent resource for biodiversity conservation when used to inform legislative frameworks for species conservation and setting regional (and global) conservation targets (Collen et al. 2016). However, the use of the Red List criteria to assess species at a fine geographical scale is discouraged as the assessment of extinction risk using the current criteria becomes increasingly unreliable at a finer scale. As yet no specific lower geographical limit has been set and assessment depends on the nature of an area (regional or national) and in the case of more mobile (faunal) species, dispersal barriers. Robbirt et al. (2006) use herbarium data and probabilistic statistical models to look at species across Ecuador (regional scale), and found that species which had sufficient collection records had the best model results. Here, I test whether it may be possible to use herbarium and/or survey data as a means of assessing extinction risk at the local protected area scale.

4.1.2 Herbarium Collections

Herbarium collections are verifiable records of past distributions, providing spatial and temporal information of a species which can be empirically verified (Akmentins et al. 2011). The quality of data recorded and collected by the early botanical collectors is very detailed and through the development of collection protocols and standards, is today an easy systematic process to follow (Chapter 2). Present day collection trips are relatively less exhaustive and at times specifically focused on a particular topic or species. This has an impact on the overall number of collections and the quality of data recorded. A trait that all collectors across time appear to have is their attention to detail, both modern day botanists, and their early predecessors, capture/d the details of the species they were collecting with precision. However, the early botanical collectors were more opportunistic in their approach to collecting. They collected what they came across on their journeys and at a destination, they followed a very detailed methodology for specimen collection and this is something that is still required of modern day botanists.

The use of herbarium collections enables conservationists a broad scale view of threatened species localities and habitats. These collections are presence-only records that can be georeferenced for older collections when localities were recorded as narrative descriptions of the localities (Guo et al. 2008, Culley 2013) or GPS co-ordinates recorded for collections generally made after 1990. Researchers have used herbarium collections in numerous ways, for example to develop bioclimatic envelop models, map the spread of alien invader species (Lavoie et al. 2013), establish timelines on insect outbreaks (Lees et al. 2011), investigate pollination ecology (Pauw and Hawkins 2011) and measure and map the prevalence and distribution of plant diseases (Malmstrom et al. 2007). Willis et al. (2003) showed how certain information from herbarium specimens could be used to assess the threat status of flora using southern Africa plant species. Long-term data on species occurrences is in short supply (Triantis et al. 2010) and although it was found that specimen data better satisfied the distribution parameters of the IUCN criteria than demographic criteria (Golding 2004) their use has resulted in limited risk assessments.

There are limitations to using herbarium collections (Farnsworth and Ogurcak 2006) and aspects needing consideration include: collection effort (Wulff et al. 2013), whether collections are made routinely, randomly or opportunistically, and that only the presence not the absence of a species can be confirmed. Recently the number of herbarium specimens collected and stored has declined. A reason for the decline in plant specimen collection has been noted as the economic need to reduce costs (De Vos 2007) and has been highlighted in earlier chapters, and is a challenge to long-term data accumulation. The resources needed to conduct, process and store scientific collections are significant. The process is time consuming, demanding human capacity and a large storage space kept at specific conditions (Schepanek and Waller 1999).

4.1.3 Botanical Survey Data

The term botanical survey, in this study, refers to vegetation data obtained from formal surveys which do not have herbarium specimens associated with these data (Margocsy 2010). These data contain lists of species and locality information often with a description of the plant or a photograph. Identification of the species is done in the field. Henceforth botanical survey data will be referred to as survey data.

Over time the accumulation of survey data has vastly out stripped that of herbarium data acquisition (Lavoie 2013). Surveys are used to acquire botanical information at reduced field and administration costs when compared to the collection and storage of herbarium specimens. Survey data has been used in many ecological and environmental research projects, including establishing the fire regimes in the Fynbos Biome (Kraaij et al. 2013), understanding climate change impacts (Hannah et al. 2005) and in producing vegetation maps (Rutherford et al. 2012). Although not always in the same format, survey data has the benefit of being mostly available electronically. It can be formatted relatively easily to suit formulae, models and databases, and inform research and monitoring.

Survey datasets do not date back as far as herbarium collections, which date back to the early voyages of discovery discussed in Chapters 2 and 3 (circa 1597) and provide only a relatively recent short-term history and contemporary understanding of plant distribution. In generating survey data, field botanists tend to focus on species that are well known to them or have a high Red List status and often fail to record common, new or rarely known species (Garcillan and Ezcurra 2012). Botanical surveys are far more opportunistic than targeted herbarium collections and although a larger list of species may be generated from one survey it is often hard at times to verify these lists (Morrison-Saunders et al. 2001). As a result vegetative surveys may give an under-estimation of the plant richness of an area (Bowen 2002). The crux lies with the meta-data, as this is often not captured by amateur botanists or even some professional consultants doing botanical surveys, and can affect the scientific robustness of research, a core scientific principle which I highlighted earlier (Chapter 2) as a possible contribution of botany to scientific practice.

4.1.4 Extinction probability

Extinction can be defined as the irreparable loss of a species and conservationists work to avoid extinction wherever possible (Triantis et al. 2010). Extinction probability calculations provide conservationists with a priority list of species for management interventions to prevent the loss of certain species (Griffen and Drake 2008, Clements 2014). Extinction probabilities can be used in research to identify the most significant drivers and to take measures in relation to these external forces driving extinction. Extinction probability, therefore allows action both with respect to species and with respect to impact factors and drivers of change. This provides the possibility for protected areas to implement mitigation measures or to channel resources to save species through the establishment of seed banks, *ex situ* botanical collections and restoration plantings (Guerrant et al. 2004, Gotelli et al. 2012, Walters et al. 2013).

Extinction probability equations to predict species decline and extinction have been used since the 1960s (Robson and Whitlock 1964) and are continually being improved (Rivadeneira et al. 2009, Clements 2014). The basis of the equations is to look at the period of time since a species was last seen and the frequency at which it was seen before the most recent sighting, thereby inferring a period of time to extinction (Jaric and Ebenhard 2010) (Figure 4.1).

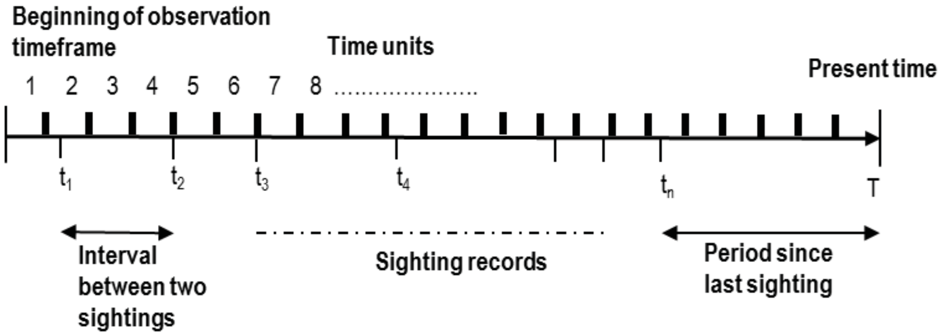

Figure 4.1. A diagrammatical representation of the observation timeframe, with the top of the line indicating time units (years) and the underside the sighting records (t_1, t_2, t_3,t_4….t_n). Adapted from Jaric & Ebenhart (2010).

The Optimal Linear Estimation (OLE) was first developed by Solow in 1993, and has been updated by many others since (Collen et al. 2010). This method provides a quantitative look at what is usually a qualitative process based on limited data. It is a nonparametric method enabling extinction dates to be estimated according to the distribution of the most recent sightings records and the observations are independent and randomly distributed through time (McInerny et al. 2006). This model assumes that sightings are constant over time and intensity does not vary, the basic statistical properties of this model have been explained in detail in numerous studies elsewhere (McCarthy 1998, McInerny et al. 2006, Rivadeneira et al. 2009).Although it has limitations, the original OLE equation is seen as the foundation when experimenting with new techniques and data to determine extinction dates and survival probability (Clements 2014). Few studies have tested the model on actual sightings data but rather on simulations, this study is a first for the data from the Fynbos Biome (Ludwig 1996, McInerny et al. 2006, Rivadeneira et al. 2009, Clements 2014).

$$p = \left(\frac{t_n}{T}\right)^n$$

p is the probability that a species has been recorded with *n* number of sightings, *t* the time of the last sighting and *T* the observation period. P-values indicate the probability that a species is still extant.

Very few species have adequate distribution data to analyse risk, as highlighted in Chapter 1, and thus predict time to extinction (Menges 2000), and this may result in misleading predictions of extinction risk (Clements 2014). In many cases protected areas do not have the resources to monitor all the species under their care including those that are listed as threatened and may require monitoring and evaluation (Rout et al. 2010). The Red List has succeeded in narrowing the global list of plant species needing conservation attention (Pimm et al. 2014), yet in places like Table Mountain National Park this list is still more than one hundred species across all taxa (Rebelo et al. 2011b).

My aim in this chapter is to determine the relative value of all herbarium collections and contemporary botanical surveys in predicting extinction of species in a protected area at present and into the future. This chapter therefore, analyses herbarium and surveys records in order to provide an evaluation of these two datasets (both singularly and combined) by using the Solow 1993 extinction probability equation to test the value of the herbarium and survey data in providing a priority list for protected area management to monitor.

4.2 Methods

4.2.1 Study Site

My study site for this section of work is the protected area of Table Mountain National Park, which runs north (33° 54’ S, 18° 24’ E) to south (34° 21’ S, 18° 29’ E) along the Cape Peninsula in South Africa. The Park is currently approximately 25,000 ha (20,700 ha are declared and 4,300 ha are in the process of being declared). The Park is bordered by the Atlantic Ocean along the western and southern sides and the metropolitan areas of the City of Cape Town on the eastern and northern sides. The Table Mountain National Park falls within the CFR which is the smallest in size of the world’s six floral regions, but contains approximately 9,600 plant species of which some 70% (6,200) are endemic to the CFR (Cowling et al. 1996, Linder 2005). The Cape Peninsula comprises three major vegetation types including predominant Cape Fynbos shrublands; rare Renosterveld shrublands with associated grasslands; and patches of forest and thicket (Rebelo et al. 2006). Table Mountain National Park experiences a fire-prone Mediterranean-type climate, characterised typically by cool, wet winters and warm, dry summers (Cowling et al. 1996, Cowling et al. 2005). Rainfall varies geographically over the relatively small area with some localities receiving as little as 400 mm of rain a year, while other areas receive as much as 2 270 mm a year. Conservation of the natural areas on the Cape Peninsula was first legally recognised in 1983 when the entire area above the 152 m contour line was delineated from the urban environment under the Environmental Conservation Act of 1982 (Swanepoel 2013). The area was problematic to manage with 14 different public entities and 174 private land owners having to work together and a Management Advisory Committee was formed. In 1989 the Cape Peninsula Protected Natural Environment (CPPNE) was established with management falling to the provincial authorities. The CPPNE provided weak legal protection for the environment and in 1994 it was recommend that the CPPNE become a protected area under the management of South Africa National Parks (Daitz and Myrdal 2009). The Cape Peninsula National Park was declared in 1998 and in 2004 its name changed to the Table Mountain National Park.

Situated immediately adjacent to the key harbour and landing point for colonial supply ships and botanical expeditions, the Table Mountain National Park has a rich history of botanical collections which I have highlighted in Chapters 2 and 3 of this thesis. Presently the metropolitan area of Cape Town is home to over four million people and has four well recognised universities within a 60 km radius from the Table Mountain National Park. Botanical surveys and research are frequently conducted on the Cape Peninsula resulting in a potentially large number of available botanical records.

4.2.2 Data Used

I used datasets from the South African National Biodiversity Institute (SANBI) for herbarium and survey data as these were the largest collated datasets available at the time of this study. Herbarium data were selected for the period 1600 to 2014. The Vegetation Distribution dataset, is a compilation of datasets of vegetation surveys used for the purposes of developing the South Africa Vegetation Map (Rutherford et al. 2012). The oldest survey dataset was the Acocks veld type data of 1953 (Acocks 1988). Botanical survey data were used as a mirror against which to compare the usefulness of the herbarium data when tested with an extinction probability equation. These data were sorted according to geographic quarter degree grid cells which occur within the National Park, or in which part of the Park may occur. The plant records for Table Mountain National Park only were extracted for analysis. The list I developed consisted of all plant species and included their IUCN Red List status as of 2013. Both datasets were checked for grammatical errors particularly with regards to the botanical name, locality and the date of collection for each record. These data were sorted taxonomically according to family, genus and species and all plant species names were updated according to the latest South Africa Plants species index. Alien plants and introduced species were removed from the working datasets. Extra information in the databases regarding collectors name, habitat notes and collection codes were removed for running of the extinction probability equation. There were many duplicate records (records of the same species on the same day, specimens with the same taxonomic identity, collection date, collector and number), and these records were removed from the dataset. Once cleaned and sorted data were merged to form a combined dataset of herbarium and survey sighting records.

Fynbos is associated with three main taxonomic families; Proteaceae, Ericacea and Restionaceae (Cowling et al. 1997). A large number of individual species of the family Fabaceae are known to occur in the fynbos due to the fact that it is a fire prone system (Cowling and Holmes 1992) and therefore the Fabaceae were included in this study. Only these four families were used in the analysis, all records for these families were extracted regardless of Red List status and all records identified to species level retained in the dataset. Lastly, the datasets were sorted into four groups for analysis according to their Red List status (Table 4.3). The Red List categories are grouped according to how they are currently prioritised for monitoring in the Park (Rebelo et al. 2011b). Group 1 is given the highest priority, with Group 3 and 4 currently not monitored at all.

Table 4.3. Grouping of selected fynbos families according to Red List status

Group Number	*Red List categories*
Group 1	Critical Presumed Extinct (CR PE), Critically Rare, Rare
Group 2	Critically Endangered (CR), Endangered (EN), Vulnerable (VU)
Group 3	Near Threatened (NT), Data Deficient (DDD)
Group 4	Least Concern (LC)

4.2.3 Data analysis

The Solow (1993) extinction probability equation used assumes a constant rate of sightings or in the case of herbarium specimens, constant collection effort. To validate whether the data met the assumption, sightings records were arranged in chronological order for each dataset. Analyses were run for the individual herbarium and survey datasets respectively and the combined dataset of the herbarium and survey data. To test the predictive validity of Solow's (1993) extinction probability calculation on the species in Table Mountain National Park, I extracted all sightings data up to a specified year in the past to allow a run of a number of years (e.g. 35 years= 1980). A major Biome wide project was initiated in 1977 to study all ecological aspects of the Fynbos Biome (Van Wilgen 2009). This resulted in a mass of fieldwork, collections and publications on the fynbos, which has to-date not been repeated, hence the year 1980 was chosen for the analysis. This is termed the 'stop date' for back testing. Solow's 1993 model was run on the extracted data and I selected the survival probability for each species at the selected stop date. I then assessed the strength of the relationship between the survival probabilities generated and the actual sightings history in the period after the stop date. This procedure effectively uses an initial portion of data (e.g. up to the chosen stop date) to generate survival probabilities and predicted extinction years for each species at that date (i.e. 1980). It then uses the remaining data (i.e. after 1980) to test the accuracy of those predictions. To test for model accuracy I looked for a correlation between survival probabilities and sightings after the stop date. A good model requires that species with lower survival probabilities (or earlier extinction times) receive fewer sightings in the follow-up period after the stop date. The presence of a positive correlation is sought between good survival probability and positive sightings, or poor survival probability and fewer sightings. I then grouped species into two classes depending on whether these were seen at all in the follow up period, or not. A good model requires that mean survival probabilities should be lower, and mean extinction times earlier, in the class of species that were not seen again after the stop date. I used the stop date of 1980 to test the sensitivity of my conclusions.

As an additional test, I assessed whether there was a relationship between status on the IUCN Red List and modelled survival probabilities at three random time points (1995, 2000, and 2005).

4.3 Results

4.3.1 Solow 1993 and back testing

There was a total of 8463 herbarium records for individual species (1629 for the selected families) in Table Mountain National Park and 58 468 survey records (32 762 for the selected families). These survey data had many records with misspelt species names and taxon authors and this required substantial effort to sort and correct before analysis could be done. Both datasets had to be compared with the latest taxonomic revision lists as they were often inconsistent with the latest published species names. The herbarium data did not perform well as it was too patchy to be of use on its own, with empty spaces in the result tables and small sample sizes, particularly when splitting by family, therefore it was abandoned as an entity on its own.

Results for the back testing are shown in Tables 4.4 and 4.5 below. Mean survival probabilities (MSPs) are lower in the group of species not sighted after the stop date, of 1980. A positive association exists between MSPs obtained from Solow (1993) and the number of post-stop date sightings. It was observed that there are many non-significant and occasional significant results and some positive associations are observed at the species level. The expected extinction year validated extremely poorly when tested. In most cases the predicted extinction year was earlier in the group of species that was sighted again, and this difference was on occasion significant. There are little or no differences between the conclusions drawn with the survey data and those drawn from the combined survey-plus-herbarium data. A possible reason is that by taking all data prior to the stop date, one is including a very long period of time (>100 years), over which the assumption of constant collection effort cannot possibly hold.

Table 4.4. Survival probabilities and expected extinction years obtained from Solow (1993) using survey data only. NSA = not sighted again, SA = sighted again. *** = p<0.001, ** = p<0.01, * = p<0.05.

				Survival probability				**Expected extinction year**			
Stop date for back testing	Family	N in NSA group	N in SA group	Cor	Mean in NSA group	Mean in SA group	p	Cor	Mean in NSA group	Mean in SA group	p
1980	ALL	40	240	0.16**	0.37	0.54	0.02	0.02	1993	1990	0.25
1980	ERICACEAE	10	86	0.29**	0.34	0.49	0.55	-0.09	1993	1988	0.19
1980	FABACEAE	24	75	0.22*	0.37	0.49	0.19	-0.03	1992	1989	0.71
1980	PROTEACEAE	1	33	0.48**	-	-	-	-0.02	-	-	-
1980	RESTIONACEAE	5	46	0.42**	0.45	0.72	0.02	-0.09	1999	1995	0.26

Table 4.5. Survival probabilities and expected extinction years obtained from Solow (1993) using combined herbarium and survey data. NSA = not sighted again, SA = sighted again. *** = p<0.001, ** = p<0.01, * = p<0.05.

				Survival probability				Expected extinction year			
Stop date for back testing	Family	N in NSA group	N in SA group	Cor	Mean in NSA group	Mean in SA group	p	Cor	Mean in NSA group	Mean in SA group	p
1980	ALL	43	244	0.16**	0.30	0.52	0.00	0.05	1986	1989	0.78
1980	ERICACEAE	10	87	0.31**	0.30	0.46	0.41	-0.01	1986	1986	0.17
1980	FABACEAE	27	75	0.28**	0.27	0.47	0.02	0.11	1982	1988	0.13
1980	PROTEACEAE	1	34	0.48**	-	-	-	-0.04	-	-	-
1980	RESTIONACEAE	5	48	0.42**	0.45	0.71	0.04	-0.10	2000	1996	0.29

4.3.2 Correlations with Red List groupings

Mean survival probabilities for the survey and combined herbarium and survey data in each IUCN grouping are shown in Table 4.6 and Table 4.7 respectively, with standard errors given in parentheses. Mean survival probabilities are lowest for species in the ‘least concern’ Group number 4 (which should in theory be most abundant), but in general there is little differentiation between the groups. It can be seen that the average survival probabilities decrease over time much faster for species in Group 3 than for any other group with a decrease of 0.18 from 1995 to 2005, compared to 0.08 for Group 4, 0.06 for Group 2 and 0.05 for Group 1 in Table 4.6. Table 4.7 shows the same trend with Group 3 decreasing faster than the other groups from 1995 to 2005; Group 3 is 0.16, compared to 0.08 for Group 4, 0.06 for Group 2 and 0.05 for Group 1.

Table 4.6. Red List correlations for the survey dataset

		Mean survival probability (std error)		
Red list group	n	1995	2000	2005
Group 1 (CR PE, Rare)	24	0.89 (0.06)	0.86 (0.07)	0.84 (0.07)
Group 2 (CR, EN, VU)	56	0.81 (0.05)	0.80 (0.05)	0.75 (0.05)
Group 3 (NT, DDD)	20	0.94 (0.05)	0.88 (0.06)	0.76 (0.08)
Group 4 (LC)	225	0.80 (0.02)	0.78 (0.03)	0.72 (0.03)

Table 4.7. Red List correlations for the combined dataset

		Mean survival probability (std error)		
Red list group	n	1995	2000	2005
Group 1 (CR PE, Rare)	24	0.89 (0.06)	0.86 (0.07)	0.84 (0.07)
Group 2 (CR, EN, VU)	56	0.79 (0.05)	0.78 (0.05)	0.73 (0.06)
Group 3 (NT, DDD)	20	0.95 (0.05)	0.89 (0.06)	0.79 (0.07)
Group 4 (LC)	225	0.78 (0.03)	0.75 (0.03)	0.70 (0.02)

4.4 Discussion

My results show that herbarium and survey records cannot be used for monitoring and management by SANParks staff to immediately and conclusively draw a priority list of species, as there are insufficient sightings data in both datasets. This mirrors results found by Chong et al (2012) that the models are fraught with errors if the data used in very sparse. The results clearly show that, in the case of plant species data for Table Mountain National Park, herbarium data cannot be used on its own to reliably identify at-risk species as the records are not constant, this was also found to be the case in a study by Caley and Barry in 2014. The additional survey data allowed for the extinction probability to be run but results were still poor. Solow (1993) relates extinction in relation to number of sightings, low probabilities show a population decline or extinction, especially if there are a high number of sightings in the initial period and few thereafter. This result can be seen when using the stop date of 1980. An atlassing project, The Protea Atlas Project, was initiated and completed from 1991 to 2001, to bolster the few sighting records of protea species prior to this. The role of research interests and funding commitments is evident here as sightings records were constant for a period of time while there was interest and funding. However, there were then less sightings after 2001 hence the equation results shows some positive associations. The results may also be a product of these data and the sporadic sightings records captured in the SANBI datasets (Caley and Barry 2014). The results from this study as to the performance of the Solow 1993 probabilistic model are that, given adequate collection data, it could be used to infer threat and decline of species in Table Mountain National Park. Further, the performance of other extinction probability equations, though less generally agreed on as useful (Rivadeneira et al. 2009, Caley and Barry 2014) and therefore not used here, may generate different results. A different equation may work better in relation to the high biodiversity found in Table Mountain National Park or with an increased number of sighting records should more survey records be made available, such as in-field detection surveys done in Chapter 5. Some of the probabilistic models which may yield better results include; Burgman (Burgman et al. 1995), Partial Solow (McCarthy 1998), Solow/Roberts (Solow and Roberts 2003) and Sighting Rate (McInerny et al. 2006).

There is also clearly little in the way of a meaningful relationship between IUCN status and mean survival probability of species within Table Mountain National Park. Group 4 (Least Concern) had the lowest mean survival probability for both data sets, which seems counterintuitive, but is possibly explained by the fact that some of these species are not actively sought out or recorded by field botanists and collections of the more ‘common’ species are not kept by herbaria (Willis et al. 2003, Rivers et al. 2011). As a result the information on these species is very sparse and provides a false impression that these species are not being seen and may be declining (Garcillan and Ezcurra 2012). This is a potentially serious problem as the tendency to collect threatened and rare species leads to overrepresentation of the species in collections and databases and creates bias in extinction risk assessments that use these data. This may indeed be the situation in my study where Least Concern, Near Threatened and Data Deficient species appear to be declining faster than highly threatened species as they are not collected or recorded (Tables 4.6 and 4.7). Ground truthing is required to validate whether this is indeed the case.

Conservation targets are often set using the Red List status of species, research and monitoring efforts are focussed on these species and funding is usually linked to these targets too. Herbarium collections and data are thus only updated for a few select species, once again biasing data towards presumed threatened species. I have shown that the well-recognised method of determining extinction probability does not work in the real world with such poor data. It has potential for use to maximise diversity at the local scale but requires significant data input to aid protected areas (and small geographic areas) in accurately determining the threat status of species under their custodianship.

The assignment of threat status by the IUCN Red List is varied and subjective due to the lack of sufficient data on many species (Robbirt et al. 2006, Skarpaas and Stabbetorp 2012). Yet long-term population monitoring is costly and laborious (Tomović et al. 2015) and at times impractical across an entire region. The chronic lack of data means that at the protected area scale the Red List status of species cannot be used to infer extinction risk. Adequate data is required to inform probabilistic equations to determine extinction risk and prioritise threats. In-field surveys need to be undertaken to ascertain whether species in Table Mountain National Park are indeed at risk of extinction regardless of their current Red List status. Building on the depth of historic collections made by early botanists, which I provide a detailed history for the Agulhas Plain in the Cape Colony (in Chapter 3), as an example of the collection effort, it is clear that continued field collecting should to take place. This will continue to build on the long-term data already in herbaria for use now and into the future. The results of this study and the in-field surveys can then be useful in strengthening the Red List assessments at the global, regional and local scales.

The severe lack of data mentioned above can be seen in the results of the probabilistic analyses, which suggest that the majority of the species in the families tested have gone extinct in Table Mountain National Park. The *p-values* for most species were small suggesting that they are close to extinction. The *p-values* are based on an assumed constant collection rate and low values are because of a decline in the rate of collections or sightings over time and not necessarily the difficulty in finding the species over time (decline in numbers). Once again this may be the case with Proteaceae as the Protea Atlas Project, which took place in the 1990s, and saw the publication of a field guide that is used extensively. Little additional information has been collected since then as researchers and botanists rely on the Protea Atlas data and only a few records of the Red Listed or rare species are now captured. So although the protea species are being seen in the wild they are not being collected or recorded on databases where they can be used in extinction probability models as up-to-date sightings records.

As has been stated previously in this chapter and Chapter 1, protected areas are the foremost tool in seeking to reduce the continued loss of rare and threatened species. Although protected areas have been able to conserve a large percentage of biodiversity hotspots it is necessary to assess if, in the long-term, they are adequately preventing loss of biodiversity and species extinctions in the borders (Kuper et al. 2004, Sutherland et al. 2011). I acknowledge that there are imperfections in these data used and this could be attributed to the species rich ecosystems and the high percentage of Red List species in Table Mountain National Park, with only a few of the species targeted, captured and/or recorded on the SANBI database (Droissart et al. 2012). This is an artefact of human collecting, where particular species or places are favoured by collectors resulting in collection rather than systematic surveying, as became evident in explaining the narrations and collections of early botanical collectors (Chapter 3), with only certain species being collected over time. In a high biodiversity rich area many species are over looked as ‘common’ or are not detected, as discussed in Chapter 5, where I show the value of returning again to an original geographical area as site-specific information informs excellent in-field detection. Similarly species that are considered ‘difficult’ to identify such as grasses and members of the restionaceae are often overlooked, as well as species that are large and hard to collect and preserve as herbarium specimens. Furthermore, it is known that collectors have different interests and purposes, often collecting samples and data both systematically and /or opportunistically (Burgman et al. 1995, Moerman and Estabrook 2006). Numerous survey records exist regarding surveys on the Cape Peninsula completed by students, botanical consultants and amateur botanical collectors. However, they are not on the central SANBI database and thus are not easily accessible and useful to conservation. The datasets that are available are noisy, incomplete and not readily usable for this kind of analysis which limits the kind of exploration and research that could be conducted.

While my results using the equation show that most species in Table Mountain National Park are either extinct or will be shortly, this cannot be verified by using extinction probability models alone since the models rely on poor data and all data on these species remains inaccessible and untested. It must also be noted that Table Mountain National Park has a high number of narrow range endemic species, intrinsically rather than extrinsically rare species (Helme and Trinder-Smith 2005, Linder 2005, Rebelo et al. 2011b). Concomitantly, herbarium collections are no longer increasing due to limited funds and space. Rare and threatened species tend to be favoured by collectors, funders, and herbaria have over representative samples of these species. The lack of records and completeness of existing datasets, clear curation and the lack of ongoing systematic recording is a major problem. A standardized format for both herbarium and survey data, including standardised meta-data files, which can be uploaded electronically, updated and used with relative ease and speed will increase the usability of these datasets (Rhoads and Thompson 1992, Haripersaud et al. 2010). It should also be a regulated requirement that researchers conducting surveys collect a herbarium specimen, to be verified and stored for future use. This will allow for the use of probability equations to determine at-risk species and add to the biodiversity knowledge-base (Chapman 2005). The use of the Red List status on its own is not suitable as a means of setting monitoring targets, given the uncertainty as to which species, how large the populations are and where they are located within a protected areas. Sole reliance on the Red List of species for conservation priority and monitoring should be phased out and alternate dual methods found. My methods are by no means intended as an alternative to existing IUCN Red List assessment procedures but rather to strengthen and augment them and give a greater understanding of the threats to species within protected areas and the need to monitor certain priority species with the resources available in protected areas.

4.5 Conclusion

The number of sightings records of current plant data is insufficient to address conservation concerns at the finer scales required by protected areas. The limitations of using a database with few records in extinction probability equations are, that it is often a few well collected species that show accurate results, with the majority of species being under collected and giving false readings (Park 2012). Research to find species that have not been seen in a long time period or that are listed as Data Deficient should be made a priority for conservation in general. There is no substitute for fieldwork and this needs to continue and be supported with people in the field observing and collecting data. From the evidence presented here and in Chapters 2 and 3, it can be seen that botanical collections have gone from a period of very intense engagement and collecting to a serious decrease of effort in more recent times. This reduction of recent collection effort is attributed to a lack of funding and support for in-field work, but also the perceived notion that data is readily available for all species. This chapter shows a clear lack of extensive robust and well curated data illustrating this perception to be false in Table Mountain National Park. The collation and curation of all biodiversity data requires improvement if it is to benefit conservation, it may even be a requirement to make the submission of survey data a legal obligation to ensure that the data is captured for future use.

I also recommend that a national initiative be developed to collate and store all botanical survey data with meta-data, in a standard format that is updated with species status and taxonomy. This could possibly be an online submission of data, making it more attractive to researchers both submitting and accessing the data. The protocols for the maintenance of data should follow those of herbaria to align the two datasets and ensure survey data follows the same strict and rigorous regime as herbarium records. Predicting extinctions is an important aspect in conservation planning and management (Hedenas et al. 2002) and determining if species are extinct or extant within a protected area has funding and policy implications (Wilcove 2005). Sightings records alone cannot accurately say whether a species is extant or extinct. The results of the extinction probability equation when considered in isolation provide a bleak view and to determine whether species are indeed in decline in Table Mountain National Park. Field detection and verification is required (Krupnick et al. 2009)as Table Mountain National Park is home to many narrow range endemics which can affect the sightings records as well as the fact that they may already be affected by climate change, particularly montane species which have migrated to the highest possible habitats. In the following chapter I use the combined dataset of herbarium and survey records to undertake in-field detection of species subpopulations within Table Mountain National Park, to determine the accuracy of the probability equations with what is actually the case on the ground.

CHAPTER 5: The validity of extinction probability in the field: Implications for monitoring and management.

Prologue

This chapter takes the results of the Solow 1993 extinction probability equation used in the previous chapter to generate extinction dates and validates them with regard to in-field searches for subpopulations of target plant species in Table Mountain National Park. The need to conduct in-field monitoring is an inherent part of the work required by conservationists and protected areas. Protected area staff around the world are required to fulfil many duties in their jobs, often with very restrictive budgets. In order to guarantee that in-field surveys and monitoring is performed within these constraints, monitoring techniques used should be cost effective and efficient while still being robust to provide scientific data to inform decision making. To achieve this I adapted in-field detection methods used in other studies on rare and cryptic plant species that would fulfil the needs of protected area staff, to be economic, efficient and effective anywhere in the world.

5.1 Introduction

It has been recognised in this study that there is an urgent need to develop new systems for monitoring to get a clearer picture of biodiversity loss through detailed, quantitative changes in the dynamics of habitats and populations (Balmford et al. 2003). Biodiversity is like a brick wall, each species is a brick and as species are lost so the bricks begin to fall out the wall, until the whole wall crumbles and it ceases to function. Numerous studies have found that biodiversity plays a bigger role in ecosystem functioning than previously thought (Broszeit et al. 2017, Pinho et al. 2017, Pollock et al. 2017, Schmeller et al. 2017). Plants are complex organisms and as important as the most charismatic animals. Without plants to convert the sun’s energy into food, life would cease to exist, and the biodiversity wall will fail (Weisser et al. 2017). Yet floral species are being lost faster than they can be saved, as they sit on the precipice of extinction and time is running out to deal with the myriad of threats they face (Tilman et al. 1994, Tilman et al. 1997, Hanski 2000, Hanski and Ovaskainen 2002). The establishment of protected areas as one of the main mechanisms used to combat the loss of species has been discussed in this study in Chapters 1 and 4, where I highlight the benefits to conservation of protected areas. In Chapter 4, I elaborated one of the greatest challenges faced by protected areas that with so many species under threat, management urgently needs to prioritise which to target and monitor at a fine scale. However, until it is known what is currently happening to species on the ground this is a futile exercise. A means to do this is to determine the extinction risk for each species and prioritise according to which is most at risk of being lost, this I attempted in Chapter 4, using extinction probability to calculate risk. A note of caution needs to be introduced as assigned conservation status has major repercussions for conservation and implications for management; the wrong action and a species may actually go extinct (Rivadeneira et al. 2009, Chong et al. 2012, Pimm et al. 2014). Providing an area with protection status and managers with a list of species occurring in a protected area may not prevent the loss and extinction of a species, on-the-ground actions need to take place too (Kingsland 2002, Mora and Sale 2011, De Palma et al. 2017). With this in mind protected areas require not only a list of species but one that is prioritised and can be used to make informed management decisions with associated implementable actions. Management actions include monitoring but also relate to rehabilitation of a habitat or system, restoration of a species to an area and attending to threats by for example clearing of invasive alien species. Rehabilitation and restoration actions are guided by the New International Standards for the Practice of Ecological Restoration (McDonald et al. 2016). However these actions are beyond the scope of my study where my focus is the first management action of monitoring of species within protected areas. Many international strategies and plans have been developed to help in this process of identifying and prioritising species for management attention and action (Callmander et al. 2005, IUCN 2012b).

One of the international strategies for species conservation is the Global Strategy for Plant Conservation (GSPC) the objective of the GSPC is to ensure long-term survival of floral species. This strategy was developed through international collaboration and approved in the 6th meeting of the Conference of Parties (COP) to the Convention on Biological Diversity (CBD) in 2002 (UNEP 2002, Balmford et al. 2005). A specific target exists in the Convention to reduce extinction risk. The South African government has been a signatory of, and Party to, the CBD since 1995 (Crouch and Smith 2011). It has since enabled a series of conservation acts and regulations that rely mainly on protected areas to achieve the conservation goals for the country. The National Environmental Management: Biodiversity Act (NEMBA) requires monitoring of South Africas biodiversity assets and the National Environmental Management: Protected Areas Act (NEMPAA) requires that SANParks conduct this monitoring (Sections 50, 1-3). SANParks is thus required to monitor and report on progress towards strengthening South Africa's protected area estate and the conservation status of threatened biomes, vegetation types and species.

In order to implement efficient conservation management strategies, protected areas personnel need to understand the distribution and threats to species within their borders. This will enable them to target the species most likely to go extinct and allocate resources for maximum returns (Farnsworth and Ogurcak 2006, Rout et al. 2010). Within a protected area a metapopulation of a species consists of subpopulations (Hanski 1998). Conservation management actions aim to reduce the extinction risk of a species, yet no actions can be taken without knowing where the subpopulations occur and what their threats are in order to conserve the integrity of the metapopulation. The spatial resolution of current plant data are insufficient to address conservation concerns at the scale required, because of an absence of empirical data for many plant populations (Gonzalez et al. 2010). A lack of compatibility of existing datasets, which I highlight in Chapter 4, is also a serious hindrance to conservation (Pereira and Cooper 2006, Joppa et al. 2013). Even though the CFR has a high proportion of endemic and niche plant species (Pressey et al. 2003, Linder et al. 2012), SANParks managers have little fine scale data available to them to support management actions pertaining to indigenous plant species in this region (Cowling et al. 1994). This results in a total reliance of protected area managers on the IUCN Red List to provide extinction risk of species and priorities for action. The listing of many plant species as threatened is a powerful argument that the conservation of plants warrants attention. There is a perceived need to use the Red List as a measure of protected area performance and managers are asked to show results on all Red Listed species under their custodianship, as highlighted in Chapters 1 and 4, where I discuss the relevance of monitoring to inform protected area assessments. The developers and supporters of the Red List highlight that this thinking is dangerous (Collen et al. 2016) and not what the Red List is intended for. This places pressure on conservationists to ensure all these species are monitored and conserved, a task which is near impossible for Table Mountain National Park with 544 plant species listed on the IUCN Red List alone. However misguided currently the Park manages to monitor only a handful of species with a Critically Endangered, Endangered and Vulnerable status. This is because the Red List is at times the only tool readily available to conservationists for identifying species with a high likelihood of going extinct in the face of the numerous and growing threats to plant species. These threats include for example, the current climate change predictions of mass extinction of species (Barnosky et al. 2011) if species are unable to move to cooler elevations (Pecl et al. 2017).

As in the example above, the current understanding of climate change is that it will become one of the main drivers of biodiversity loss globally (Thomas et al. 2004, Heller and Zavaleta 2009) and this is highlighted locally by the work in Table Mountain National Park by Slingsby et al. (2017), yet it has still to be factored into extinction risk predictions for many species. An immediate threat is the current human population growth and the expected escalation in consumption of a larger human population (Ceballos et al. 2017, Crist et al. 2017, Tilman et al. 2017). The IUCN extinction risk is generated at a global or regional scale and generally not for an individual protected area, which is discussed in the Chapters 1 and 4. As conservation management is responsible for ensuring that species do not go extinct within their particular protected area, the Red List as a conservation tool for monitoring is of limited use given the scale at which it is generated (global and regional). The Red List also takes a precautionary approach in the assessment of whether a species will go extinct and is known to over-list species (Mace et al. 2008). This results in something of a ‘cry-wolf’ scenario with the generation of large lists of species requiring monitoring. Thus by using the Red List to determine a list of species to monitor, considerable pressure is put on protected areas to take action. Similar to the Red List but on a much more local scale, the use of historic data to assess threats and provide a probability of survival in the future (Lee and Jetz 2011) is a first important step in determining which species require urgent attention within the specific confines of a protected area (Collen et al. 2016). A common error is in stopping at the past data assessment (Red List assessment) and not ground-truthing what is happening within individual protected areas at a finer scale. The combination of herbarium and survey datasets could make a powerful contribution to the locating and study of species in the field (Thompson et al. 2013).

The purpose of this chapter is to validate the results of an extinction probability analysis on herbarium and survey data from Chapter 4 by ground-truthing species subpopulations with in-field surveys. In order to examine the robustness of the extinction probability equation results, in-field testing was undertaken using detection methodologies adapted for rare and cryptic plant species (Kery and Schmidt 2008, Alexander et al. 2012). I locate subpopulations of 74 plant species using the in-field detection methods, to validate whether species are still extant or whether their predicted extinction dates (Chapter 4) hold true in the Table Mountain National Park. My results could also minimise future errors in monitoring species that are not at-risk, reduce costs spent on extensive surveys and produce realistic priority lists for protected areas.

5.1.1 The extinction probability and in-field detection

Herbarium collections are large, time-sensitive records, currently underutilised by protected areas and have increasingly been identified around the world as having significant value beyond simple taxonomic purposes, such as the role played by collection in influencing science and the possible continued learning from biocultural heritage sites explained in earlier chapters. Botanical survey data are data from formal vegetation surveys that do not have a herbarium specimen collected with data. Survey data are increasingly being used to assess ecological and conservation management questions, yet they are only used in a few cases in the IUCN Red List assessments (Brummitt et al. 2015). Chapter 4 looked at combining these two datasets, the longer term temporal datasets offered by herbarium collections and the botanical survey datasets, to determine the potential to illustrate the probability of persistence of floral species in a protected area. Recent scholarship looking at extinction probability equations using sightings records have produced mixed reviews of the applicability of the types of data used (Solow and Roberts 2003, Solow 2005, Ungricht et al. 2005, Hamer et al. 2009, Chong et al. 2012). Support from this wide range of authors to test various datasets with extinction probability equations is evident in the literature. Both herbarium and survey data as proposed in this study have rarely been tested on species that are thought to still be extant but may be declining. The testing of extinction probability equations has generally focussed on finding the date of extinction of a species already thought to be extinct (McInerny et al. 2006). The use of extinction probability equations is widely advocated in the literature and a case is made for the worth of these extinction probability equations to conservation (Rivadeneira et al. 2009, Jaric and Ebenhard 2010, Gotelli et al. 2012, Caley and Barry 2014). Using extinction probabilities to predict extinction as a proactive means of informing conservation has been investigated by a few studies (Ungricht et al. 2005, Clements 2014) but has yet to be fully investigated in the Fynbos Biome.

There is a need to establish in-field methods to validate extinction probability results from desktop studies (Clements 2014), including the work done in Chapter 4. The results from the use of the Solow 1993 extinction probability equations show a decline across all the plant families tested (Proteaceae, Ericaceae, Restionaceae and Fabaceae). Assuming that extinction probability predictions are to be adopted by protected area managers with a suitable degree of confidence, a species that is predicted to be extant (or extinct) needs to be detected (or not) and the predictions verified. Balmford (2003) promotes properly planned sampling systems that are carefully stratified across space, time and species. In-field detection addresses the concerns that locality data contains biases and gaps which could result in the monitoring of incorrect species and incorrectly declaring a species extinct or extant in a protected area (Funk and Richardson 2002, Moerman and Estabrook 2006, Crawford and Hoagland 2009). Protected area managers can then be informed of the current status of plant species in their protected areas. This can be taken a step further and the species information can be used to assess the long-term trends of the vegetative ecosystems in their protected areas for planning purposes (Linder 2005). Limited budgets are a common challenge in protected area management in the current economic climate (MacKenzie and Royle 2005, Thompson et al. 2011, Carbutt and Goodman 2013) and are particularly problematic for conservation monitoring programmes faced with large numbers of endemic and threatened species (Thompson et al. 2011). For accurate decision-making reliable field data is essential to protected areas (Alexander et al. 2012). Good predictions of extinction validated by accurate in-field surveys will save time, effort and costs in the long run.

The detectability of a species is the probability that it will be found whilst undertaking a survey and its presence verified. There are many factors which affect the detectability of a species, some can be anticipated such as the method used to detect the target species, and frequency of field visits and the time spent searching for the species (Tingley & Beissinger 2009). However, there are factors such as weather, terrain and wildfires that cannot be controlled and can have a serious impact on detecting a species in the wild to ascertain whether it is indeed extinct or matches its predicted status. Detectability also depends on the season of the search where plants may be in a vegetative state only and hard to identify, geophytes may be dormant below the ground, or only the seeds remain of an annual species and have yet to germinate (Brummitt et al. 2015). This can increase costs if repeat visits are required to sites in search of species. To mitigate costs and repeat sampling, field visits should be conducted during the peak flowering or growth time of the target species (Kery et al. 2006). Kery et al. (2006) suggest the minimum sampling effort for ‘easy’ to detect species such as large trees, shrubs or species that flower prolifically as 1.65 visits. For difficult to detect species such as cryptic and rare species, the recommended number of visits is 2.2. Cryptic or rare species are often missed as a result of their, at times reduced density, distribution, and visibility (Robbirt et al. 2006). Fynbos has a high percentage of rare and difficult to identify species and these are often overlooked, thus forcing an increase in detection efforts and associated costs (McInerny et al. 2006). To reduce effort and associated costs of field sampling (Lughadha et al. 2005), methods have been used that survey only known localities (MacKenzie and Royle 2005, Chong et al. 2012) and subpopulations then used as proxies to inform conservationists of the effects of threats to a species. This reduces the time and money spent searching for new localities of species. Once the effects of threats to the subpopulations of species within an area are known, the species can be prioritised as to which requires monitoring or active management to prevent loss. If additional funding or capacity is available, surveys to find new populations can be initiated, here volunteers and citizen science can be used. An example of a successful volunteer programme involving citizen scientists is the California Native Plant Society and its contribution to long-term surveys. Thus narrowing the list of species requiring monitoring in a protected area. The poor extinction probability results from Chapter 4 show that there is no escape from the need to do in-field surveys and monitoring to determine what the real-time situation of species in the wild is. As illustrated in Chapters 2 and 3 fieldwork also increases the amount of collection data, such as the early botanists who built up the herbarium collections from field expeditions, making the current use of such data easier and possibly results like the extinction probability equations more reliable.

5.2 Methods

5.2.1 Study site

Table Mountain National Park is approximately 25 000 ha and is situated on the Cape Peninsula with Signal Hill in the north (33° 54’ S, 18° 24’ E) and Cape Point in the south (34° 21’ S, 18° 29’ E). The vegetation of the protected area consists of fynbos with a small percentage of Afromontane forest and coastal dune veld (Moll et al. 1984, Cowling and Holmes 1992). Table Mountain National Park has fire-adapted vegetation consisting, namely of the fynbos (86%) and renosterveld (3.6%) with the remaining 10.4% of vegetation being non-fire dependant (Forsyth and Bridgett 2004). Historically natural wildfires took place from November to March, the summer season in the southern hemisphere (Van Wilgen and Richardson 1985).

5.2.2 Study species

I used the results of an extinction probability equation tested in Chapter 4 of this thesis, which provided possible extinction years for three of the main fynbos families (Proteaceae, Ericaceae and Restionaceae) in Table Mountain National Park. A total of 74 species from these fynbos families (25 Ericaceae, 24 Proteaceae, 25 Restionaceae) were selected at random for field sampling regardless of their threat status (Table 5.1). Information on locality (latitude and longitude) was obtained from the herbarium specimen labels and survey data when available. Locality information, retrieved from labels or field notes, was converted to

GIS spatial coordinates using georeferencing. Due to wildfires in the Park in 2014, 2015 and 2016 it was decided to remove the Fabaceae (in the original extinction probability analysis in Chapter 4) from the target list as the majority can only be detected and identified by their flowers. The majority of these species take an average three months to a year to flower and time did not allow for the slower growing species to flower post-fire, making identification of species impossible.

5.2.3 Field detection

Adapting mainly Alexander et al.'s (2012) methods, along with others (MacKenzie and Royle 2005, Kery et al. 2006, Garrard et al. 2008) for detection, three transects 100 m by 4 m were placed 8 m apart. For logistical reasons a random selection of transect placement was not possible, however sites were stratified according to species habitat and transects placed randomly within these (MacKenzie and Royle 2005). The species habitat was determined using the locality and GPS waypoints (where available) from the herbarium and survey data for the target species in Table Mountain National Park. Transects were divided into 20 m intervals and marked with wooden droppers. Two observers, experienced in fynbos field botany, walked 2 m apart within the transect and spent 8 minutes per 20 m section searching for a target plant species (Garrard et al. 2008). Positively identified and located species were recorded and marked with a GPS waypoint. If plants occurred more than 1.25 m apart, a new record and GPS reading was taken (Alexander et al. 2012). Habitat and population condition data was recorded for all subpopulations. Once a species was confirmed at a site, the subpopulation was recorded as extant. The next recorded subpopulation locality was then surveyed and I visited each site twice in 2016 (Kery et al. 2006) to confirm with confidence that a species was extinct or extant at the site (MacKenzie and Royle 2005). All recorded data was captured on the SANParks Data Repository System for on-going monitoring and also sent to SANBI to update their databases and the South African Red List.

5.2.4 Data Analysis

My null hypothesis was for no decline of species in the Park. Should the hypothesis be rejected this could then be an indication that in fact a species could be going extinct and require monitoring and perhaps immediate action should be taken. I assessed whether there is any association between the persistence of subpopulations of 74 randomly selected species and the predictions generated from the Solow (1993) extinction probability equation used in Chapter 4. The Solow (1993) extinction probability equation assumes a constant rate of collection over time which is used to infer extinction following an abrupt cessation of collections. Persistence was measured by the number and proportion of known subpopulations found in the 2016 field survey. Predictor variables were; (a) the probability that the species is still extant at 2015, and (b) expected extinction year, both obtained from an application of Solow (1993) to a combined set of herbarium and survey data.

I tested for the presence of an association between persistence and each of the two predictors by fitting a binomial GLM in which the number of subpopulations found in 2016 is assumed to be binomially distributed, conditional on the number of subpopulations originally found and the probability of resighting a subpopulation. The resighting probability was modelled as being dependent on either survival probability or expected extinction year. In all tests, validation of Solow (1993) required a significant, positive association (correlation or regression coefficient).

5.3 Results

It was found that there is a decline of known subpopulations across the full dataset (all families: $V = 319$, $p < 0.001$) and for each family (Ericaceae: $V = 45$, $p < 0.001$; Proteaceae: $V = 7$, $p < 0.001$; Restionaceae: $V = 77$, $p = 0.010$). Figure 5.1 displays the distributions of proportions of known subpopulations found during the 2016 field survey, for each family (boxplots show minima, maximum, medians, and upper and lower quartiles). Median survival proportions are approximately 75%.

Table 5.1. Selected fynbos species, estimated year of extinction on the basis of Solow (1993) generated predictions (Chapter 4), total number of combined subpopulations in the combined data and the number detected in 2016 in Table Mountain National Park.

Family	Species	Year of first record	Year of last record	Expected extinction years	Survival probability 2015	Total combined records	No. Of subpopulations in 2016
Proteaceae	Aulax cancellata	1825	2001	2021	0.108645	5	0
	Diastella divaricata subsp.divaricata	1892	2001	2010	3.5193E	20	20
	Leucadendron floridum	1846	2004	2011	0.005602	12	1
	Leucadendron levisanus	1856	2000	2020	0.116727	3	0
	Leucadendron macowanii	1883	2004	2014	0.030585	13	2
	Leucadendron rubrum	1826	2005	2029	0.271262	5	3
	Leucadendron spissifolium subsp. spissifolium	1847	2004	2011	0.009348	14	9

	Leucadendron strobilinum	1884	2002	2010	1.9719E	6	5
	Leucospermum conocarpodendron subsp. viridum	1846	2005	2009	4.431E	19	12
	Leucospermum hypophyllocarpodendron subsp. hypophyllocarpodendron	1887	2002	2011	3.615E	14	13
	Mimetes fimbriifolius	1847	2005	2009	5.0781E	11	10
	Mimetes hirtus	1887	2005	2012	0.001311	10	8
	Protea acaulos	1847	2005	2006	3.9555E	9	5
	Protea coronata	1887	2005	2008	2.4146E	3	2
	Protea grandiceps	1991	2000	2009	0.002025	2	0
	Protea nitida	1881	2005	2006	1.7673E	15	13

	Protea scolymocephala	1886	2005	2012	2.2257E	12	2
	Protea speciosa	1847	2005	2010	3.7652E	34	19
	Serruria collina	1846	2005	2011	0.005954	1	1
	Serruria cyanoides	1892	2005	2009	1.3061E	2	1
	Serruria decumbens	1849	2005	2013	0.014295	10	8
	Serruria glomerata	1846	2005	2009	2.0308E	11	9
	Serruria hirsuta	1831	2002	2008	0.001704	10	5
	Serruria villosa	1884	2005	2014	1.0909E	5	4
Ericaceae	Erica abietina subsp. atrorosea	1846	1999	2021	0.147287	4	1

Erica abietina subsp. constantiana	1894	2005	2017	0.078559	2	2
Erica amoena	1882	2006	2016	0.051473	12	3
Erica annectens	1890	1984	1998	0.001422	4	3
Erica capensis	1834	2008	2014	0.024581	11	6
Erica capitata	1825	2005	2022	0.178941	13	8
Erica clavisepala	1928	2007	2017	0.073945	9	7
Erica cyrilliflora	1907	2003	2022	0.211032	5	3
Erica depressa	1887	2004	2028	0.650003	2	2
Erica diosmifolia	1877	1986	2021	0.074648	3	1

Erica eburnea	1921	2007	2020	0.190784	6	2
Erica empetrina	1884	2005	2018	0.097151	5	4
Erica fairii	1892	2005	2018	0.101613	3	3
Erica fontana	1921	2007	2018	0.098116	6	4
Erica haematocodon	1900	2007	2018	0.095474	4	2
Erica heleogena	1921	2007	2015	0.034047	5	5
Erica hirtiflora var. hirtiflora	1892	2006	2011	0.001927	2	2
Erica limosa	1921	2004	2011	0.008833	4	3
Erica marifolia	1826	1992	2029	0.674609	20	8

	Erica nevillei	1886	2004	2024	0.168207	2	2
	Erica physodes	1826	2005	2030	0.504333	4	4
	Erica pilulifera	1877	2007	2025	0.463355	5	3
	Erica quadrisulcata	1921	1994	2010	0.017503	10	5
	Erica subcapitata	1853	1989	2020	0.135261	1	1
	Erica thimifolia	1879	1964	2047	0.748282	3	3
	Elegia asperiflora	1918	2005	2038	0.495411	4	1
	Elegia cuspidata	1930	2001	2026	0.606516	13	12
Restionaceae	Elegia filacea	1897	1970	2028	0.274786	4	1

Elegia juncea	1830	1983	2025	0.408113	8	5
Elegia microcarpa	1919	1980	2014	0.030434	1	1
Elegia recta	1918	2009	2038	0.495411	1	1
Elegia thyrsifera	1896	1981	2044	0.802242	2	2
Elegia vaginulata	1940	1982	2014	0.035767	3	3
Hypodiscus albo-aristatus	1878	1977	2033	0.337155	4	4
Hypodiscus aristatus	1886	2003	2020	0.298246	4	2
Hypodiscus willdenowia	1897	1987	2013	0.024252	9	6
Mastersiella digitata	1830	1980	2032	0.333811	4	4

	Platycaulos major	1827	1978	2017	0.055958	10	5
	Restio bifurcus	1940	2005	2021	0.134874	3	2
	Restio cincinnatus	1903	2001	2015	0.033972	2	1
	Restio communis	1965	2004	2013	0.024066	10	7
	Restio dodii var. dodii	1896	2010	2031	0.688740	6	4
	Restio filiformis	1853	1974	2025	0.135022	4	3
	Staberoha banksii	1897	2003	2027	0.282613	12	10
	Staberoha cernua	1846	1981	2014	0.025564	1	1
	Thamnochortus gracilis	1935	1983	1990	7.8973E	1	1

Thamnochortus levynsiae	1935	2006	2029	0.269061	6	3
Thamnochortus nutans	1853	2001	2027	0.253649	3	3
Thamnochortus spicigerus	1940	2001	2023	0.126673	1	1
Willdenowia glomerata	1918	1980	2017	0.077765	3	3

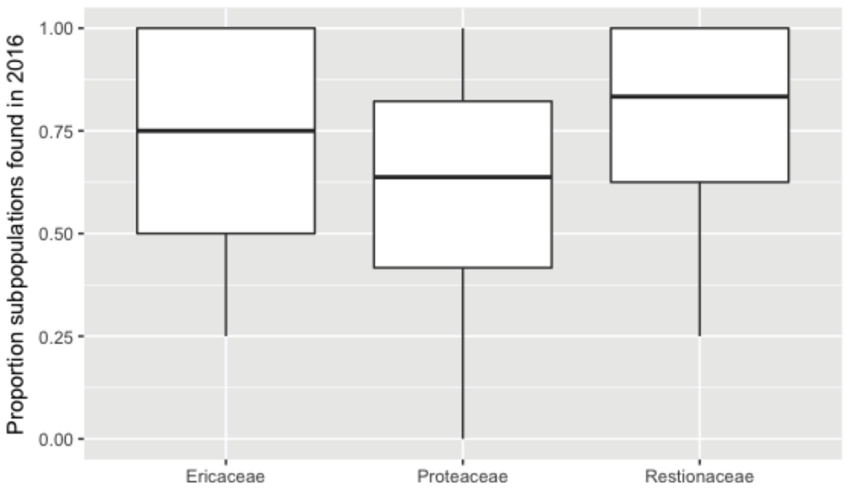

Figure 5.1. Boxplots showing distributions of proportions of subpopulations found in the 2016 field survey, for the Ericaceae, Proteaceae and Restionaceae.

My analysis found little or no significant relationship between predictor and outcome. Figures 5.2 and 5.3 plot the relationship between each of the predictor variables (probability a species is extant at 2015, and expected extinction year) and observed persistence. Figure 5.2 gives the probability that a species can still be expected to be found in Table Mountain National Park in the year 2015. While Figure 5.3 gives the expected year that a species has or will go extinct in Table Mounatin National Park. This is the more traditional use of the extinction probability models that are discussed in detail in Chapter 4, and used to determine year of extinction. Lines of best fit are shown, and it is clear that the 95% confidence interval contains the horizontal line, suggesting little or no significant relationship between predictor and outcome.

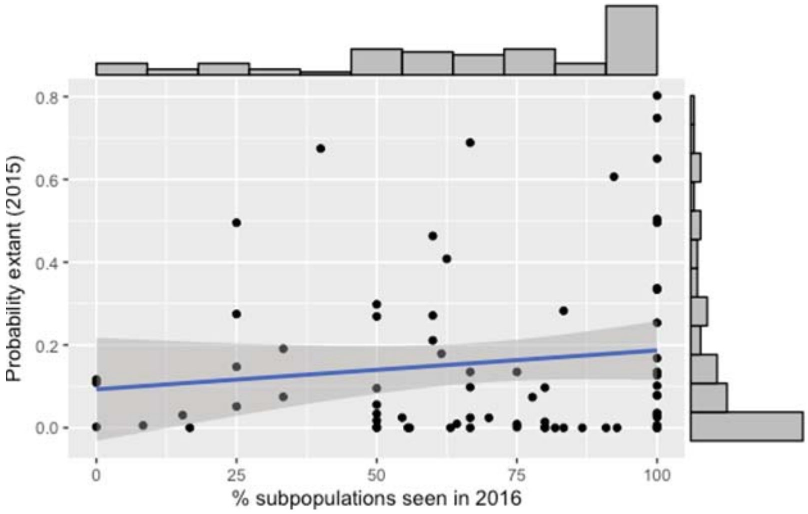

Figure 5.2. Scatterplot showing association between observed persistence (% subpopulations found in 2016) and probability species extant at 2015. The line of best linear fit is shown, with the shaded area denoting 95% confidence intervals. Histograms opposite the horizontal and vertical axis show the marginal distributions of survival probability and % subpopulations found in 2016 respectively.

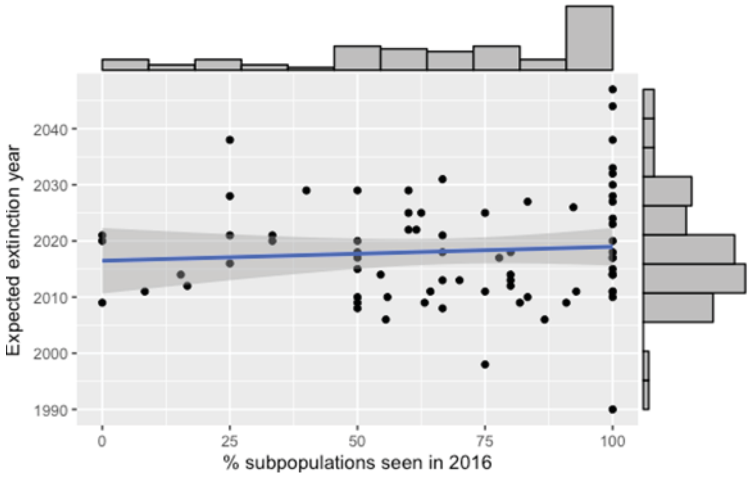

Figure 5.3. Scatterplot showing association between observed persistence (% subpopulations found in 2016) and expected extinction year. The line of best linear fit is shown, with the shaded area denoting 95% confidence intervals. Histograms opposite the horizontal and vertical axis show the marginal distributions of extinction year and % subpopulations found in 2016 respectively.

Hypothesis tests from the binomial GLMs showed no significant positive associations between either survival probability or expected extinction year (generated from Solow, 1993) and observed persistence. Main effects were not significant in both cases (survival probability: z = 0.70, p = 0.48; extinction year: z = 0.40, p = 0.68) and no interactions between these variables and any of the families were significant (survival probability: all |z| < 1.0, all p > 0.35; extinction year: all |z| < 1.1, all p > 0.28. Figure 5.4 and 5.5 show model predictions from the two GLMs, clearly showing both substantial variability in the predicted responses and the lack of any significant relationship.

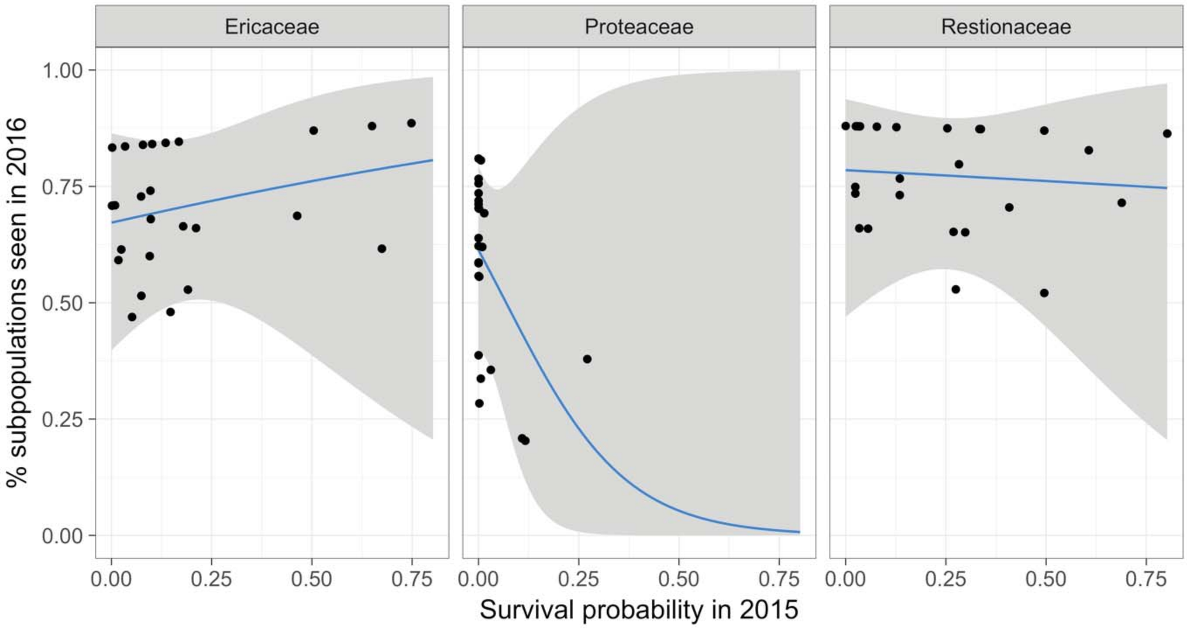

Figure 5.4: Mean predicted proportions of resighted populations as a function of family and survival probability (blue line), as obtained from a binomial GLM. The grey shaded area shows 95% confidence intervals for the predicted means, while the observed data is plotted as points.

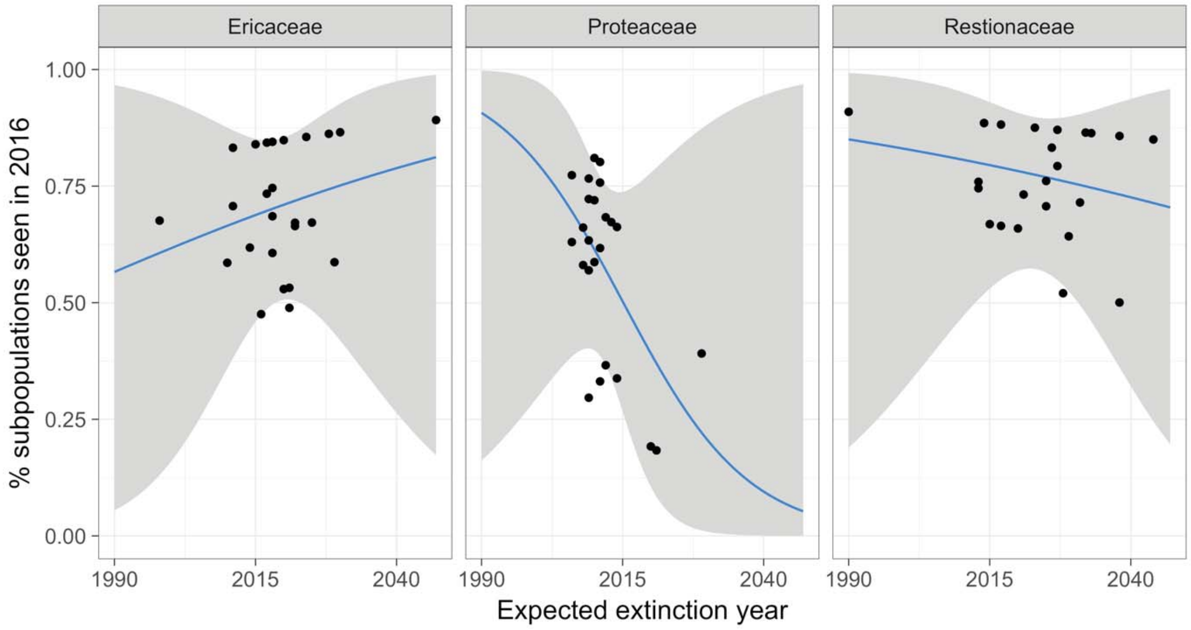

Figure 5.5: Mean predicted proportions of resighted populations as a function of family and expected extinction year (blue line), as obtained from a binomial GLM. The grey shaded area shows 95% confidence intervals for the predicted means, while the observed data is plotted as points.

No significant relationship was found between the outputs of the Solow (1993) equation and observed persistence. Yet, my field detection work found 80% of the Proteaceae, 88% of the Ericaceae and Restionaceae respectively, still extant as a few subpopulations in the protected area. *Aulax cancellata* was not detected at its last known locality, this may be due to the wildfire of 2015 and it may be possible that this species still persists. A total of four species in the Proteaceae and Restionaceae were not detected at any of the targeted subpopulations (*Protea grandiceps, Leucadendron levisanus, Restio filiformis, and Aulax cancellata*). Although confirmed extant in the protected area, 15 species only had one or two subpopulations left, these included *Leucadendron floridum, Leucadendron macowanii,* and *Erica heleogena.*

5.4 Discussion

Collection efforts need to be improved with more people getting out into the field and recording species data (Balmford et al. 2003), in order to increase botanical data. Similarly those collecting the data need to be properly trained in order for the information collected to be of good quality. Systems then need to be easily available to capture and store this data for future use by both scientists and managers. This could enable the use of these tools more effectively, which could be invaluable to conservation efforts in the face of rapid climate and land use change, within the constrained circumstances of protected areas. Currently only a small proportion of taxonomic, geographical and habitat types are being monitored. It should be acknowledged that protected area rangers are expected to undertake in-field monitoring, yet they are also expected to conduct other duties including anti-poaching and safety patrols, general maintenance and administration. This impacts on their time in the field spent on monitoring and recording data, and I recommend that the responsibility for monitoring be shared across protected area staff (scientists and rangers) and external botanists.

There are still areas on the planet that have not been explored and even in places that have been explored in detail, such as Table Mountain National Park, new species are continually being discovered (Greene and Losos 1988, Bilton et al. 2015). Monitoring is a form of repeat sampling or systematic review, and the efforts of monitoring are important for conservationists to assess human impacts on the natural environment, it assists with both long- and short-term data gathering. I believe that increased, sustained, and joint collection efforts between protected areas and society will aid in complementing the predicted extinction probability results and that short cuts and short-term monitoring do not work. Field sampling, monitoring and collections provide crucial raw data for use in a number of analyses and are particularly important to modern conservation management decision making. The fieldwork required in present day protected areas is reminiscent of the collection effort and fieldwork done by the very early botanical collectors (as described in Chapters 2 and 3), where collections and detailed records of all species need to be made. The early collectors established methods and protocols that are used today and the procedures used in this study are direct results of the foundations laid by those first botanists. The systematic collection, naming and labelling of many herbarium specimens stems from the work done by Linnaeus and his collaborators (Sparmann, Mason, Solander in the Cape Colony) back in the 1700s (Chapter 3). The early botanical collectors tried to be consistent in their field methodologies of collection effort and data recording, which myself and other conservation ecologists mirror today.

My results indicate that there was little support for probability values from the extinction equations regarding the expected survival and extinction dates of species in Table Mountain National Park. However, the extinction probability equations are known to be robust and work with other datasets (Jaric and Ebenhard 2010, Gotelli et al. 2012). In this situation it would seem they need to be refined and ideally foster methods that do work when there are sparse data available. Given more data to run the extinction model, it may be possible to establish a stronger relationship with observed subpopulation numbers. Work is ongoing in SANParks to acquire more data and test for possible relationships in the future. The establishment of thresholds of subpopulation reduction also require further exploration to help identify which species are in imminent decline and to prioritise which to allocate limited resources to for management action (Greene and Losos 1988).

In making the case for more investigations into possible relationships between extinction probability results and in-field survey results, I do not intend to cast doubt on the accuracy of the probability equation used here or others mentioned in my fourth chapter on the use of herbarium and survey records to predict extinction in protected areas. I caution that the poor performance of the Solow (1993) equation may be due to the dataset used here. The Solow (1993) Optimal Linear Estimation, was chosen given that the dataset tested was so sparse and the Solow (1993) equation works when the number of records is at least five, while other equations required more records to run optimally. The fault in the Solow (1993) estimation is that it assumes a constant rate of collection before an abrupt stop and then infers a collapse to extinction. The combined dataset used here (herbarium and surveys records for Table Mountain National Park only) is still very sparse, with the consistency of collections dropping off rapidly for periods of time for each family tested. The extinction probability equations of McCarthy (1998), Roberts and Solow (2003) and Solow and Roberts (2003) for example are less limiting in their need for consistent sampling over time. However, one should be cautioned that the equations of Roberts and Solow (2003), and Solow and Roberts (2003) produce the undesired results of large confidence intervals (Solow 2005). The rapid decline in sightings records has been cited as the main reason for false or misleading extinction probability results (Solow 2005, Rivadeneira et al. 2009). Such inconsistencies in the records can be caused by increased botanical interest in a species, natural disasters like wildfires and flooding, or political and financial support for research which affect and direct collection effort. While there is truth in the fact that interests change or disasters affect sightings of species, it should not deter researchers from using the extinction probability equations as a quantitative check to produce more robust qualitative conclusions when it comes to extinction of a species. There is certainly scope for more work on the equations to account for factors that affect sightings frequency.

A vast majority of probabilistic models have only been demonstrated for their potential using desktop analyses, yet have not been assessed in the South African context for their actual effectiveness when applied to in-field realities (Hamer et al. 2009, Chong et al. 2012). The underlying principle of the probability equation is the more recent the recorded collection or sighting of a species the greater the confidence in the results and the existence, or extinction, of the species (Solow and Roberts 2003). Despite this there is still a decrease in the number of herbarium collections made (Culley 2013), and survey data from environmental impact assessments or research projects is not made available to other users as has been highlighted in Chapter 4, where the SANBI database was used and has limited survey records. Herbarium data are generally more widely used by researchers and conservationists, as they are more readily available than research project and scientific collection surveys (Linder et al. 2012). As mentioned in my fourth chapter I recommend that documented targeted searches for species during botanical or research surveys be made available to national databases. This will increase the number of sighting records for species and increase the confidence in, and potential application of, a wider range of extinction probability equations. A shortfall in the capturing and storing of data is a global problem and one that needs urgent attention. Large scale data collation projects should be implemented in universities and botanical institutions and make use of volunteers and citizen scientists to help deal with the enormity of this problem.

The role of extinction probabilities of species could be fundamental in the interpretation of non-detections for in-field survey results. Given that using sparse data in extinction probability equations and for detection is far more challenging than generally acknowledged, I repeat my argument that a relationship may still exist and has yet to be found. Moreover, these results are a sobering reminder that long-term biodiversity data is extremely important and that poor and sparse datasets have negative impacts for the use of conservation tools such as the probabilistic models and Red List assessments. The challenges of utilising sparse data has also been identified elsewhere in the literature (Jaric and Ebenhard 2010, Thompson et al. 2013, Caley and Barry 2014). That the persistence of biodiversity may be directly affected by the lack of data is vitally important and actions need to be taken to remedy this dearth of data. The potential for probability equations to inform local and even global plant conservation actions exists and could possibly increase greatly should data availability be more substantial. I have illustrated in Chapter 4 that combining herbarium records and botanical surveys can benefit the extinction probability results, with better results than each dataset used on their own, if only marginally. This is a step in the right direction for conservation.

Conservation needs to consider the challenge of how to expand the scale, range and consistency of species and population monitoring (Greene and Losos 1988). Unfortunately, there is a misconception that botanical data are readily available and that collection of new data can be done using remote sensing (Chang and Heinz 2000, Lunetta et al. 2006, Gross et al. 2013). Even when this holds true, it is only for a handful of well-studied groups. There is also the notion that scientists know all there is to know about nature that will be necessary to save it and that what is not known can be obtained at short notice or that precise information is not required where it is lacking. This is simply not the case. A further challenge is that botanists and ecologists are finding less time to spend in the outdoors collecting and monitoring, driven in part by the current funding environment and associated burdens of bureaucracy (Swaisgood and Sheppard 2010). This then tends to favour more time spent behind a desk, working with remotely gathered data and on mathematical models over collection of long-term ecological research in the field. As a result of less fieldworkers the loss of a species and the main causes often goes unnoticed (Balmford et al. 2003). The flip side of the coin is that models, such as the extinction probability equations, can be refined further which is what is suggested as an outcome of my study. The need to collect data and monitor in the field, to complement the accumulation of decades of knowledge gathered by botanists and researchers (also discussed in Chapters 2 and 3) must be made explicit to those supporting and funding conservation and protected areas. Substantial increases in financial support for field collections and monitoring are needed, to supplement the long-term data already available to run extinction probability analyses and other models (Balmford and Whitten 2003). An appreciation by funding agencies of the connections between basic field botany and critical conservation management, needs to be nurtured.

My selected detection protocol addresses the temporal and spatial requirements of monitoring and data collection through ground-based sampling (Wintle et al. 2012). It also achieves the requirements of protected areas with lower costs via reduced time and man power while retaining integrity of the sampling data. But before proceeding to the discussion on the results of the in-field work, it is worth mentioning the impact that wildfires had on the detection of species. Following a wildfire event perennial species take longer to mature than annual and bi-annual plant species. As is the case with the Fabaceae family in the fynbos, the majority are slow to mature and the key characteristics used to identify them appear in the flowering and fruiting stages (Schutte et al. 1995). Wildfire occurrence and species growth traits must be taken into account when conducting in-field detection work, particularly when it is to determine whether a species is extant or not, as evidenced in Chapter 3 when searching for localities in Agulhas National Park. Rivadeneira et al. (2009) cite the incorrect sampling time and a variation in species abundance as one of the reasons that herbarium and survey records are at times incomplete. False assumptions that a species is extinct can have serious consequences for protected areas and conservation actions, where a species may be removed from a monitoring list and funding is no longer received for its conservation, resulting in it inadvertently going extinct because of this (Ungricht et al. 2005). The IUCN Red List, although providing a category for extinct species, does not provide a time period for surveys to detect extinction (Chong et al. 2012). The answer lies with the suitability of a detection protocol for a given situation including logistical considerations, resource availability and the specifics of the species in question.

From the field detection data it was possible to verify a species as extant and I was able to find a relationship between historic locality records and the current number of subpopulations in Table Mountain National Park, albeit that they appear to be declining. The historic collection records proved more valuable than the extinction predictions in this instance. From the detailed locality descriptions the species subpopulation could be located and assessed for population health and threats. I found that there was a reduction in species subpopulations in the protected area. This shows that the overall metapopulations of species within the Table Mountain National Park are being reduced and the survival of species may be at stake. Individual species can now be identified and prioritised for monitoring to assess the extent of the loss and mitigate for further loss in Table Mountain National Park, regardless of Red List status. This illustrates that although a species may be extant in a protected area, its future may not be secure and it could indeed go extinct within the protected area if the loss of subpopulations is not addressed. The notion of an extinction debt can then be investigated, whereby a protected area may be 'carrying' an extinction debt as it has the last known population of a species within its border (Pimm and Raven 2000, Kuussaari et al. 2009).

From my field notes at each subpopulation site, I found that the majority of the rare species subpopulations in the protected area, are now growing on suboptimal habitat. This confirms findings by Farnsworth and Ogurcak (2006) that there is a higher percentage of rare plant populations that occur in suboptimal habitat and along the margins of their former ranges. This is another extinction debt factor to potentially investigate (Pimm and Raven 2000) along with the imminent threat of climate change (Moncrieff et al. 2015, Slingsby et al. 2017). A further threat to these populations is that protected areas with sudden land use change on their boundaries are even more susceptible to species losses (Heller & Zavelta 2009). The reasons for species decline include over harvesting (*Protea grandiceps*), habitat destruction and transformation (*Leucadendron levisanus, Thamnochortus gracilis*) and alien invasive species (*Erica diosmifolia*) (Raimondo et al. 2009), all consequences and impacts of a growing human population. Knowing this conservation managers can plan for monitoring of priority species subpopulations thereby maintaining the integrity of the biodiversity wall in a protected area. For a species to persist it must generally be able to disperse to prevent genetic stagnation and be resilient to natural disasters, thus multiple subpopulations must be conserved (Guardiola et al. 2013). If unable to do this the result may be the progressive decline of a species until it ceases to exist. This is indeed the situation in Table Mountain National Park as it is bounded by the sea and the city on either side with little options for species to disperse to cooler climate for instance, except upslope to cooler altitudes. Many of the species found in the park are narrow range endemics and are genetically fit without the need to disperse (West et al. 2012). However, these species are negatively impacted by anthropogenic factors such as an alteration of the natural fire regime (too frequent or infrequent). This makes the conservation management of Table Mountain National Park extremely important and complex. A possible solution is to conserve these species and prevent genetic erosion in *ex situ* collections at botanic gardens and seed banks as a means of ensuring the persistence of species into the future (Maunder et al. 2001, Guerrant et al. 2004, Ryan 2015). More effort and support should be given to botanic gardens to maintain collections of plants in support of wild plant conservation, as they are the cornerstones of *ex situ* conservation have the necessary horticultural expertise (Maunder et al. 2001).Management, in the face of looming plant extinctions involves a willingness to take risks and be flexible, this could include maintaining the status quo and being willing to frequently assess changing situations (Biggs and Rogers 2004, Heller and Zavaleta 2009). My field detection results shown in Table 5.1, certainly help identify species in the protected area which merit immediate monitoring and management action such as habitat rehabilitation and risk prevention measures including path closure and invasive alien plant clearing (Farnsworth and Ogurcak 2006). The lack of certainty regarding significant relationships between extinction probabilities and in-field data should not deter managers from undertaking monitoring and conservation actions. I caution that these results should be used carefully and that as new data is acquired that it be used to update and inform further analysis, within an adaptive feedback loop for management (Biggs and Rogers 2004).

The study found that through in-field surveys I was able to correct certain errors and problems with the historical herbarium data, particularly those species localities that had been incorrectly georeferenced and an accurate GPS waypoint could be captured (Rhoads & Thompson 1992). Similarly errors in the survey data, including taxonomic and locality details, could be addressed. Another possible use for the verified field data is to investigate phenological changes in populations of the fynbos flora. This could be achieved by collecting additional data during resurvey work that will complement the original historic data collected (Park 2012). Newly collected data on the habitat condition and threats to subpopulations of plant species in Table Mountain National Park will be used to update the information used by the IUCN Red List to assess these species. However, this brings the discussion back to the question of whether the Red List is of use to Table Mountain National Park.

The Red List has played and continues to play a major role in the guiding of conservation policy and selection of protected areas (Balmford et al. 2005). At the global and regional scales it is an invaluable tool to conservationists. My work has shown that all species tested are declining and that the current use of the Red List to monitor species does not work for the purpose of prioritising actions in a protected area. Fine scale in-field detection of species and recording of population health and threats can be used to update lists, often to reflect an increase in knowledge of the species in the protected area, rather than actual change in conservation status globally (Pimm et al. 2014).

The insights from my study on in-field detection in conjunction with the probability model used here emphasize the importance of frequently collected data and use of in-field detection methods to validate extinction probabilities before declaring a species extant or extinct within a protected area. The clarification of data used pre- and post in-field detection proved extremely useful in highlighting the need to get data from other sources such as citizen science projects. The increase in collection and monitoring efforts can be made more affordable by using volunteers and citizen science involvement. Current citizen science programs are already looking at this possibility and collaborating with institutions such as museums, universities, and nature conservation bodies. While this raises the debate of citizen science its use and its potential pitfalls (Dickinson et al. 2010), more eyes in the field doing surveys and recording accurate usable data is urgently needed by conservation (Bonney et al. 2009, Silvertown 2009). Rather than merely documenting the decline of a species conservation practitioners need to engage with the broader community and include them in conservation monitoring and management (Swaisgood and Sheppard 2010). A greater awareness of the use of accurate field data would improve the quality of collections and their value to conservation would increase (Akmentis 2011). However, when dealing with rare, threatened and possibly near extinct species, discretion and care is needed as not all citizen scientists have the best interests of the species at heart (Dickinson et al. 2010). Defined citizen science projects such as atlas projects can help prevent inappropriate use of data and exploitation of species and other challenges relating to the use of citizen volunteers in botanical surveys. Using atlas projects and citizen science groups, new data can be collected systematically at a reduced cost. Given the increasing demand for baseline information and the costs associated with its collection, the use of ‘non-scientists’ to collect data is becoming ever more popular. Yet it is well known that atlas data, although useful also has limitations such as the Protea Atlas discussed in Chapter 4 as it can be spatially biased and a result of flawed infrequent collection and identification (Farnsworth and Ogurcak 2006). The development of statistical models to quantify and correct biases (Lande 1996) has improved the accuracy of surveys making it possible to predict the number of unidentified species and aid in planning citizen science surveys. Sampling attributes of survey data can now be preselected including the number of sample sites, size of the sample and spatial distribution of data, helping reduce several biases (temporal, geographic and taxonomic) known to occur with herbarium and survey data collection (Suarez 2004).

5.5 Conclusion

It is important to bear in mind that all species are important to a protected area and the requirement for an initial assessment of which plant species require monitoring is important. Although a species may have a Red List Status it may not need monitoring if it is not under threat of loss within a protected area. It is important to recognise that the first step in species conservation in a protected area is to determine whether a species is at risk of being lost at the global or regional scale according to the IUCN Red List. The second is to assess what is happening within a protected area using in-field detection of species, and in time, hopefully, refined extinction probability equations. As illustrated in this chapter and Chapter 4, these data used must be accurate and be of a sufficient volume to run the equations (Caley and Barry 2014). The third step is to prioritise whether or not that species requires intervention, whether it is persisting on its own, or whether it requires monitoring, or active management to prevent extinction (Grilli et al. 2015). To achieve this, in-field detection is required and when planned and done strategically, costs can be reduced. Should these steps not be followed management decisions could be fraught with impractical applications and assumptions that species are doing well when they could be going extinct within protected areas. The alternative is also true where a lot of time and effort is spent on a species thought to be extinct or going extinct when it is in fact doing well within a protected area.

This work found that all three of the above steps can be achieved with a thorough assessment of data collection and storage. Increased effort and data will enable protected areas to make informed decisions about where to invest finances and resources for surveys and monitoring. In presenting my results to park management they were able to see the benefits of using strategic in-field detection with historic and survey data, and have indicated their willingness to implement monitoring of those species most in decline. Although the extinction probability results in this study may not provide a reliable list of species that are extinct, the potential still exists for their use. The herbarium and survey data do give an idea of where gaps in the collection data may exist and provides an initial list of species to search for in-field. Given the diversity of species, gamut of threats and protected area challenges, I recommend that refined extinction probability equations and in-field detection methods be used together in the future. Surveys and monitoring in-field is vital work and shortcuts cannot be taken if ecological diversity is to be conserved in protected areas.

In summary, it was Chong *et al* (2012) who stated that the use of herbarium data (and other natural history data) needs to be investigated for new ways to utilise it for the determination of threats to and extinction of species. They also advocate for the use of probability models coupled with in-field surveys to be fed into adaptive management cycles. A reliable extinction probability has not yet been found, particularly when compared to in-field detection data and thus remains a complex and difficult problem for conservation. My analysis raises questions about the current methods of analysing and understanding herbarium and survey data with the view to use it for setting priorities for conservation monitoring. Short cuts cannot be taken in using desktop analyses alone, field verification is required, particularly when data used are sparse. The in-field detection gives honest insights and augments poor data for future use in conservation and research. Given the challenges faced by conservationists, notably a lack of resources such as funds, people and time to undertake surveys and monitoring, there is an urgent need to find an effective solution. The time and money spent refining extinction probability equations and, herbarium and survey datasets, is worth the effort in the long-term. Further research into the relationship between extinction probability and in-field surveys is therefore required.

CHAPTER 6: Thesis Synopsis

Prologue

The nature of the current challenge in conservation requires new and innovative tools for saving species. This study highlights a moment in conservation that requires a multidisciplinary approach. The work at hand was carried out within the theoretical context of science as a discipline and the mandate of protected areas to prevent biodiversity loss. It deals with the epistemology of science, biocultural heritage, extinction probability and species detection in protected areas using two parks in the unique Cape Floristic Region of South Africa as case studies. By investigating the ecological and heritage value of herbarium collections, and establishing whether herbarium and survey datasets can be used as floral biodiversity baselines I aim to assist conservation management of protected areas in South Africa to prioritise species for monitoring. This chapter draws together the key findings of this study. The results of this work contribute to our understanding of the current state of data and floral species in the case study protected areas, and provides a basis for using quantitative approaches to inform conservation decision-making. Lastly, I provide recommendations and highlights for future work and research needed.

6.1 Introduction

This thesis seeks to demonstrate the value of botanical collections to science, conservation, and protected area management. Drawing on different methods and fields it endeavours to use a multidisciplinary approach to make a contribution to current thinking in conservation by establishing the value of herbarium collections to protected area conservation. The study integrates knowledge from scientific and social areas of research and learning (Steiner and Posch 2006) since conservation is now recognised as a social and ecological endeavour. Indeed this is manifested in the SANParks mission and reflects global shifts through time as learning progresses (Cumming et al. 2015). In order to do justice to the examination of the contribution of herbarium data to science it had to be approached from multiple angles. A single perspective, from a single discipline, would have failed to reveal the cultural heritage and biological conservation inherent in the richness of herbarium data. Therefore several perspectives were used to find the links between biodiversity conservation and cultural heritage.

The central theme of this study as stated in the Introduction, is ‘the dire need for conservation and protected areas, as the mechanisms for conservation, to prevent the loss of natural-cultural heritage and biodiversity’. Engagements with conservationists in protected areas and rapid biodiversity loss have highlighted our continued poor understanding of biodiversity functioning worldwide (Midgley and Thuiller 2005). Research into biodiversity loss in the past decade has found that climate and land use change and an increase in human population are the top three threats. However, lack of data to help understand the relationship between heritage, biodiversity and these threats has left many studies with result statements such as ‘maybe’ and ‘might’. This research sought specifically to expand our knowledge on global plant species loss from both a heritage and biological biodiversity perspective. To this end work was carried out in protected areas in the Fynbos Biome, a biodiversity hotspot in the Western Cape Province of South Africa, using herbarium and botanical survey data.

The implications of each of the chapters are detailed in their individual conclusions, in this chapter I reflect on how the findings emanating from my thesis can contribute to an expanded understanding of biocultural heritage and biodiversity conservation in protected areas globally.

6.2 The role of botanical collections as objects of information

This study interrogates the degree to which botany may have contributed to the understanding of the natural world in the form of pure analytical science (Pickering 1992), and in keeping with the more holistic recognition of what modern science entails, the multifaceted layers of social and heritage knowledge are illustrated by the social networks of early botanical collectors. Little has been done in the realm of understanding the culture of science in the context of conservation. This research attempts to demonstrate the connections between cultural heritage and science for the benefit of conservation. This thesis advances Sverker et al’s (2012) argument that scientists working in the biological field defined the concept of the environment following World War II. In terms of this argument it was botanists who at an early point in history helped define science and scientific methods such as replication and sequential data capture through the timeous discovery and collection of natural objects of information (Culley 2013). Herbarium specimens have contributed to and continue to contribute to the development of science (Browne 2001, Delisle et al. 2003). It is evident from this current research that early botanical collectors may have played a role in influencing what are the common practices in science today.

The material object of a herbarium specimen embodies more than just the information recorded on the specimen sheet, it has value as an object of information itself, enabling knowledge generation broader than only the specimen (Posey 1999, Alberti 2005). Indeed the presence of herbarium specimens enabled research to take place far from the original site of collection. Today, many herbarium specimens are in scanned electronic format, and available online, thus continuing knowledge generation. This has also made research more streamlined and knowledge generation faster (Häuser et al. 2005). I found that there are still many records requiring collation and scanning which could be made available electronically. These could be used in research and the development of new methodologies and understandings and lend support to Dolan et al.'s 2011 findings, where they call for well documented historical records that can be used in conjunction with new technologies.

To bridge the gap between heritage and science this work authenticates the value of herbarium collections historically, in terms of approaches and methods that were tried and tested and have stood the test of time, in both botany, and more generally, scientific practice. This research reveals that botany has consistently contributed to science, both social and biological, from the role of botany and herbarium specimens in the development of scientific epistemology and practices, to the recognition of historic herbarium specimens and the sites of *in situ* plant populations as biocultural heritage. In more contemporary studies and in modern conservation practice, the value of the detailed records and practices to ensure detailed records, which in turn help to guide in-field detection are explained. Throughout the thesis the possible role botany plays in the development of science as a discipline, in the collection and gathering of specimens as new discoveries and describing species, the cross fertilisation of techniques, ideas and practices is stressed (Carruthers 2009). Botanical collecting made connections between plants and the habitats they grew in, and today connects the past with the present in the form of biocultural heritage and biodiversity data. Conservation in the modern world embodies a spectrum of approaches (Gavin et al. 2015) and this thesis has attempted to illustrate that the conservation of biological diversity and cultural heritage can be achieved if biocultural practices are supported.

6.3 Historic herbarium collections and extant localities as biocultural heritage

Management of protected areas has chiefly focussed on the ecological integrity of ecosystems contained within them and little attention is given to the biocultural heritage which they also protect (Cumming et al. 2015). Biocultural heritage, is a key element of this study. The biocultural heritage literature is focussed mainly on indigenous peoples biocultural heritage within a landscape such as in Peru (Argumedo and Stenner 2008) and China (Yiching and Jingsong 2011) and is lacking on the aspect of protected areas conserving biocultural heritage assets in the form of historic plant localities. In this study my focus is on the interaction of the landscape and early botanical collectors. The value added by these biocultural heritage sites and herbarium specimen records is as yet unrecognised in national and international literature. The loss of biocultural heritage, where the decline of plants in the environment (living plants) affects the vitality of the cultural heritage involving those plants (paintings, poetry, music, memories) must be avoided by protected areas.This study therefore, expands on a currently limited understanding of our biocultural heritage in protected areas by establishing a connection between historic specimens and the associated collection narratives of early botanists and the window they provide on a time that has since past. Biocultural heritage sites are areas that show the footprint of people on the landscape, be it for positive or negative impacts over time (Price and Lewis 1993). The herbarium specimens record their stories which are connected with nature and ought to be recognised as part of the landscape. The historic localities and living plant populations provide a link between the broader landscapes, and connect biodiversity and the people who visited, lived and still reside on it. Biocultural heritage is embedded into the landscape and cannot be separated, it forms part of a richer history for protected areas to conserve, side-by-side with the conservation of biodiversity.

Using the Agulhas National Park as a case study, historical elements such as the herbarium collections, the collectors, their experiences, and the history of the farms on the landscape were considered collectively to highlight the value of historic herbarium collections as biocultural heritage. Crawford and Hoagland (2009) argue that it is only the herbarium specimens that can be used to find a species in the veld, where I used the combined botanical records to locate historic plant localities. These original sites and if possible extant plant populations from which historic specimens were collected, are biocultural heritage sites, as their presence highlights the spaces where society and science came together to generate knowledge (Figure 6.1). Biocultural heritage informs modern scientific epistemologies through historic herbarium specimens and the original *in situ* plant populations as well as the social character of science via narratives, people and places (Cocks 2006, Zytaruk 2011).

Figure 6.1 Historic locality site of *Senecio pillansi* at Ratelriver in Agulhas National Park, a biocultural heritage site which is currently being monitored by park rangers and adding to our knowledge of the species, its habitat, and the cultural landscape in the Park (C. Cowell 2017).

Bringing together historic specimens and their *in situ* localities, this work proposes to make a theoretical and empirical contribution to the conservation of biocultural heritage. This will safeguard biocultural heritage in order for people to continue learning and science to continue advancing. Part and parcel of biocultural heritage is the recognition of the cultural heritage of the collections (Lourenco and Gessner 2012). The value of historic plant populations should also be recognized by visitors and communities, thereby sharing the information regarding their discovery, collection and conservation with a larger audience. The historic and contemporary collection registers and diaries with anecdotal details are invaluable and when pulled together and seen as a whole with the *in situ* plant populations they have considerably more value than previously identified. Both should be conserved as they add to the cultural and scientific wealth of history and knowledge of the natural environment. Ensuring the persistence of specimens and *in situ* localities will aid protected areas in achieving their mandate to conserve both the biodiversity of a region and the botanical heritage of an area (Phillips 2002) and provide added interest and value for tourists.

Herbarium collections and their associated *in situ* plant populations are important heritage sites both locally and globally. As pilgrims return to a site of significance so scientists can return to an historic locality where a species was found, to continue to study and document its presence, other species around it, its habitat and ecosystem for threats (Figure 6.1). This is a continued learning and the sharing of knowledge, which highlights the value of biocultural heritage sites. As new technologies are discovered that can use herbarium specimens to answer questions about the world, so their value increases and the contribution of botany to science can continue. Lister et al. (2010) surmise that there is a risk that as modern scientific research evolves so the use of natural history collections such as herbarium specimens will fall out of use and may result in the collections being destroyed and disappearing altogether. However, this study found that the impetus to use herbarium collections has increased over the last decade in South Africa and globally (Crawford and Hoagland 2009, Lister et al. 2010, Droissart et al. 2012, Linder et al. 2012). My study supports the understanding that herbaria are historical archives with new additions adding value to the older specimens. Growing this long-term data asset is vital to ensure continued learning is made possible (Roberts et al. 2005, Lavoie 2013).

Historical collectors often did not record localities as they are known today, as they did not have the benefits of modern technology such as GPS or topographic maps with the kind of accuracy we take for granted today. I faced challenges in the form of poor and incomplete data. I have now ground-truthed many of the original historic localities in Agulhas National Park and corrected errors with regards to the georefencing of the historic localities. In correcting errors and biases older herbarium records can be valuable to modern scientists and conservation managers when seeking the original sites of species collections. I sound a note of caution as when using historic herbarium records that were made prior to the 1900s, many were collected and then propagated in a botanic garden. The name of the botanic garden is recorded on the specimen label and the provenance of the specimen is lost. These records, while of value in other regards, are of little use when searching for biocultural localities *in situ* and should also be removed from extinction probability analyses, as it can lead to wasted collection efforts and resources. By checking the provenance of specimens in this work with the historic localities in Agulhas, restoration projects where re-introductions of a lost species are needed, may be able to locate the closest population to an extinct species which could be used in the restoration process. The provenance of specimens is also important for finding wild crop relatives for climate change resilience research (Meyer et al. 2012). The continued existence of historic localities also enables monitoring for changes in population vigour, phenology and abundance, thus contributing to the advancement of our scientific knowledge and understanding of the world.

Throughout the thesis the idea of seeing what the past can tell us about the future emerges, a theme of reflection appears and how using historic botanical collecting and collections can help in modern day conservation management planning. Just as a country’s national diversity is viewed as a national asset, the datasets of these collections are assets that can be used in guiding conservation efforts, in particular where it guides in-field detection and monitoring. Gaps in the herbarium record data can be addressed with the search for historic biocultural heritage sites using historic specimen localities, early botanical collectors’ notes, and in-field detection work to verify if species are extant. Research such as this can contribute to the quality of ecological data through investigation and in-field surveys of species, where the value of fieldwork surveys to ground-truth these data is demonstrated.

6.4 The relative value of herbarium collections and botanical surveys in generating extinction probabilities

Predicting extinctions is an important aspect in conservation planning and management (Hedenas et al. 2002) and managers are reliant on research to inform best practices. International studies looking at species-area relationships and protected areas in biodiversity hotspots echo similar results to this research; that species are less susceptible to immediate loss due to global climate change and that finer scale land use change (from anthropogenic and alien invasive species) is a much more prevalent threat (Brooks 2002, Leroux and Kerr 2012, Olivier et al. 2013, McCarthy et al. 2014). This research agrees with Heller and

Zavaleta (2009) that urgent action is needed in protected areas with sudden land use change on their boundaries as they are even more susceptible to species losses.

In ecological systems that require long-term data, herbarium specimens provide a solution as they can be combined with short-term ecological studies and surveys to provide a comprehensive view of the temporal long-term trends for species and systems (Bromberg and Bertness 2005, Rowe 2005, Pimm et al. 2014). I found that herbarium data was too poor to be useful alone in the extinction probability equations. Combining the herbarium and currently available survey data, was still insufficient to produce significant results from the Solow (1993) equation. The survey data was also biased towards easily detected species and Red List species, and did not necessarily reflect the true abundance of species in Table Mountain National Park. The results showed that it misled conservation estimates of extinction probability (Tingley and Beissinger 2009) and in-field verification of species occurrence was still needed. Although the Solow (1993) extinction probability enables better comparability between species with multiple sightings records over time (McInerny et al. 2006), the results deviated from that of McInery et al (2006) and Clements (2014) in that it did not perform as expected using the herbarium and survey data. I echo the statements made by Clements (2014) that extinction of a species has to be prevented and in this study it is particularly pertinent to protected areas which were the focus of my research.

Areas closer to cities and research institutions are often repeatedly collected yet the greatest loss of species has occurred here too due to population expansion resulting in land use change. This occurred in Table Mountain National Park, which is in close proximity to the City of Cape Town, where collections increase temporally but decrease spatially as one gets further from the city. As a result of frequent surveys and research projects, data available are potentially fairly large. However, this was not the case with data for Table Mountain National Park. This maybe a product of the species rich ecosystems in the Park, where only a few of the species are recorded and others are not detected (Droissart et al. 2012) and also as a result of a lack of a central hub for all botanists to send data to for it to be stored. The alignment of historic herbarium records and newer survey data enabled me to see that the quality of herbarium and survey data was questionable. Particularly with the survey data there are no standards in place for recording, cleaning or storing it. Where data does exist, little work has been done on integrating existing data sets for research. This research did enable the correction and updating of the historic and contemporary floral data from SANBI.

This study had similar problems to Barker and Wood (1999) and Wilkins (2003) with the survey data used, in that survey data are affected by inaccuracy in measurements, insufficient collection of data as a result of budget or time constraints, and failure to secure collected data. The single most important variable in explaining differences in the quality of surveys is directly linked to the experience of the botanist (Barker and Wood 1999). Training of field botanists in broad taxonomy coincided with the up-surge of surveys and enabled vegetative surveys to be conducted more accurately, improving terrestrial biological survey standards worldwide (Treweek 1996, Thompson et al. 1997, Bonney et al. 2009). However, this momentum has tapered off and field studies are being undertaken less often and fewer scholars are getting in-field training on a regular basis. Looking at the rigor of collecting practices and how they developed, it is evident the same degree of effort and rigour are still needed in the present day. The height of botanical collection, and exploration, coincided with a worldwide period of significant knowledge generation (encyclopaedic thinking) and scientific advancement with the development of the binomial classification system and a rapid expansion in global understandings of the natural world (biodiversity). This thesis demonstrates the significant value of the vast amount of work undertaken by early botanical collectors and the information gathered at a certain point in history and emphasises the urgent need for an increased effort of modern explorers and naturalists to once again embark on fieldwork and collections to advance our understanding of the natural world.

Although there is a perception that all data has been collected and is available on the World Wide Web, I found that we still do not have sufficient baseline information to accurately assess and monitor biodiversity. I am not alone in my view that generally people no longer use books or libraries, preferring to use electronic media for ease and instant answers (Gross 2004, Rice 2006, Lemire et al. 2008). Scientists and scholars need to see what is happening on the ground, experience nature and not be disconnected from nature while connected to electronic media. Conversely, electronic media is also the answer, more data from more sources can create a new ‘hub and spoke’ system in a Star Trek type world. This central data hub would be efficacious to conservation and science, while still recognising the sovereignty of data ownership. The past repeats itself in cycles, colonisation is no longer the mechanism but social media and the internet is now connecting people and places, it is the new driver of information availability and enabling knowledge generation. To be of value to science however a systematic and universally agreed system needs to be agreed on in this new electronic storage space.

In order to prioritise species for conservation action such as monitoring, a protected area must define why species are important to that protected area in conjunction with its national and global threat status. A threatened species list for each protected area can be designed to serve the purpose and needs of that protected area. The analysis done in this study of the species status on the Red List shows that the opposite is true, species with lower statuses are in need of monitoring. This may also be true for other protected areas around the world, where species with lower Red List status are being lost. As a result of the extensive work done to-date on Red Listed species, non-listed species do not receive as much attention and data records (where available) reflect this as a decline in the species being seen and recorded. It is my suspicion that misunderstanding of the correct use of the Red List is the cause, as species with higher statuses are sought out by researchers and rangers for monitoring and others with lesser statuses are not. By validating the herbarium data against the Red List it is shown that the assessments used to determine species threat status at a global scale are inadequate at the smaller scale required by protected areas.

This study provides empirical evidence that can be used to test the rigor and accuracy of global extinction risk assessments, thereby making them more robust. Managing protected areas requires authorities to view the protected area as an individual entity where species cannot be lost. For this reason species with lower Red List status may indeed be under severe threat in a park and require urgent conservation action. This study does not propose to replace existing Red List assessments but rather to strengthen them at the local protected area scale. There is still a need for more and better quality data to make the most of fine scale assessments using extinction probability models and to prioritise monitoring of species.

6.5 In-field detection methods to determine anticipated and actual conservation status

This thesis explores the temporal and spatial scale of data available to conservation for applied management decision making. In order to ease the work load of the few field botanists and managers in protected areas, this study sought to identify a method to determine which species are declining and which should be monitored closely. When coupled with in-field survey data, long-term and historic data can produce more accurate predictions which result in buy-in from park management who can see that on the ground conservation efforts can be maximised. My study recommends the use of careful observational protocols for the in-field detection of both rare and common plant species. The method used in this study was both efficient and cost effective, addressing two major challenges of protected area authorities: capacity and funding. The detection methods employed in this study also allow for more than one species to be detected at a time where the habitats they occur in are similar. It was also possible to do simultaneous population counts and habitat condition assessments. Not all protected areas have the same species component as Table Mountain National Park with its high numbers of endemic and rare plants (Linder 2005), thus the in-field detection method used is flexible and can be adapted to the needs of a particular protected area anywhere in the world. For example the transect length can vary as long as the standard collection effort is set and maintained and is repeatable over time. From the field detection data it was possible to verify a species as extant at its known subpopulation localities, but more importantly whether a reduction in species subpopulations had occurred.

The use of historical and contemporary data in the Solow equation found no correlation between the Red List status of a species at a broad scale and the actual status of that species in Table Mountain National Park. This by no means implies that the Red List should not be used by protected areas for conservation planning for the overall global conservation of species. However, species that are in decline in a protected area, irrespective of their Red List status, should be listed and monitored and action taken to prevent their loss. More species can be saved from extinction by prioritising where resources are placed and efforts to save species can be maximised. This study found through in-field surveys of species subpopulations in Table Mountain National Park that there was a general decline of all species. Those with greater decline or more immediate threats can now be prioritised for monitoring and other management actions (Midgley and Thuiller 2005). Many protected areas follow the ‘precautionary principle’ which leans towards the assumption that a species is extinct rather than extant in a protected area. Scientists and conservationists tend to take a conservative view and an overly cautious approach to extinction (Swaisgood and Sheppard 2010), often listing species as extinct in an area according to risk assessments by the IUCN Red List and focussing on finding, and at times documenting, the decline of these species with little to no remedial actions taken. This can be detrimental to time and effort spent searching for species that are indeed extant and thriving, when others are disappearing.

Prioritisation of conservation actions depends on a number of factors, and the risk of species loss has to compete with financial costs, resources and human capacity. Although the IUCN Red List attempts to prioritise the likelihood of species extinctions it does not take into account threats at subpopulation level and these competing factors. This study articulates the degree to which the IUCN Red List is used for conservation planning but also how, at a finer scale, it does not align with extinction predictions or in-field survival of species in a protected area. The next stage in the evolution of the Red List may be setting small scale limits on how to prioritise action and monitoring in protected areas (and other small geographically defined areas). Fieldwork is required to establish and monitor extant populations and define threats at the level of habitat health and species survival, such micro-assessments require time, resources and support from policy makers (Balmford et al. 2005, Novellie et al. 2016). Should such small scale assessments be made part of the Red List tool box, the reported results will be real and tangible, making a difference to plants and people's lives, in the form of resource use and ecosystems services.

Certain species may continue to occur in small populations as they did in the past as evident in the historic herbarium and collection records as long as their habitat is secure and the more immediate threats have been mitigated (i.e. alien vegetation, frequent fires) (Linder 2008). This research verifies the presence of species in protected areas and adds to the literature on field detection and monitoring of species under threat. I reiterate that the fieldwork data needs to be robust and accurate and hence field observers must be trained to know a range of species in the biome in which they are working. I restate my earlier argument that scholars and students need to undertake fieldwork in their training and be exposed to real-world scenarios and not textbook or desktop descriptions alone. This on-the-ground training is desirable when interpreting results and findings of methods such as the extinction probability equation used in this study.

Financial support for botanical expeditions and the maintenance of herbaria has been drastically reduced globally as cited in the works of numerous authors who use herbarium specimens (Garcillan and Ezcurra 2012, Lavoie 2013, Lavoie et al. 2013, Brummitt et al. 2015). For conservation of biodiversity to succeed, plants and the places where they were and are found must have value in human society. Field collecting and monitoring can enhance those values and their cultural acceptance, in that knowledge exposes the practical applications and inspires further learning. The importance of herbarium records for conservation thus lies in defining the different contributions they have made to our development as a cognisant species, via biocultural heritage, development of a global classification system to name species or to modern conservation practices to prevent species extinction.

6.6 Future research and recommendations

This study has argued that historic herbarium specimens and the *in situ* sites where they were collected meet the criteria for biocultural heritage. They are irreplaceable and are important biocultural heritage assets. These historic sites should be conserved, as well as the historic collection registers and diaries that capture the stories of the people who collected species in the area for science. In light of the current global trend towards a conservation agenda that extends beyond just species preservation (Gross et al. 2013, Turnhout et al. 2013, Pimm et al. 2014, Novellie et al. 2016) protected area management should establish whether historic collections have been made in the protected area and embark on in-field surveys to establish if the historic localities and plant populations are still there. If this proves true then these sites should be included in biocultural heritage monitoring activities, regardless of the Red List status of the species.

The collection effort that took place in the past was tremendous and the passion and enthusiasm of the botanical collectors is still evident in their herbarium records. The need to continue collecting and recording species is no less important today. Long-term observations and monitoring of natural populations is possibly the best way we have to track the survival of species and this should be supplemented with information from herbarium material (Weisser et al. 2017). Although the reasons may have changed, the underlying need for data, both long and short-term, is still paramount, and this sentiment is echoed throughout the literature (Jeger and Pautasso 2008, Masubelele 2012, Tomović et al. 2015). Along with the collection and curation of specimens, the practice of keeping detailed diaries should be encouraged in students and young botanists as they are writing the archives of our future histories (Roux et al. 2010). From these records biocultural heritage will continue to be developed and recorded.

This also highlights the need for the training of more people in the kind of skills needed by SANParks Regional Ecologists working in the multidisciplinary environment currently found in conservation. These skills could include fieldwork, analysis, literature research, stakeholder relations, problem solving, horizon scanning, lateral and creative thinking. The Fynbos Biome attracts many botanists and researchers from around the world and locally, and efforts need to be made to harness their expertise and share it with local scholars. There are many places around the world with similar situations where scholars can benefit from in-field botanical collection training.

The economics of conservation should be considered in a business-like manner and the best methods for investing in biodiversity conservation should be found and communicated to all parties involved (scientists, managers, policy makers and funders) (Balmford et al. 2002, Balmford et al. 2005, Novellie et al. 2016). Currently it is not feasible to monitor all IUCN Red List species within a protected area given the economic climate most protected areas find themselves in (Sieck et al. 2011). As discussed in this thesis the limited resources available to protected areas must to be used for the best outcome for a species. By targeting high-priority species for monitoring in a protected area and those which have the greatest return on investment for the conservation of the species, pressure on protected area management to monitor all species just because they have a Red List threat status will be reduced.

The literature on government support for conservation increasingly suggests that field work is underfunded, viewed as unnecessary and too costly (Bradshaw and Borchers 2000, Dunlap and McCright 2008, Kepe and Kobokana 2008, McCright and Dunlap 2011). The evident lack of financial support suggests a failure to recognise the contribution of field work and biological collections to science. This thesis serves to stress the varied and numerous contributions that herbarium collections have made in the field of botany, and arguably more broadly to science, and their continued contribution to modern science and current conservation research. The narrative and quantitative evidence produced here ideally speaks to this gap in understanding, making this available to a broader audience could serve to stimulate the kind of funding interest required to secure and extract the potential value of these important records. What is needed now is an increase in financial support for botanical monitoring and field work. Government and research institutions should be made aware of the value of herbarium specimens and that financial support be secured for historic specimens and more recent collections to be kept in herbaria. Support for the collection of herbarium specimens and the maintenance of herbaria is urgently needed. By using these data more, the scientific community can highlight the financial value and scientific worth of these collections, such as this study has sought to do. Although herbarium specimens are some of the best long-term records of plant species, there are those that are only from a single collection and datasheet. This makes the use of such data extremely difficult as many models and formula require between five and 15 specimens or records (Rivers et al. 2011). Studies should therefore be initiated to collect these species, regardless of threat status and they should be retained in herbaria along with the more charismatic and rare species. This research supports the views of Green and Losos (1988) and more recently Swaisgood and Sheppard (2010) who highlight that an appreciation by governments and funders of the connection and dependency of modern conservation management on botanical collecting and monitoring field work needs to be established.

The research at hand shows that using herbarium and survey records, although old and at times incomplete, can aid in the location of species at a very fine scale within a protected area. In accessing and using the survey data, from research, botanical assessments and conservation monitoring, it was evident there is a significant shortcoming in the management of this resource. What appears to be needed is better interaction between survey and herbarium data to determine extinction probabilities. To address the problems found in these records the development of synergies between the botanical surveys and storing these data on a centralised database are needed. Data should be placed into a central repository, with standardised checking and maintenance , a prime example of a working system for taxonomy is the Tropicos System of Missouri Botanic Garden started in 1983 (Winston 1999), which since 1983 has made over 1.3 million scientific names and 4.4 million specimen records available to the public. It is evident from this thesis that a standardised global information system needs to be developed for all botanical (and perhaps other) field surveys and herbarium records, and made available on open access networks. This would serve to increase the use of herbarium specimens and contemporary survey records as well as their associated collection information. For example initiatives are currently being rolled out around the world that use standardised templates, uniform nomenclature standards like those developed by Linnaeus and consistent georeferencing techniques, these include the Botanic Gardens Conservation International Threat Search Database and the Mammal Networked Information System of North America. One such way of doing this efficiently is the use of collaborations between institutions that hold more data (particularly survey records), these include museums, universities, private consultants and nature conservation bodies (Rowe 2005). The next step is then to obtain further understanding of the risk of species loss is to investigate new practical methods of data collection such as remote sensing, citizen science and social media.

I echo the recommendation of Brummit et al (2015) that these datasets be ground-truthed for a true reflection of a species status. Notwithstanding these challenges the information at hand has several strengths but these results do demonstrate the need for further testing and refinement of the extinction probability equations to use sparse and poor data sets as are available in the real-world. Once protected area managers are aware of the stability or decline in species metapopulations under their management they can set thresholds of concern, conduct regular monitoring of priority species, and implement actions supposing a threshold is breached and a red flag raised. Protected area authorities, by defining the threatened species important to them, can also set standards to control the quality of data that is collected in their areas (Collen et al. 2010). As demonstrated in this thesis using in-field detection methods, new surveys, and survey locations can also be undertaken once a baseline of species subpopulations has been determined. Citizen science has played a significant role in collecting biodiversity data around the world and in South Africa. Advances in technology also provide new opportunities to connect and share observations, and have made it possible to engage a wider community for more varied projects. These technologies and citizen science projects have engaged members of the public in innovative ways and provided many opportunities for data collection and should be encouraged by conservation organisations such as SANParks. In using existing networks, such as student research projects and citizen science programmes, to ground-truth plant population localities (Brummitt et al. 2015), protected areas can reduce effort and costs in developing new collaborations.

One of the greatest challenges of our time is to realise that humans have altered the planet and threaten the future of the species on it, and it is up to science and conservation to find a solution to prevent the loss of biodiversity rather than recording the decline. One such way is by studying the speed with which species are capable of changing genetically to adapt to new climatic conditions as they develop. We may then be able to mitigate the loss of many narrow range endemic and rare species such as occur on the Cape Peninsula and other similar habitats. Historic records provide a glimpse of what the situation may have looked like prior to human induced climate change and massive anthropogenic changes. Current survey and herbarium data provides a present temporal scale, by employing both of these data, species declines can be found and possibly future extinction can be forecast, enabling conservation actions to be put in place to try prevent the loss of species.

6.7 Final thoughts

Historic herbarium specimens allow us to reach back and, potentially, forward in time in a way that no other current botanical dataset can. At a fine scale they are invaluable in finding historic populations of biocultural heritage sites and aiding in-field detection of subpopulations in protected areas. Their character, detail and their preservation of a particular moment are a considerable asset to conservation and science. Beyond their own immediate value they provide lessons from the past, highlighting shortfalls in our current botanical conservation practices. Drawing on the rich history of botany and its evolution in science, this study found evidence to recognise the value of herbarium specimens for ecological study but also a new aspect to science; the influence of people. The role of people in the collection of specimens and the interpretation of information into knowledge is evident in this study.

The thesis demonstrates the importance of field biology. The historic chapters show how extensive effort and attention to detail in developing useful methods in botanical collecting persist through time. There is a need to revive the role of the field-biologist, to reinitiate a period of collection, data gathering and knowledge generation. This thesis highlights the current situation protected areas find themselves in, with recognition of the biodiversity crisis, fiscal constraints, and data limitations imposed on them. A central electronic hub where botanical collection data, consisting of herbarium records, and all freely available botanical survey records, and their associated meta-data is vital if the conservation and research of biodiversity is to be successful.

The results presented here move beyond the South African protected areas, by providing grounds for important future work on the development of fine scale Red List assessments for localised areas (such as protected areas) and also highlight the need for ongoing field work and a standardised synthesis of all available botanical data for making more informed decisions in the field of conservation. This research has shown that advances in science occur when empirical and theoretical studies embrace multidisciplinarity in their approach to finding solutions to conservation and environmental needs.

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