Strategies for the development of plant systematics in a floristically diverse region

by

Janine Elizabeth Victor

Submitted in partial fulfilment of the requirements for the degree

Philosophiae Doctor

in the Faculty of Natural & Agricultural Sciences

(Plant Science)

University of Pretoria

Pretoria

Supervisor: Prof. Dr. A.E. van Wyk

Co-supervisor: Prof. Dr. G.F. Smith

July 2015

DECLARATION

I, Janine Elizabeth Victor, declare that the thesis/dissertation, which I hereby submit for the degree Doctorate of Philosophy at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: ....JEVictor...................

DATE: 1 July 2015

ABSTRACT

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South Africa is one of the most biologically diverse countries in the world, and harbours one of the richest floras. Vast areas of the country remain under-collected, and a large proportion of species are taxonomically problematic and under-represented in herbarium collections. These factors hinder management of biodiversity. The main intention of this study was to develop a strategy for plant taxonomic research that would meet the needs of end users, and make efficient use of scarce human and financial resources in South Africa.

The development of plant taxonomy in South Africa from 1600 to 2014 is reviewed, with emphasis on the main driving factors that have influenced the research direction, techniques used, and choice of taxonomic research topic. At present the predominant culture of taxonomy is directed towards electronic dissemination of taxonomic information, leading to increased accessibility and connectivity.

An assessment of plant taxonomic capacity in South Africa is provided. From an analysis of the existing gaps in taxonomic information, current research trends, and existing resources, it is apparent that there is a critical shortage of human capacity in South Africa to conduct plant taxonomic research for the benefit of biodiversity and society.

An objective method of prioritising taxa in urgent need of taxonomic research was developed and can potentially be used for all organisms and be equally applicable to other parts of the world. This methodology informed the development of a *Strategy for plant taxonomic research in South Africa 2015–2020*. Three research programmes are proposed to focus on the main gaps in taxonomic knowledge, and a plant collecting programme is suggested to improve foundational biodiversity data. The maintenance of high quality standards for information contained in taxonomic databases is crucial, hence recommendations are made for addressing data quality.

Since implementation of the Strategy at SANBI in 2011, progress has been satisfactory. It is anticipated that by 2020, South Africa will have a centralised online electronic resource for plant taxonomic information; the number of genera in urgent need of revision will have halved; and taxonomically problematic taxa reduced by 20%. In this way strategic planning benefits both taxonomy and end users.

Keywords: barcoding, biodiversity, botanical gardens, botany, capacity, connectivity phase, development, flora, herbarium, plant taxonomy, SABONET, SANBI, research, strategy, southern Africa, systematics, taxonomists, training.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Biodiversity is the diversity of genes, species, populations, communities and ecosystems, and interactions among them. Taxonomic research underpins biodiversity studies and involves the discovery, naming, description and classification of taxa, and encompasses evolutionary and phylogenetic investigation. The terms taxonomy and systematics are commonly used interchangeably (Stace 1980; Singh 2004), although some authors prefer to differentiate between them by restricting the term taxonomy to the study of classification, and systematics to that including investigation of the causes and processes of evolution and the study of phylogeny (Stuessy et al. 2014). In this thesis the term taxonomy is intentionally used as synonymous with systematics as the word 'taxonomy' is used in the mandate of the South African National Biodiversity Institute (NEMBA 2004). Moreover, the International Association of Plant Taxonomy uses the term taxonomy, and it is perhaps a better known and understood term outside of scientific circles. The term 'biosystematics' is also sometimes used by taxonomists to refer to the discipline of taxonomy in a broad sense; in other words, to the taxonomy of organismal groups that cover the full spectrum of biological diversity. However, it was initially introduced to refer to studies on evolutionary relatedness of taxa, and later came to refer to experimental studies in taxonomy using data aside from traditional morphology and anatomy (Stuessy et al. 2014).

The primary purpose of taxonomy is to describe, name and classify organisms based on facts as observed, with an understanding of the kind of processes that underlie those facts (Johnson 1996). Unless organisms are correctly named, and therefore each taxonomic group with a particular circumscription, position and rank bears only one correct name, accessing the wealth of information that is available for biological organisms is impossible. This is one of the Principles (Principle IV; p. 3) of the *International Code of Nomenclature for algae, fungi, and plants* (McNeill et al. 2012). Scientific discovery in the biological sciences is severely constrained without reference to validly published names and stable classification systems. In this way, taxonomy is a fundamental science that is essential to all users of names of organisms. This thesis will focus mainly on plant diversity in South Africa, and consequently the taxonomy of plants, rather than other groups of organisms.

The South African National Biodiversity Institute (SANBI) was established upon its forerunner, the National Botanical Institute (NBI) on 1 September 2004 when the National Environmental Management: Biodiversity Act (NEMBA) was signed into law by President Thabo Mbeki. The mandate of SANBI includes the responsibilities to study and conserve the full diversity of South Africa's fauna and flora, and to promote this to the public through education, and visitor and information services. Specifically in the Act relating to taxonomic research, SANBI is mandated to:

a) coordinate and promote the taxonomy of South Africa's biodiversity;

b) collect, generate, process, coordinate and disseminate information about biodiversity; and

c) undertake and promote research on indigenous biodiversity.

It needs to be acknowledged that a considerable amount of biodiversity research on the South African biota is conducted outside SANBI both locally and abroad, notably at institutions such as universities and museums, as well as by amateur/private taxonomists and naturalists. Tertiary institutions such as universities are also responsible for the training of the human capital and to build capacity for taxonomic research in South Africa.

1.2 Plant taxonomic research in South Africa in context of international initiatives

Botanical exploration of South Africa started early in the 17th century (Gunn & Codd 1981; See also Chapter 2 of this thesis). Most taxonomic research aims towards revisions of taxonomic groups, or other similar compilations (such as conspectuses, Floras, synopses and monographs). Despite an extensive body of literature published on the South African flora over more than 400 years, mostly in the past 100 years, gaps still exist. A vital step for prioritising current and future taxonomic research is to evaluate what has been done, and what is most urgently required.

It is well known that taxonomy has been tainted as a pseudo-science in the past, integrating information from other fields and making subjective judgements based on personal perceptions (Sokal & Sneath 1963). This has led to the development, inter alia, of numerical approaches to systematics, including the cladistic method (for reconstructing phylogeny), that are purported to be more objective, explicit, and repeatable. Besides this, taxonomy involves making repeated measurements and collating data on variation in all characteristics of plants, such evidence which is weighed up to make decisions that would result in groups (taxa) that have high information content and predictive value.

The importance of taxonomy as a vital discipline for all other fields of biological science is undisputed (Lowry & Smith 2003; Wilson 2003, 2004; Smith et al. 2008; Victor & Smith 2011; Ebach et al. 2011). In spite of this, various international conventions, including—initially—the original Convention on Biological Diversity (CBD), impose obligations towards biological diversity without specifically mentioning taxonomy, assuming that this resource is globally accessible (UNEP 1992). At the second meeting of the Subsidiary Body on Scientific, Technical and Technological Advice of the CBD in 1997, it was acknowledged that declining taxonomic expertise, coupled with inadequate taxonomic information and infrastructure, hindered effective decisions regarding conservation and management of biodiversity. This 'taxonomic impediment' was recognised by governments and lead to the establishment of the Global Taxonomic Initiative (GTI) at the fourth meeting of the Conference of Parties to the CBD (COP) in 1998. The objective of the GTI is to remove the taxonomic impediment through development or strengthening of human capacity to generate information (UNEP 2010a). Since South Africa is a signatory to the CBD and has ratified the convention, the country is obligated to deliver on these objectives. SANBI was given the mandate to fulfil these obligations.

Taxonomy was explicitly addressed in the first target of the initial Global Strategy for Plant Conservation (GSPC): to understand and document biodiversity in having a "widely accessible working list of all known plant species, as a step towards a complete world Flora" (UNEP 2002). At COP 10, held in Nagoya, Japan, an amended and updated GSPC was adopted as part of the plan of work of the CBD (UNEP 2010b). Two additional goals were included in Target 1 of the 2011–2020 GSPC (UNEP 2010b): (1) to add descriptive and other flora-style information to the checklist; and (2) to disseminate such information electronically. As a result, the first target of the GSPC now aims to produce an electronic online Flora for all the plants of the world by 2020.

At COP 11, held in Hyderabad, India, in 2012, a capacity building strategy for the GTI was adopted. Amongst other things, the capacity building strategy aims to identify gaps and prioritise capacity-building needs, and to generate and maintain taxonomic information to meet the identified taxonomic needs. The first strategic action proposed in this regard is to "review taxonomic needs … and set priorities to implement the Convention and the Strategic

Plan for Biodiversity 2011–2020." This strategy will contribute to the government of South Africa's obligation to fulfil the aims of the capacity building strategy for the GTI.

In South Africa, biodiversity is a national asset in terms of industries such as tourism, horticulture, agriculture, medicinal use (traditional and commercial). Therefore one of the most important questions is how to manage this asset considering the challenges that are posed by the high diversity coupled with a developing economy and rapid population growth. Taxonomists need to supply foundational biodiversity information as a first step towards managing the biodiversity and in this way, facilitate its protection for future generations. Conservation and economic use of plants are two examples of disciplines hindered by taxonomic problems. This is especially evident in conservation as taxa that are insufficiently known can be mistaken as rare or threatened as their apparent scarcity results from lack of specimen collections or knowledge about them. Conservation assessments therefore need to distinguish between species that are truly conservation priorities from those that are artefacts of inadequate taxonomic knowledge of the taxon (Victor 2006).

1.3 Strategies for developing taxonomy in other parts of the world

Very few taxonomic research strategies exist for institutions similar to SANBI in other parts of the world. In the United Kingdom a committee was set up by the Natural Environment Research Council to ascertain whether there should be a national strategy for taxonomy and if so, how it should be developed. The report submitted in 2011 concludes that "taxonomy and systematics is a science with a series of unique features that make the explicit development of a national strategy very advantageous," and recommends that a committee be set up to develop the national strategy (Godfray et al. 2011). Furthermore taxonomy in support of conservation in the Overseas' Territories is considered a priority. It is iterated that the committee should bring together the United Kingdom taxonomic community to prioritise major research programmes that will advance taxonomy. Although to date (2015) this has not been done, the report went on to speculate on some examples of what major taxonomic research programmes might entail:

a) major digitisation campaigns;
b) establishment of web-based taxonomies of significant taxa;
c) completion of significant taxonomic resources (such as identification guides) for the United Kingdom;
d) assembling key branches (phylogenies) of the Tree of Life;

e) barcoding campaigns;
f) taxonomic inventories of selected United Kingdom Overseas Territories; and
g) major micropalaeontological resources to reconstruct climate change.

A comparison and discussion of South African taxonomic research programmes, including those resulting from the current study, is presented in Chapter 7.

1.4 South Africa: a megadiverse country

The Flora of southern Africa (FSA) Region (South Africa, Namibia, Botswana, Lesotho and Swaziland) has the richest temperate flora in the world with approximately 22 000 species described to date, and ten percent of the world's vascular plant flora in conjunction with extremely high levels of endemism, and three global biodiversity hotspots, namely the Cape Florstic Region, Succulent Karoo and Maputaland-Pondoland-Albany hotspots (Mittermeier et al. 2004). A fourth Hotspot, the Eastern Afromontane, is also well represented in the FSA region, although this fact has accidentally not been explicitly highlighted in Mittermeier et al. (2004). The bulk of this diversity (> 20 000 species of vascular plants and bryophytes) is found within the Republic of South Africa, an estimated 57% of which is endemic to the country (Germishuizen et al. 2006). Consequently, South Africa has been listed by Conservation International as one of the 17 megadiverse countries of the world, qualifying according to the criteria of having at least 5 000 of the world's plants as endemics, and having marine ecosystems within its borders (Mittermeier et al. 1997). These countries harbour the majority of the Earth's species and are exceptionally diverse. Taxonomic research in South Africa has historically been driven by curiosity in the rich and diverse flora that develops through the normal course of exploration and curatorial work on preserved and living collections, and by personal motivation to investigate groups of interest, in which problems are uncovered and investigated. The disadvantage of this approach is that the real value of the results can be underestimated or remain unrecognised, and sometimes urgent problems remain unresolved.

1.5 Problem statement and rationale for study

Unresolved taxonomic problems, problematic classifications and lack of a clear strategy for developing plant taxonomy hinder management of biodiversity and hamper opportunities for the management or sustainable use of species for economic purposes. Lack of financial or human capacity for taxonomic research, as well as lack of resources such as infrastructure, study material (plant specimens) or data, can impede taxonomic research thus impacting ultimately on management of biodiversity. Addressing these problems forms the basis of the rationale for the current study. Suggestions for capacity development and improving resources are made but detailed strategies for these are beyond the control and scope of the study. Thus the main intention of the study is to provide a method for prioritising taxonomic research so that a strategy can be developed to meet needs of end users and make efficient use of scarce and dwindling resources. For this it is important to investigate the current needs of end users, gaps in taxonomic knowledge, taxonomic research products needed, and capacity and resources required, and to produce objective and universally applicable methods for determining research priorities.

1.6 Key questions

a) What are the current and historical driving factors of taxonomic research priorities in South Africa?
b) How can SANBI fulfil its mandate to provide a coordinated framework (that would also be of value to other national institutions) for taxonomic research on plants?
c) Who are the end users of taxonomic research products?
d) What are the needs of end users of taxonomic research information?
e) What are the gaps in taxonomic information?
f) What capacity and resources are required to fulfil these taxonomic requirements?
g) What sources of data can be interrogated to determine taxonomic priorities?
h) How should data be interrogated to determine taxonomic priorities?
i) What methodology can be developed to objectively determine taxonomic priorities for all organisms, including plants?
j) Is it feasible to produce a taxonomic research strategy for all groups of organisms?
k) Is it feasible to produce a taxonomic research strategy for plants?
l) Would taxonomic research benefit from having a coordinated strategy to address the needs of end users?
m) Would prioritised taxonomic research improve the relevance and impact of derivative research products that are aimed at benefitting end users?
n) What is the possible impact of a taxonomic research strategy on society?

1.7 Aims and objectives

The aims of this project are therefore to:

a) give an assessment of the history and current state of plant taxonomy in South Africa;
b) investigate the capacity associated with taxonomic research (human, financial and otherwise), and the needs and requirements for taxonomic research;
c) develop methods to determine the priorities for taxonomic research;
d) implement a strategy for plant taxonomic research in South Africa; and
e) evaluate the success, failure, results and impact of implementation of the strategy.

Objectives associated with these aims are to produce a strategy for plant taxonomic research to be implemented in SANBI that can be used to promote taxonomy nationally, and to assess the effectiveness of the initial priority setting exercises. It is hoped that some of the experiences, approaches and outcomes of this study may also provide guidance to decision makers of taxonomic research in other parts of the world, especially the so-called megadiverse countries.

1.8 Hypotheses

a) SANBI can better fulfil its mandate by providing a coordinated framework for taxonomic research on plants.
b) Taxonomic research priorities have been driven partly by personal influences such as curiosity or financial gain.
c) Taxonomic research priorities have been driven partly by external influences, such as searches for economically important plants.
d) Targeted taxonomic research would improve the relevance and impact of derivative research products (such as Floras) that are delivered to the benefit of end users.
e) Gaps in taxonomic information can inform research priorities.
f) Existing taxonomic data derived from databases can be analysed, and the literature interrogated to determine taxonomic priorities.
g) An objective methodology can be developed to determine taxonomic priorities.
h) Taxonomic research would benefit from having a coordinated strategy to address the needs of end users.

1.9 Research approach

The objectives of the research for this thesis were achieved using intensive literature studies, herbarium plant specimen database interrogation, consultations with experts, analysis of data, application, implementation and evaluation of the results. Because this thesis addresses taxonomic research in South Africa, discussions on herbarium collections, data capture and dissemination are not emphasised. The following steps were taken (for more details on the methodological approach followed, see Chapter 3):

1. literature survey to establish the history and drivers of taxonomic research;
2. assessment of capacity for plant taxonomic research;
3. identification of end users and needs of end users;
4. development of a method to highlight taxonomic problems in conservation assessments;
5. resulting methodology applied to prioritise families for taxonomic research;
6. indicators of taxonomic problems and priority groups chosen;
7. methodology for prioritisation of taxonomic research taxa developed and refined;
8. herbarium plant specimen database interrogated;
9. draft strategy and list of taxonomic research priorities developed and implemented;
10. ongoing consultation with taxonomists and end users in South Africa, and international taxonomists, to refine resultant priority list produced, and to improve methodology and strategy;
11. collaboration with experts in fungi, bacteria and archaea, and algae to develop a coordinated research strategy for these organisms; and
12. results of implementation of strategy for plant taxonomic research evaluated.

Although the long term monitoring of the success of the strategy falls beyond the scope of this study, it is hoped that projections from initial results will give a prediction of expected success or failure of the project.

1.10 Thesis structure

This thesis comprises a series of chapters, as well as published contributions on developing and implementing a strategy for plant taxonomic research in South Africa. The published work is presented in the Appendices, and referenced in the chapters. Chapter 1 is a general introduction, which is followed by a more in-depth literature review on the history and drivers of plant taxonomy in South Africa in Chapter 2. In Chapter 3 the methods used and approach followed are presented, with the list of experts consulted during the course of the study given in Appendix 1. The results of the study are provided in Chapters 4 and 5. Chapter 4 gives an overview of the results of a survey of current capacity for taxonomy in South Africa, including the resources available to taxonomists. In Chapter 5 the results of the development of strategies for taxonomy in South Africa are presented. This includes the needs analysis; the development of methods to determine taxonomic problems; and presentation of the taxonomic products required and research strategies to achieve these. In presenting the published and submitted contributions, in each case the topic is briefly summarised and refers to the full comprehensive article that is included in the relevant Appendix (Appendices 2–8). As these appendices form part of the study, this necessitates some repetition of text between the papers and presentation in the chapters. Chapter 6 expounds an evaluation of the initial strategy after implementation, with case studies conducted by the author discussed, and resulting publications included in Appendices 9–11. The general discussion is presented in Chapter 7. The final chapter, Chapter 8, summarises the conclusions reached and reiterates the recommendations made. This is followed by the References, Summary, Acknowledgements, Curriculum Vitae, and Appendices. The final appendix (Appendix 12) contains supplementary information referred to in Chapter 4.

CHAPTER 2

HISTORY AND DRIVERS OF PLANT TAXONOMY IN SOUTH AFRICA: A LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to put the current study into context by examining the development of plant taxonomy in South Africa, to discern the main driving factors that have influenced the research direction, techniques used and choice of topic for taxonomic research. For this it is necessary to review and analyse some of the history of the development of taxonomy in South Africa, including the establishment of universities and institutions for studying botany, governmental legislation, as well as international drives that influence taxonomy. Since the mandate to coordinate taxonomy in South Africa belongs to SANBI, and SANBI and its forerunners have historically always played a leadership role in this regard, this review inevitably gravitates towards aspects of the history and development of this institute. Discussion of notable botanists not related to SANBI who may have influenced the course of taxonomy focuses mainly on those who made contributions before 1980. Numerous amateur botanists and eminent scientists or plant collectors have contributed significantly to the development of South African taxonomy. Timelines depicting key events in development of plant taxonomy in South Africa from 1600 to 2014 are supplied in Figures 1–3 at the end of this chapter. Biographic notes on many botanists who contributed to the progression of plant taxonomy in southern Africa are provided in, amongst others, Gunn & Codd (1981), Codd & Gunn (1985), Glen & Germishuizen (2010) and Moffett (2014). A bibliography of South African botany up to 1951 was published by Bullock (1978), and one for South West Africa, by Giess (1989). Additional articles that provide a historical overview have been written by De Winter (1970), McCracken & McCracken (1988), Rourke (1999), and Huntley (2012). Many observations on recent developments were made through interpretation and personal communication by the author, hence the lack of citation for recent historical events.

2.2 Influence of exploration on plant taxonomy in South Africa

The first European travellers who ventured to the southern tip of Africa, and beyond, by ship were undoubtedly intrigued by the fascinating new plants encountered at the 'Cape of Storms'—the name coined for Table Bay and its surroundings by Bartholomeu Dias who passed by the Cape in 1488 (Jackson 1980). Some 10 years later another of Portugal's great seafarers, Vasco da Gama, who commanded the first ships that sailed from Europe to India, again rounded the Cape during an outbound journey that took him all the way to the true East and its treasures (Axelson 1998). However, the collection of plant specimens for shipping back to Europe for naming and description apparently only started about 100 years later when Gouarus de Keyser collected two *Haemanthus* species in 1600 that subsequently flowered in Belgium (De Winter 1970). These were illustrated by Mathias de l'Obel in *Rariorem* in 1605, approximately the same time that Jules C. L'Cluse published a plate and description of a flowerhead of *Protea neriifolia* R.Br. in *Exoticarem* (De Winter 1970).

The early interest in South Africa's flora and, by implication, its taxonomy was initially driven by curiosity. In particular the collections of the German missionary Justus Heurnius, described in 1644, pioneered botanical exploration in the region. Contributions such as this, arising from the early exploration of the country, along with the search for plants of medicinal or other economic importance, stimulated the naming and description of plants in the pioneering phase (*sensu* Jones & Luchsinger 1987) of South African botanical history. These initial efforts to document the plants of South Africa hardly attempted to cast them into a classification system. This changed after 1753 when Carl Linnaeus published his *Species plantarum*, introducing binomials (initially referred to as 'trivial' names) and a classification system based predominantly on reproductive organs. This so-called sexual classification system, based on, for example, number and type of floral reproductive parts, facilitated the identification of species rather than reflecting natural groupings, and is now accepted as having been largely artificial. This was about a century before the publication of Charles Darwin's *On the origin of species* in 1859, in which evolution became better understood, and eventually incorporated into classification systems. Initially, the intention of taxonomy was to explore and document the flora and to enable identification and record the beneficial properties of plants.

Early herbarium collections are often devoid of good locality notes and descriptions, with 'Cape of Good Hope' or 'Cabo Bona Spei' being examples of typical early locality descriptions. This can pose difficulties when later botanists attempt to relocate specimens or reaffirm taxonomic concepts. William J. Burchell was one of the first natural history collectors to provide comprehensive notes on exact locality, plant description and additional information collected in the field. Burchell advocated the establishment of a botanical garden in Cape Town, and collected over 40 000 botanical specimens between 1811 and 1815. The large majority have not been preserved but most of those that exist today are kept in the herbarium of the Royal Botanic Gardens, Kew. Johann F. Drège was another botanist who collected a sizeable amount of specimens (200 000 between 1826 and 1834) that were enhanced by good field notes. The collections of Drège were also sent to European herbaria, the majority of which were unfortunately destroyed in a fire at Hamburg in 1842.

Up until about 1850 more than 170 people had collected specimens of South African plant species (Glen & Germishuizen 2010), although only 6 276 of these are in SANBI herbaria with the majority having been sent to European herbaria by early collectors. After 1850 the number of collectors and collections in South African herbaria accelerated rapidly as the interior of the country became more accessible following the Voortrekkers embarking on the Great Trek, and the discovery of diamonds (Kimberley) and gold (Mpumalanga and the Witwatersrand). Hence the interior became increasingly populated by immigrants interested in rapidly emerging economic opportunities. Improvement of rail and road transport infrastructure resulted in the intensified botanical exploration of the country, which peaked over the period 1976–1980 according to specimen accession records of SANBI's herbaria (Figure 4). The subsequent decline in number of specimens collected as represented in SANBI herbaria can be attributed to, inter alia, the introduction of handling fees for identification of plant specimens at the end of the 1980s; increased security risks; reduced access to land granted by owners; increasingly onerous permitting requirements for plant collecting; and increasing costs of carrying out fieldwork.

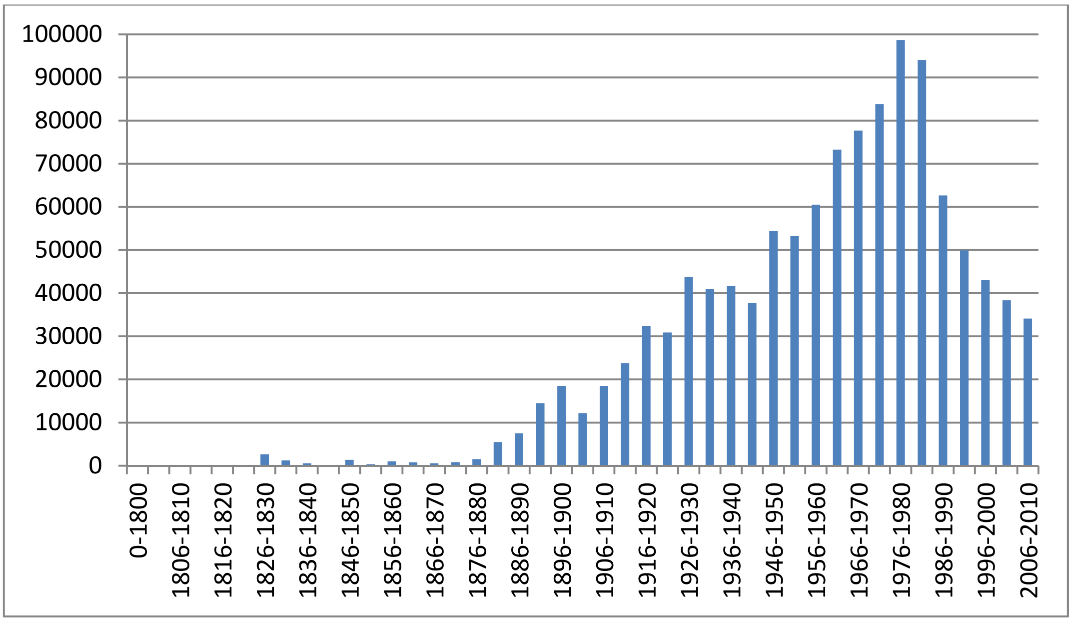

Figure 4. Number of specimens of South African plants collected per five year interval represented in SANBI herbaria.

Many plant collectors (especially taxonomists, conservationists and ecologists) have contributed, and continue to contribute, extensively to the herbarium collections representative of the South African flora, including trained botanists, students and amateurs. Gunn & Codd (1981) and Codd & Gunn (1985) compiled extensive records of notable botanists have contributed to the exploration of the country up to the 1980s, including prominent plant collectors and their contributions. Even collectors who have not contributed large quantities of specimens to herbaria may have added important collections for example by targeting economically important plants, rare or threatened plants, or those in previously unexplored areas. All contributions add value to the information that can be disseminated from databases into which the specimen information is added. Collections stored in the herbaria provide an essential resource for taxonomists to conduct their work.

In South Africa formal training in botany at the start of the 20th century was virtually non-existent, and one of the important plant collectors of the time, Harry Bolus, did much to advance botany as a science to be studied at universities in the country. Bolus was a stockbroker who became an enthusiastic botanist collecting all over the country and amassing what was to become one of the most important herbaria in the country. In addition he published a comprehensive account of orchids, some of which he illustrated himself. Bolus provided student bursaries and assisted young botanists in various ways. In 1902, he founded a chair of botany at the South African College, now the University of Cape Town (UCT), later designated the Harry Bolus Chair of Botany. Upon his death in 1911, he bequeathed his herbarium to the South African College. Today it is known as the Bolus Herbarium and is administered by UCT.

2.3 Influence of establishment of formal botany in South Africa

In 1759 Carl Linnaeus published the first *Flora capensis* of 502 species of plants that he received from the Cape, classified according to his sexual classification system. The first trained botanist to do fieldwork in South Africa was Carl P. Thunberg, a student of Linnaeus, who arrived in the Cape in 1772 and stayed for three years (Nordenstam 1994). Thunberg undertook a number of excursions to collect over 3 000 plants, and published numerous academic dissertations describing the plants he had collected of which over 1 000 were new to science. These were condensed into the *Prodromus plantarum capensium* with the classification still based on that developed by Linnaeus. The next substantial botanical work published on the South African flora (and the first to be published in South Africa) was *The* *genera of South African plants* by William H. Harvey in 1838, which used natural family designations and described 1 086 genera. Harvey was the Colonial Treasurer at the Cape but had a passion for plants and was driven to collect and research them in his spare time. His motivation for writing a consolidated book on the genera of South African plants was that literature from fragmented and sometimes "ancient" works existing at the time "would have proved perfectly useless to my lady friends, who, not being blue-stockings, could have derived little instruction from the crabbed Latin in which they are written" (Harvey 1838). Harvey was later appointed as the Chair of Botany at the University of Dublin, and was approached by Joseph D. Hooker to assist in a series of Colonial Floras along with Otto W. Sonder. Harvey and Sonder commenced with the *Flora capensis* to consolidate all information on plants of the Cape Colony that existed as an assortment of scattered illustrations, descriptions and other information in various publications around the world. This information was published as five *Flora capensis* volumes of which Harvey contributed substantially to the first three.

In South Africa it was only in 1858 that the first official botanist, who was trained as a medical practitioner, was appointed. This was Carl W.L. Pappe, who had become interested in plants when researching medicinal properties of the local flora. In the 1800s, it was conventional for botanical research to be carried out by medical practitioners who were interested in plants. Pappe established the Cape Government Herbarium and immediately set about collecting plants to send to Harvey for the *Flora capensis*. The search for medicinally important plant species therefore continued to stimulate taxonomic research of the South African flora. Pappe's collections, together with the herbarium of Karl L.P. Zeyher (which Pappe acquired), formed the basis of the original herbarium at the South African Museum (SAM), which was donated to the Compton Herbarium of SANBI in 1956 (Smith & Willis 1997, 1999). For the remainder of the 19th century, South African plant taxonomy continued with routine search for and description of new species, often conducted by amateurs. At this time in history, botanists prepared plant specimens for sale to herbaria. For example, Zeyher's collections fetched a rate of £2 per 100 species (Harvey 1838). Zeyher, along with Harvey and another eminent collector, Christian F. Ecklon, contributed many collections to the Cape Government herbarium that was under the curatorship of Peter MacOwan (who was also Government Botanist) after Pappe's death. Amongst other duties, Zeyher was responsible for collecting and preparing plant specimens for the Cape Government herbarium, as well as instructing apprentices in theoretical and practical botany.

In 1898 Reino Leendertz was appointed as botanist in the Staatsmuseum in Pretoria, managing a collection of plants purchased from F.R. Rudolf Schlechter and adding to this by going on collecting trips in the area by bicycle. Leendertz established a Transvaal herbarium at the Staatsmuseum; this herbarium was donated to the National Herbarium in 1953.

1903 marked two significant appointments in South African botany. Henry H.W. Pearson was appointed to the South African College, where he first introduced taxonomy to students, a tradition that was continued by his successors. Up until 1960, although many universities had been founded in the country, very few taxonomists were trained. The appointment of Pearson initiated formal taxonomic training in South Africa, which was further established around the country with appointments of Selmar Schönland at Rhodes University College in 1905; John W. Bews at Natal University College in 1910; and Cornelis E.B. Bremekamp in 1924 and in 1928 his student, Herold (Hans) G.W.J. Schweickerdt, at the Transvaal University College, later the University of Pretoria. At these and some of the other more established South African universities of the time, taxonomic research and training developed and became an established part of undergraduate botany courses.

The second important appointment in 1903 was that of Joseph Burtt Davy in the Department of Agriculture as a botanist and agrostologist in the Division of Botany, Pretoria, which had its own herbarium. He particularly focussed on plants with economic significance, including plants with agricultural potential and weeds. Burtt Davy is credited for introducing both *Eragrostis tef* (Zucc.) Trotter (teff) and *Pennisetum clandestinum* Hochst. ex Chiov. (Kikuyu grass) into South Africa. The overarching influence on plant taxonomy for a few decades at the beginning of the 20th century remained the search for economically important plants. In 1913, after the resignation of Burtt Davy, the Division of Botany amalgamated with the Division of Plant Pathology which was headed by Illtyd B. Pole Evans, and Pole Evans became chief of the Division of Botany. The same year, the Natal Herbarium was placed under the Division on agreement with John Medley Wood, the curator of the herbarium, thus imparting a national character on the Division. The plant collections of the Division expanded through acquisitions of various collections, and in 1918 the herbarium in Pretoria was named the National Herbarium. The same year Pole Evans recommended the establishment of the Botanical Survey Advisory Committee to coordinate botanical research in South Africa. The *Memoirs of the Botanical Survey of South Africa* were the published results of this, eventually to be replaced by *Strelitzia* in 1994. Ecologists such as John P.H. Acocks contributed significantly to this research programme from the survey work conducted to map the veld types of South Africa, and also contributed numerous specimens to herbaria throughout the country (more than 28 000 in the case of Acocks). Pole Evans also founded *The Flowering Plants of Southern Africa*, now *Flowering Plants of Africa* (1920 to current), and *Bothalia*, now *Bothalia–African Biodiversity and Conservation* (1921–present). At that time Inez C. Verdoorn had been appointed as a herbarium assistant in the Division of Botany and Plant Pathology, and began to conduct self-taught taxonomic research by becoming acquainted with the *Flora capensis* and revising plant groups that required taxonomic attention. Two students of Pearson, Margaret R.B. Levyns and Edwin P. Phillips, made careers out of botany, with Levyns being the first South African to have a dissertation in plant taxonomy accepted for a doctoral degree in 1933 at the South African College, where she took up a lecturing position (Rourke 1999). As a lecturer Levyns was required to teach taxonomy, which stimulated her interest in the subject, especially as it was seen as a suitable pursuit for women of that era (Bennett 2015). Her frustration at her perceived inadequacies of *Flora capensis* stimulated her to develop an updated guide, *Guide to the Flora of the Cape Peninsula* (Levyns 1929). This book, which served as a set work for botanists at UCT until her retirement, is an example illustrating that South African botany had entered a phase of 'synthesis' (Jones & Luchsinger 1987). This period is characterised by consolidation of plant taxonomy in which species had been studied both in the field and herbaria, and formal taxonomy conducted by trained taxonomists had become established and took on a more coordinated approach through the methodical revisions of plant groups. An additional valuable contribution to the knowledge of South Africa's flora at the time was that of Hermann W.R. Marloth, an analytical chemist at Victoria College (later the University of Stellenbosch), who produced a *Flora of South Africa* during the period 1913–1932 as well as amassing a herbarium of more than 15 000 plant specimens which was donated to the National Herbarium after his death.

With the addition of various other responsibilities, the Division of Botany grew and was renamed the Division of Plant Industry; however after the retirement of Pole Evans in 1939 it was once again divided into smaller more manageable units of which the Division of Botany and Plant Pathology was headed by Edwin P. Phillips. Phillips published the *Genera of South African plants* in 1926 and a revised version in 1951. He was succeeded by Dr Robert A. Dyer in 1944 who established the Botanical Survey Section within the Division. Under Dyer's guidance, the staff component expanded, collections grew further, and taxonomic research increased as new plants were continuously discovered during the vegetation surveys. In 1951 the Division of Plant Pathology was separated from the Division of Botany, and the Division of Botany was renamed the Botanical Research Institute (BRI). Dyer's major influence on plant taxonomy in South Africa was co-initiating the *Flora of southern Africa* (FSA) series, and establishing a Flora Research Section within the BRI to work on this series (Crouch et al. 2013). Dyer had recognised that Harvey's *Flora capensis*, of which the first in the series was published in 1860 and the final in 1933, was outdated. The first FSA volume was published in 1963 and the project continued beyond the conversion of BRI to the National Botanical Institute (NBI) and dissolution of the so-called 'Flora team.'

After his retirement, Dyer published *The genera of southern African flowering plants* (Dyer 1975, 1976), popularly known as Dyer's *Genera*, which essentially was an updated and expanded version benefitting from the earlier works of Phillips. In this book Dyer encouraged taxonomists to further revise the work for publication in 2000. This statement influenced taxonomic research activities in South Africa in the 1980s and 1990s.

Leslie E.W. Codd became Director of the BRI when Dyer retired in 1963, followed by Bernard de Winter (see 2.5 below) in 1973. Codd was a gifted plant taxonomist who was very supportive of young taxonomists, nurturing taxonomic capacity for the future. Many of his treatments have stood the test of time, such as his FSA volume on the Lamiaceae which has yet to be improved on.

2.4 Influence of the South African botanical gardens and their herbaria

In 1652, Jan van Riebeeck, first governor at the Cape when the Dutch East India Company decided to establish a victualing station at the southern tip of Africa, had a master gardener from Amsterdam, Hendrick H. Boom in his company to assist with creating a garden for provision of fresh food for passing sailors. In what became known as the Company's Garden (Karsten 1951), indigenous plants were also cultivated to ascertain medicinal properties, and later for their economic importance. A subsequent Dutch governor, Simon van der Stel, encouraged cultivation of indigenous plants collected on expeditions to the interior. At this time, Heindrich B. Oldenland was made Superintendent of the Garden, and during an expedition to the South African interior he established a collection of preserved plant specimens accompanied by Latin descriptions. This naming and description of plants characterised the early history of South African botany and it is clear that the expeditions to populate the Company's Garden contributed to the early development of South African plant taxonomy in this way.

In 1910, in a presidential address, Pearson proposed the establishment of a Government department of botany to be established in a botanical garden on the Cape Peninsula, with greenhouses, a herbarium, library, museum and laboratories. Furthermore, the proposed botanic garden would facilitate the training of botanists through providing a living laboratory. His vision was unique and influential in that the emphasis of the purpose of the garden would be on the study and preservation of the country's indigenous flora, a tradition that was carried forth by all the subsequent national botanic gardens of South Africa, and continues today. The National Botanical Society (now the Botanical Society of South Africa) was established simultaneously to augment government grants towards the development of Kirstenbosch (Huntley 2012) and came to play a very important role in promoting awareness of the indigenous flora and conservation to the nation, and the world. Pearson was duly made Director of the new garden that was established on the government's estate, Kirstenbosch, in 1913, and established in it a section to cultivate economically important plants such as buchu (*Agathosma* spp.). Pearson died prematurely in 1916. Robert H. Compton was made Director in 1919 and was faced with the daunting task of documenting the indigenous flora of the scientifically orientated botanical garden. Hence Compton published extensively on the taxonomy of the South African flora, mainly in the *Journal of South African Botany* (later amalgamated with the *South African Journal of Botany*, which is still published currently) which he initiated in 1935, and made a significant contribution of more than 35 000 specimens for the herbarium. The Compton Herbarium was established at Kirstenbosch after the Bolus Herbarium was transferred from Kirstenbosch to UCT in 1935. Winsome F. Barker was the first curator of the new Compton Herbarium when it was finally founded in 1939. After Barker retired in 1972, plant taxonomists at the Compton Herbarium conducted research under the guidance of the new curator of the herbarium, John P. Rourke. This research was directed at the dominant fynbos plant families such as Ericaceae, Iridaceae and Proteaceae that were characteristic of the vegetation of the Cape Floristic Kingdom.

Pearson, in his presidential address, had advocated for an experimental botanical garden to be established in each region of South Africa, administered through a common network. When Compton retired, he was succeeded by Hedley B. Rycroft in 1954, an ecologist and visionary leader who succeeded in establishing such a network of botanical gardens. Thus the National Botanic Gardens (NBG) network came to include the Karoo Botanic Garden (presently the Karoo Desert National Botanical Garden) for the cultivation, display and study of succulents; the Harold Porter Botanic Garden in Betty's Bay with a wealth of indigenous flora characteristic of the Western Cape; the Orange Free State Botanic Garden (now Free State National Botanical Garden) in 1967; Natal Botanic Garden in Pietermaritzburg (now KwaZulu-Natal National Botanical Garden) established in 1874 and added to the NBG network in 1969; the Lowveld Botanic Garden (now Lowveld National Botanical Garden) in Nelspruit (1969); and the Transvaal Botanic Garden (now Walter Sisulu National Botanical Garden) in Roodepoort (1985) to represent the flora of South Africa's Highveld. The Pretoria National Botanical Garden, opened in 1958, was established with the purpose of providing scientists of the National Herbarium with living material for research, and was not open to the public daily until 1984 (Huntley 2012). In 2007 SANBI purchased the farm Glenlyon near Nieuwoudtville to become a National Botanical Garden representing the flora of the Northern Cape. In 2014 the Kwelera National Botanical Garden near East London in the Eastern Cape was established, however it is not yet open to the public.

Botanical gardens that were not part of the NBG network were also established around the country. In the 1800s a botanical garden was established in Grahamstown, in which Selmar Schönland of the newly established Rhodes University College would hold classes on the study of living plants. The botanical garden established in King William's Town was curated by Thomas R. Sim who proclaimed that until botany was taught in schools the importance of botanical gardens would not be realised, and was then successful in getting the subject introduced into Dale College in 1893 (McCracken & McCracken 1988). The Durban Botanic Garden was established in the 1850s. Within this garden, the Colonial herbarium was founded as a result of a condition made by Medley Wood when he was appointed director of the garden in 1882. Medley Wood contributed extensively to the collections in the herbarium and discovered at least 62 new species of plants. In addition he published a series of botanical monographs on KwaZulu-Natal plants. Medley Wood continued as director of the Colonial herbarium after the botanical garden was transferred to the municipality and lost some of its functions associated with a botanical garden (McCracken & McCracken 1988).

In 1976 a committee chaired by Stefan Meiring Naude, the former President of the Council for Scientific and Industrial Research, criticised the NBG for the fact that taxonomy was the only research conducted at the institution, and it was deemed inadequate. In contrast, the BRI had been established within the Pretoria National Botanical Garden and quickly gained a respectable international reputation in taxonomic and other research, having the advantages of a much larger staff component of not only taxonomists but other fields of botany, and significantly greater financial aid and infrastructure. After his appointment as director of the National Botanic Gardens in 1983, Jacobus [Kobus] N. Eloff devised a strategy to enhance and emphasise the scientific orientation of the NBG. The Forest Act Number 122 of 1984 gives the objective of the NBG as the conservation of and research into the flora of the southern African subcontinent as a whole. In 1987 Eloff further impacted on NBG's science philosophy by proclaiming that the NBG should be run on business principles with clear objectives and resources directed towards achieving these objectives. The era of separation between the NBG (predominantly in the South) and BRI (in the North) was now over and the amalgamation of these organisations was announced in 1988.

Aside from the significant contribution of botanical gardens on expansion of plant taxonomic knowledge in South Africa, botanical gardens have long been an interface between botanical research, especially taxonomy, and the public. Among other things, it is this association with research that distinguishes botanical gardens from parks or nature reserves. From the beginnings in South Africa as providing sailors and settlers with agricultural supplies, to becoming attractive green belts to promote human psychological and physiological well-being, they now in addition play an increasingly important role as havens for the cultivation of rare and threatened species. Aside from being places for public to relax and enjoy nature, they are important in the promotion of indigenous plants for cultivation, and in education. Interaction with horticulturalists remains a very important role of plant taxonomists.

2.5 Modernisation of taxonomy in South Africa

De Winter (1970) recognised that then modern approaches to taxonomy, using information obtained from as many fields of research as possible, would enhance traditional taxonomy based mainly if not exclusively on macromorphology. Modern approaches at the time, which were in vogue in Europe and Northern America, included using additional taxonomic evidence derived from sources such as anatomy, palynology, cytology, genetics, physiology and chemistry to improve classification. South Africa lagged behind these countries in terms of technological advances, but with the increasing number of well-trained taxonomists in the country since the 1960s, and influences of technological advances, South African taxonomy entered the experimental phase (Jones & Luchsinger 1987) in which data was interpreted to make phylogenetic sense of the classification system. The BRI acquired a scanning electron microscope (SEM) in 1977, which was replaced by a more modern version in 1984. A survey of taxonomic papers in the *Journal of South African Botany* and *South African Journal of Botany* shows that in South Africa SEM studies, first published in the 1970s, gained popularity in the 1980s and especially 1990s, with pollen studies being particularly popular. In addition, De Winter believed that taxonomy should serve as a source of all kinds of information concerning distribution, economic uses, poisonous properties, but recognised that this could only be made accessible through databases (which was at that time known as Electronic Data Processing). Thus under his guidance in the early 1970s, the National Herbarium, Pretoria (PRE), Computerised Information System (PRECIS) was initiated and subsequently became the largest botanical database in South Africa and the southern hemisphere, progressively capturing and documenting the information from labels of over 1.2 million preserved plant specimens. This was in spite of De Winter's declaration that "injudicious use of a computer can lead to a reduction instead of an increase in efficiency" (De Winter 1970). This database facilitated the publication of the first checklist of southern African plants, *List of species of southern African plants* (Gibbs Russell & staff of the National Herbarium 1984). This book and its updates were used until *Plants of southern Africa—names and distribution* was published in 1993 by Arnold & De Wet, recording 22 211 species of plant for the FSA region. Compilation of taxonomic information for this checklist entailed teamwork from most NBI staff members, which had significant impact on their time for a few years. Subsequent updates have been published, and the South African Plant Checklist now has a full time coordinator tasked with updating the list electronically so that it always reflects the most recent taxonomic treatments.

In 1981 the NBG passed under the jurisdiction of the Department of Environmental Affairs. Under the provisions of the Forest Act, number 122 of 1984, the institution became a statutory board, i.e. an autonomous state-aided institution. The Cape Provincial Administration in the early 1980s decided that *ex situ* cultivation of threatened plants should be carried out at Kirstenbosch. Concurrently the first conservation assessments of South African plants were initiated by Anthony V. Hall, a taxonomist at UCT. He relied heavily on herbarium-based taxonomic information for its compilation. Cultivation of threatened plants also spurred research projects regarding autecology and propagation (see for example the pioneering work of De Lange & Boucher (1990) on the promotion of seed germination through smoke treatment carried out at Kirstenbosch). Aside from horticulture, the roles assigned to the NBG included undertaking and promoting research on plants, investigation and promotion of the utilisation of economic potential of indigenous plants, and promoting appreciation of indigenous plants among the public (broadly, horticulture, research, utilisation and education) inter alia through displaying them in the NBGs (Smith et al. 1999a). The use of plants for economic potential had long been a priority, but the interest in horticultural potential was reinvigorated by the emphasis of NBG's roles and promotion of these by Eloff.

In 1985 a Flora Section was created within the BRI, which remained in place until the early 1990s. However, taxonomic research has been carried out up to the present day and throughout the various changes to the Institute. In 1986 the Department of Agriculture and Water Affairs reviewed all botanical sections within the department as a concern was that some fields of botany were being duplicated in different departments, as mandates were unclear. BRI was faced with much uncertainty as the Department ruminated on whether to rationalise all botanical sections or dismantle the BRI. BRI and NBG (including the Compton herbarium and its research staff) amalgamated in 1989 to form the NBI, with Eloff as acting Director (later Director of Research) and Brian Huntley as Institutional Director. The objectives of the NBI, contained in the Forest Amendment Act 1991 (Article 58), were as follows:

a) by itself or in cooperation with any person assess the botanical research and conservation needs of the Republic and develop programmes to meet the needs;
b) establish, develop and maintain collections of plants in national botanical gardens and in herbaria;
c) undertake and promote research in connection with indigenous plants and related matters;
d) study and cultivate specimens of endangered plant species;
e) investigate and utilize, and promote the utilization of, the economic potential of indigenous plants; and
f) promote an understanding and appreciation of the role of plants among the public.

In 1991, under the guidance of Huntley, the NBI produced its first Corporate Strategic Plan (CSP) to confirm the mission and responsibilities, and clearly establish the identity of the Institute. From this step forward, the CSP, and its subsequent updates, guided taxonomic research activities. Within this first plan, the importance of completing the FSA project was noted with an intention to obtain funding for newly graduated plant taxonomists. This did not materialise, and the FSA project therefore remained far from completion. An Institute priority that had an indirect impact on taxonomic research was the Conservation Biology Research Programme's obligation to revise the South African Red Data Book for Plants in collaboration with taxonomists, who became increasingly aware of the importance of recording good information about plants during collecting trips and disseminating this in subsequent taxonomic publications.

The NBI's next CSP was for the 1996–2000 period and was influenced by and aligned with the government's Reconstruction and Development Plan. The CSP again placed emphasis on the importance of threatened plants but acknowledged that such activities would be hampered by inadequate staffing levels. In the CSP for 2001–2006, use of cladistics and later molecular techniques in plant taxonomy was iterated as a priority, along with compilation of regional Floras for South Africa, production of an annotated checklist for South African flora, and giving input into the newly created Threatened Species Programme's Red List project.

After the appointment of Huntley as Chief Executive Officer of the NBI in 1990, Gideon F. Smith became the Director of Research, and influenced taxonomic work in many profound ways through establishing large internationally funded initiatives. Thereafter the CSPs prioritised specific projects rather than giving broad guidelines for prioritisation.

2.6 Influence of funding on South African plant taxonomy

One of the most influential biodiversity capacity building initiatives globally established within the NBI was the Southern African Botanical Diversity Network (SABONET) project, which officially started in 1996 under the guidance of Huntley and Smith (Huntley et al. 2002; Siebert & Smith 2003, 2004). The project had an enormous impact on confirming the relevance of herbaria and botanical gardens, not only in southern Africa, but also globally. This project, which was funded by the Global Environment Facility, through the United Nations Development Programme, in 10 southern African countries, supported postgraduate studies of 26 students, and arranged training courses and workshops for over 180 southern African botanists. The project ended in 2006 and generated 43 major publications covering, amongst others: checklists of plants of virtually all participating countries; full or partial Red Lists of plants for all countries; reports of country-collaborative collecting excursions of explorative nature; a textbook derived for herbaria and herbarium training courses; and information on the southern African herbaria. The impact of this project on plant taxonomy was to train a new generation of botanists (such as Christopher Cupido, current curator of

Compton Herbarium; Solomon Nkoana, current curator of the Pretoria National Botanical Garden, and several other staff members of the NBI, and other institutions), generate a variety of collaborative projects between countries, and to empower some neighbouring countries that had previously been reliant on South Africa to take on responsibility for their own floristic work. NBI botanists subsequently became increasingly focused on the South African flora as a result, rather than the flora of surrounding countries, although plant groups of course occur across political boundaries.

For sub-Saharan Africa as a whole, the NBI (which then became the South African National Biodiversity Institute [SANBI]) took the lead, along with the Conservatoire et jardin botaniques (CJB) in Geneve, Switzerland, to produce a checklist for the entire region (Klopper et al. 2006a, b, 2007). This was a world first for a continent with a flora of over 50 000 species (Klopper et al. 2002). The publication of this work, and launching an associated website, pre-dated the deadline for achieving Target 1 of the first Global Strategy for Plant Conservation (GSPC) by four years, placing SANBI, the CJB, and the continent in a leadership position in cataloguing plant diversity (Smith & Smith 2006).

In 2003 Smith authored the founding document that gave rise to the African Plants Initiative (API) which expanded into the Global Plants Initiative (GPI) (Smith & Figueiredo 2014; Walters et al. 2010; Smith et al. 2011). This project aimed to create high resolution electronic images of as many type specimens of African plants as possible (Smith 2004), and to disseminate these through the worldwide web. Following the work in Africa, the project was extended to Latin America and later the world. To date, with the cooperation of hundreds of scientists and institutions, and an investment of well over US$78 million by The Andrew Mellon Foundation, nearly 1.7 million images of type specimens and other botanical artefacts have been placed online, and are accessible through the worldwide web at http://plants.jstor.org, making this a significant success of the global botanical community.

Formal research strategies are new to South African plant taxonomy. At SANBI and its predecessors, the NBI, the BRI and the NBG, taxonomic research in plants has been guided by the demands of the prevailing research programmes at the time, or based on specific needs identified by directors. The 1990s saw the NBI publishing one of the first deliberate efforts in the world to establish a strategy for taxonomy through determining a series of criteria according to which projects were to be assessed (Smith et al. 1996). The NBI additionally aligned its research activities to the international environmental conventions of which South Africa is a signatory (e.g. CITES, Ramsar, CBD and Agenda 21) and in this way provided support to the national government's then Department of Environmental Affairs and Tourism. These activities had minor influence on plant taxonomic research at the time. At the NBI, the majority of researchers were engaged with creating a comprehensive annotated checklist of all southern African plants for publication (Arnold & De Wet 1993; Germishuizen & Meyer 2003), as well as updating Dyer's *Genera* (Leistner 2000). Not only did these major corporate projects impact on NBI researchers' time, but collaboration with researchers from universities and amateurs was exceptionally valuable for achieving these products. For example, for updating Dyer's *Genera*, contributions were received from eight taxonomists from South African universities, two from universities abroad, and one from another overseas institution. Taxonomic research was put on hold by many scientists, especially in the NBI, who considered providing this foundational biodiversity information as the highest priority at the time.

The NBI became the South African National Biodiversity Institute (SANBI) in 2004 through the signing into force of the National Environmental Management: Biodiversity Act 10 of 2004. Within SANBI the division for taxonomic research still exists and is now named the Biosystematics Research and Biodiversity Collections Division, with Smith as Chief Director until February 2015. The CSPs for that decade commencing in 2001 reflect that NBI and then SANBI endorsed a wide variety of taxonomic research projects, which were mainly influenced by the establishment of the Leslie Hill Molecular Laboratory in December 2000 (for example, of the 25 plant taxonomy studies underway at SANBI in 2005–2006, 12 were utilising molecular techniques, mostly to compile phylogenies). Funding agencies throughout the world inadvertently promoted a decline in alpha-taxonomy by funding research on phylogenetic reconstruction using nucleotide sequencing rather than alpha-taxonomy (Wortley et al. 2002). Furthermore, journals in which molecular papers could be published often have a much higher impact factor than those in which conventional taxonomic revisions could be published—all these had a massive influence on plant taxonomic research in South Africa, determining the type of research that was carried out over probably about two decades (Buys & Smith 2006; Smith et al. 2007). There has been a recent movement away from this trend, as the Department of Science and Technology has changed the conditions of funding to make it more relevant to society, by emphasising the final uptake by end users of outputs of funded projects.

As the SANBI mandate expanded, the emphasis and driving force of research increasingly became geared towards the needs of other divisions in the organisations. This is evident in the strategic plan of 2009–2013, where one of the activities listed for taxonomists is to "support high profile taxon and/or bioregionally driven programmes" such as those on climate change, ethnobotany, the Consortium for the Barcoding of Life, genetically modified organisms, bioregional projects (Grasslands Project, Subtropical Thicket Ecosystem Project, Succulent Karoo Ecosystem Plan, Cape Action Plan for the Environment), and the Threatened Species Programme. This was the first time in a SANBI CSP that the Division's role in supporting other divisions or programmes was explicitly addressed. Note, however, that the NBI's earlier Research Directorate was formally named 'Research and Scientific Services Directorate' to strengthen the notion that taxonomy (and other research thrusts for that matter) had a significant utilitarian role in the Institute and beyond (Smith & research staff 1998).

2.7 International initiatives that drive South African taxonomy

As discussed in Chapter 1, the first target of the original GSPC aimed to produce a checklist of all known plant species of the world, a target which was achieved in South Africa by SANBI in collaboration with external botanists in 1993. The internet has given rise to a new form of publishing and disseminating taxonomic products, the two most popular at present being electronic web-based Floras (and their building blocks, such as catalogues of type specimens) and interactive keys. Thus the updated GSPC aims to produce an electronic online Flora for all the plants of the world by 2020, in line with the current worldwide trend of making data electronically accessible on the internet. This provides the opportunity for taxonomy to be modernised, and to become more effective at attracting financial support (Godfray 2002). Developments over the last decade have enabled taxonomic work to contribute to such international projects such as the Encyclopedia of Life (http://eol.org/), inspired by Wilson (2003), which aims to have a webpage for every species on Earth, as well as a number of electronic Floras that focus on restricted geographic areas such as the *Flora iberica* project.

Recently the International Code of Phylogenetic Nomenclature and DNA barcoding have been among the most topical subjects in taxonomy and biological nomenclature. DNA barcoding has potential to identify unknown samples of organisms, but is ultimately based on a pre-existing classification system and correctly identified, vouchered specimens that are curated and preserved for prosperity in herbaria. Progress in molecular techniques, and the development of statistics in phylogeny (e.g. Bayesian analysis), has enhanced the popularity of these fields of study.

2.8 Conclusions

Research in plant taxonomy has evolved from initially being driven by curiosity, exploration, and the search for useful species, to then being influenced by pressures on taxonomists from researchers with interests in many fields such as vegetation exploration, economically important species, and species of conservation importance; and finally progressing to refining classification systems using studies incorporating increasingly modern techniques from fields such as cytology, palynology, anatomy, chemistry and later nucleotide research. Modern taxonomic research employs more complex methods of analysis including statistical/numerical techniques and cladistics. The advent of easy and rapid electronic dissemination of taxonomic research products and data online has had a significant impact on the way in which such content is delivered to society, and increasingly such endeavours, partly driven by the availability of funding, are receiving global attention (Victor et al. 2013b). This in turn influences the manner in which taxonomic work is prioritised and conducted. Although aspects of exploration, synthesis and experimentation will continue in taxonomy for the foreseeable future, the predominant culture of taxonomy is now towards electronic dissemination of taxonomic information, and can therefore be seen as a new phase which is here termed the 'connectivity phase' of taxonomy.

Strategic planning of plant taxonomy at SANBI developed from prioritising general areas of importance, to becoming gradually more specific and directed. South African researchers have increasingly needed to account for how government money is spent, and relevance and impact of research products on society needs to be justified. This has pressurised SANBI leaders to develop more stringent prioritisation exercises.

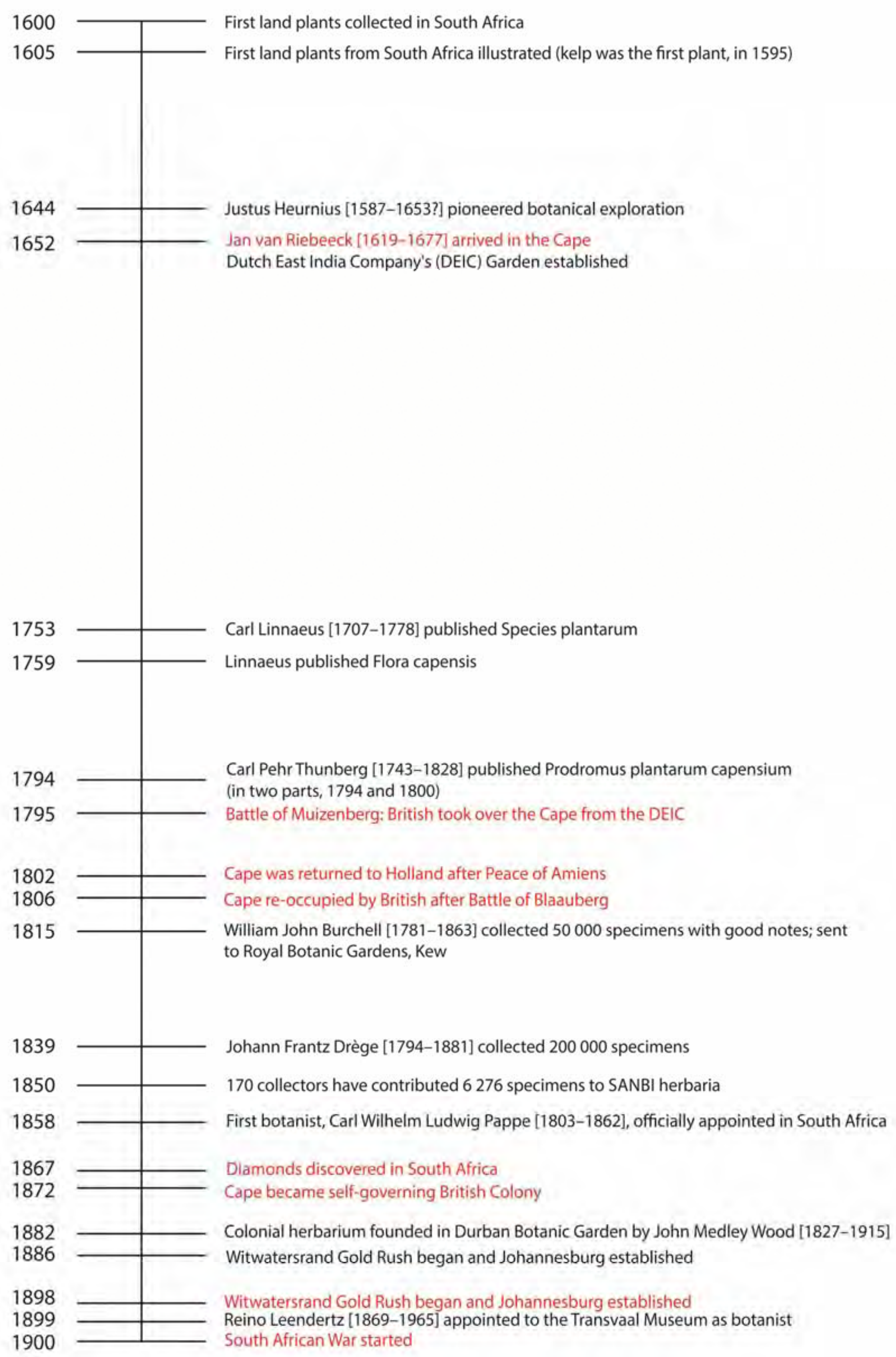

Figure 1. 1600–1900: the exploration phase in South African botanical taxonomy, covering about 300 years. Historical events are indicated in red text.

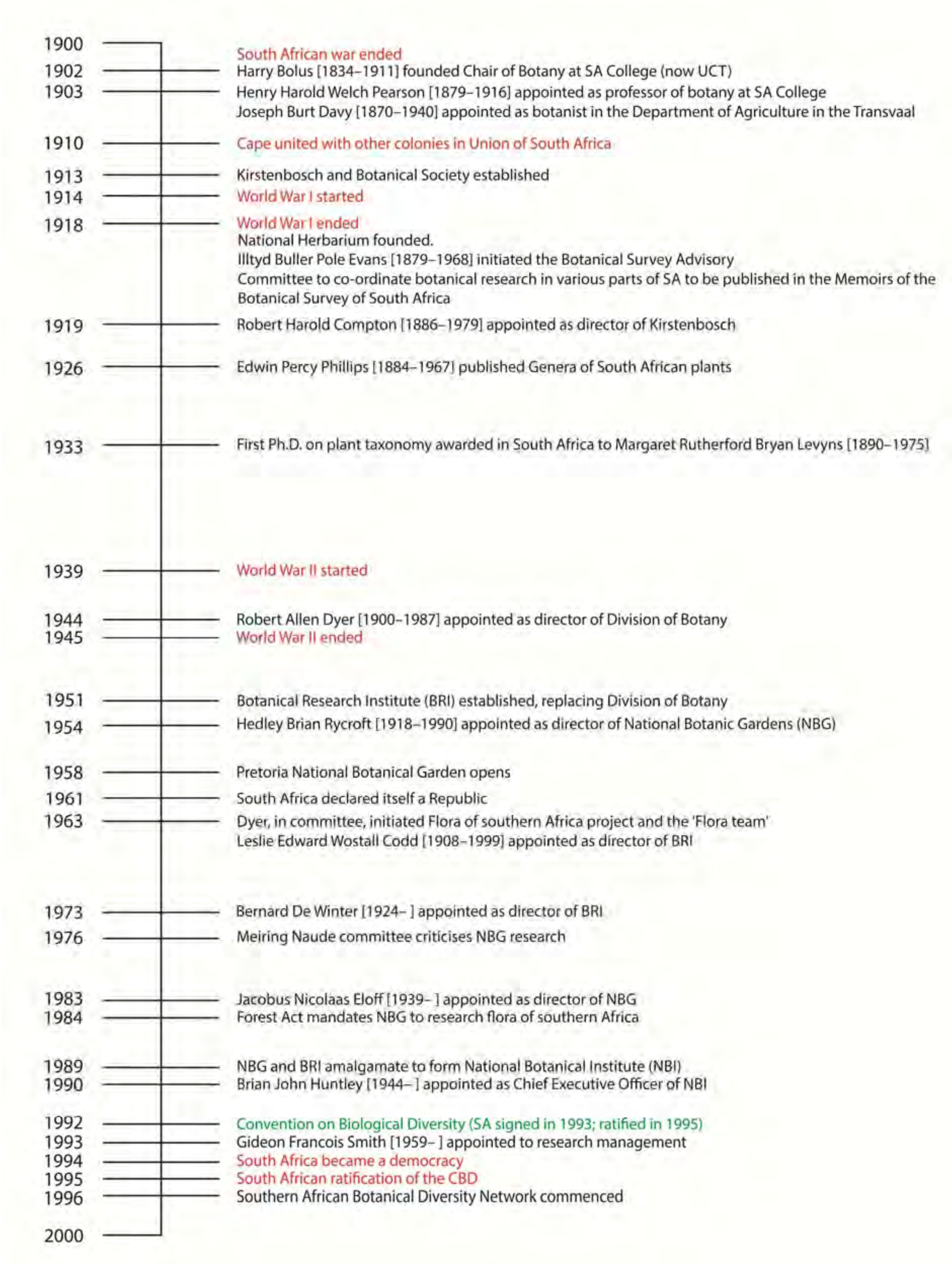

Figure 2. 1900–2000: the synthetic and experimentation phase in South African botanical taxonomy. The synthetic phase covered about 70 years, and transitioned into the experimentation phase with the application of modern technology and computerisation in South Africa in the 1970s. Historical events are indicated in red text, and international conventions are indicated in green text.

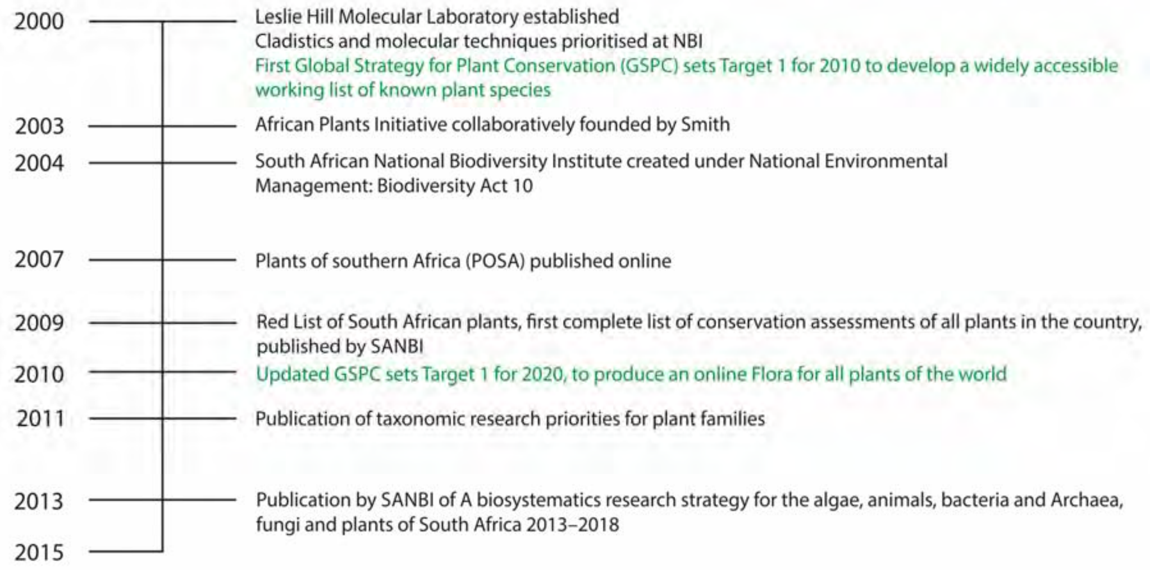

Figure 3. 2000–2015: the phase of connectivity of South African taxonomy. International conventions are indicated in green text.

CHAPTER 3

METHODS

3.1 Introduction

The word ‘strategy’ is defined by the *Oxford Dictionaries* (2015) as a “plan of action designed to achieve an overall aim”; and that strategy generally involves “setting goals, determining actions to achieve the goals, and mobilizing resources to execute the actions. A strategy describes how the ends (goals) will be achieved by the means (resources).” In this sense, the strategy to be developed as part of this thesis has the overall aim of addressing the needs of end users of plant taxonomic research to improve the relevance and impact of research products that are delivered, as well as to improve the efficiency with which limited available resources can be used to achieve these goals.

In this Chapter only a broad outline of the methods and approach followed is given; more specific details are supplied in some of the publications emanating from the study.

3.2 History and drivers of plant taxonomy

A survey of literature pertaining to strategies that have previously been published for taxonomic research was conducted and is presented in Chapter 2. In this survey emphasis was on three aspects of taxonomic research: (1) historical development of plant taxonomy in South Africa; (2) driving factors that influenced what type of research taxonomists in South Africa carried out; and (3) strategies for botanical or specifically taxonomic research elsewhere in the world. Because of the paucity of information on the topic of taxonomic research strategies globally, considerable prominence was given to the history of the development of plant taxonomy in South Africa to elucidate factors that influenced plant taxonomic research. Published literature on South African botanical history was comprehensively reviewed, as well as SANBI’s Annual Reports and Corporate Strategic Plans for more recent developments. Major events in the history of South Africa and South African botany, as well as political events, including global eco-political ones such as the ratification and signing of the Convention on Biodiversity that could have influenced taxonomic research, are summarised in timelines (Figures 1–3 of Chapter 2).

3.3 Determining capacity for taxonomic research in South Africa

A survey of existing capacity for plant taxonomic research at SANBI and South African universities was conducted and the results are presented in Chapter 4. This included an analysis of the number of researchers, lecturers and supervisors for plant taxonomic research, as well as the research output of taxonomists. For the latter, publication lists were derived from university websites, Scopex, Researchgate and the majority from authors themselves. The total numbers of peer-reviewed papers published by each taxonomist per year from 2000 to 2014 were included in the analyses, and university-based taxonomists were analysed separately to SANBI-based taxonomists. All the years of employment by each taxonomist employed at SANBI or the University as at December 2014 were totalled, and publication output was the total number of papers published divided by the number of years worked (for total number of papers per person per year); or number of first authored papers published divided by the number of years worked (for number of first authored papers per person per year).

To support the review of capacity for conducting taxonomic research in the country, trends in plant collecting intensity are presented based on data derived from the SANBI Brahms database. This includes the number of new specimens accessioned by SANBI herbaria per five year period from 1800 up to and including 2010, as well as a map showing distribution of plant specimens collected and accessioned into the SANBI herbaria per quarter degree grid square for South Africa.

A survey of the number of new South African plant taxa described per year from 1980 to 2013 was conducted and is presented to elucidate trends in taxonomic research. The number of taxa of South African plants described per year since 1980 was obtained from a survey of the literature (see 3.6) in conjunction with the following sources: the SANBI Brahms database; TSP database; the Kew database; Tropicos; and IPNI. The number of new taxa described per year was allocated to the following categories: number of taxa published as part of a revision; number of taxa published independently of revisions, i.e. in stand-alone papers or with a few other taxonomic notes or taxon descriptions; number of taxa described by South African botanists; and number of taxa described by non-South African botanists. These results were plotted in a histogram and presented in Chapter 4.

A discussion forum was held by SANBI staff members (D. Raimondo in collaboration with L. von Staden, M. Hamer and J.E. Victor) at the Southern African Society for

Systematic Biology conference in Arniston, July 2012, to determine ways to stimulate the production of taxonomic revisions. The participants were asked, inter alia, what obstacles prevented them from carrying out taxonomic revisions and answers were recorded and are discussed in Chapter 4.

3.4 Determining indicators for research needs

Gaps in taxonomic information and, by implication, taxon coverage can be influenced by and determined from a number of potential factors relating to the group of organisms or geographical area in question.

a) How out of date a taxonomic treatment is

The potential use of date of publication of the last taxonomic treatment of a group (e.g. revision of a genus) has been assessed as a possible indicator of whether the information is outdated or not, and therefore, whether the group should be researched. For example, a group not treated since *Flora capensis* was published between 1860 and 1925 might well qualify as a taxonomic priority.

b) Quality of taxonomic treatment

Taxonomic treatments that are relatively old may well be adequate in terms of species demarcation and nomenclature, in which case it might not be necessary to revise the group. Conversely, some groups having been relatively recently revised may be inadequate or already out of date. For this reason it is necessary to seek and consider expert advice. This criterion is essentially subjective.

c) How well curated the collection is, including the number of unidentified specimens in herbaria

The proportion of unidentified herbarium/museum specimens within a group (especially a genus) was assessed to determine whether it could be an indicator of potential taxonomic problems resulting from inadequate taxonomic treatments, and therefore a dearth of identification tools for preserved specimens.

3.5 Possible criteria for prioritising groups that require taxonomic research

Apart from indicators that can be used to determine which taxonomic groups may be in need of revision, of those groups that need revision it is also possible to further prioritise which ones should be researched based on their importance.

a) Economic importance

Economically important plants are those that play an important role in human welfare and animal husbandry, including the following: crop and subsistence food plants; fodder plants grazed and browsed by livestock; plants with medicinal properties; plants with horticultural value; plants used for timber; plants important in eco-tourism (e.g. with high aesthetic qualities); and alien invasive plants. Problems with the taxonomy of economically important plants can negatively impact on these and associated industries.

b) Conservation importance

Bridging the taxonomy-conservation impediment to identify taxonomic problems that impede conservation effort is an important factor in terms of setting taxonomic research priorities. When Red List assessments are conducted, taxonomic literature and information from specimen databases provide a resource of fundamental importance. If this information is lacking or inadequate, it can result in an assessment of Data Deficient (DD) being applied, and the taxon can escape conservation attention. A method to distinguish taxa listed as DD due to taxonomic problems from those listed as DD due to lack of other data e.g. on population status, was developed (Victor 2006; see Appendix 2) so that these taxa could be used for analyses to determine priority families, genera and species for taxonomic research.

c) Endemicity

The proportion of species occurring in, or restricted to, a country (either as a percentage of indigenous or a percentage of endemic out of all species of the genus) can be an important factor to consider when prioritising groups for research. When the majority of the members of a genus do not occur in the country, the cost and complexity of doing a taxonomic revision escalates when fieldwork is necessary to collect material for examination.

d) Ecological importance

Management of biodiversity and rangelands can be hampered by a lack of knowledge of species composition, and how these species function in the ecosystem. The proportion of species in each genus that function as ecological keystone species, that are important for ecosystem function or integrity, is important from a conservation point of view, and it is therefore vital that the taxonomy of such taxa is clear.

3.6 Sources of information used in this study

a) Consultation

During the development of a strategy for plant taxonomic research in South Africa, taxonomists from SANBI, from most universities in the country, as well as from institutions abroad (e.g. Royal Botanic Gardens Kew, Missouri Botanical Garden, and the University of Zürich), were consulted. The intention was to circulate for comment the early versions of the strategy for plant taxonomic research, along with the initial lists of priority taxa identified for taxonomic research, to all known plant taxonomists in South Africa, as well as a few from abroad. In addition, stakeholders from other disciplines, e.g. ecologists, conservationists and Environmental Impact Assessment practitioners, were consulted. Those consulted were invited to share their views on the strategy as well as give input into the initial priority lists, to provide further insight into the quality of existing taxonomic treatments and need for further research of those groups. Where appropriate, these views were incorporated. A list of people consulted is provided in Appendix 1. Not all who were consulted gave input, but most were very responsive and input given was constructive and supportive, and was incorporated where beneficial to development and implementation of the Strategy in South Africa. Much of the additional information on topics such as capacity was also derived from discussions with taxonomists.

An opinion survey amongst South African taxonomists enabled determination of the most economically important plant families, along with information from the literature.

b) Literature assessment

Assessment of taxonomic literature was an important part of determining gaps in taxonomic research in South Africa. A comprehensive survey of published taxonomic treatments, including Floras, monographs, revisions and other works, was conducted, and as noted above (3.4), the dates were taken into consideration for prioritisation of taxonomic research. The quality of taxonomic treatments was assessed in consultation with specialists. In addition, a literature survey was conducted to identify the most economically important plant families.

c) Conservation assessments

The *Red List of South African plants* (2015) is a useful resource to elucidate taxa that are in need of revision, as an assessment of Data Deficient (DD) can in some cases be attributable to uncertainties in taxonomic status. A method for identifying taxonomically problematic plant taxa in conservation assessments was developed (Victor 2006; see Appendix 2), and subsequently applied in prioritisation processes (Victor & Smith 2011; Victor et al. 2015a; Victor et al. in press; Victor et al. 2015b; see Appendices 3, 4, 7 & 8).

d) Herbarium collections

Until 2013, the National Herbarium, Pretoria (PRE) Computerised Information System (PRECIS) documented the primary collection data of most plant specimens housed in the three SANBI herbaria (NH, PRE & NBG), with collection information for over 1.2 million plant specimens. The information in this database was transferred to a Botanical Research And Herbarium Management System (BRAHMS) database in 2013. The PRECIS and BRAHMS databases provided a potential resource for identifying taxonomic problems, and contain potential indicators, such as number of specimens unidentified in the herbarium, to reveal problematic plant groups and thus possible gaps in taxonomic knowledge.

These gaps in taxonomic knowledge can be used to inform where priority research activities should be aimed, taking into consideration the current trends in taxonomic research within South Africa and internationally. A method for prioritising taxonomic research was developed (Victor et al. 2015a) and is presented in Chapter 5 and Appendix 4.

3.7 Needs analysis

Identification of stakeholder needs is necessary to establish important directions for research activities. Accurate and reliable scientific information about plant and animal species is becoming increasingly important in South Africa as economic development puts pressure on sustainable use of natural resources. The basis for that information is taxonomy (West 1996). Standard information provided by taxonomists includes names, descriptions, distribution and habitat information and evolutionary relationships; associated information such as unique properties, ecology, pollination syndrome and conservation information is often gathered.

Extensive lists of end users and the type of information they require were compiled by Morin et al. (1988), Steenkamp & Smith (2002, 2003) and Smith (2003). A notable omission from these lists is the needs of botanical researchers, including taxonomists themselves.

Current users of SANBI herbaria were considered to assist in identifying the full spectrum of end users of taxonomic research and their needs. Virtually all South African herbaria serve as a resource to public requiring botanical information and the identification of plants, and most herbaria offer an identification service for members of the public as well as colleagues.

In 2002, a National Workshop for Stakeholders and End users of Botanical Information and Herbaria was held at the National Herbarium of SANBI (Steenkamp & Smith 2002, 2003). One of the objectives of the workshop was to determine the kinds of botanical information needed by user groups, along with setting priorities associated with providing this information. The workshop was attended by 34 stakeholders and end users from agricultural institutions, botanical societies, conservation agencies, environmental consultants, ethnobotanists, universities, and others.

3.8 Development of the strategy

Results of the needs analysis were used to develop strategies for plant taxonomic research (Appendices 5–8). Draft versions of a strategy for plant taxonomic research in South Africa were circulated via electronic communication means to taxonomists of SANBI, universities and elsewhere, as well as other stakeholders (see 3.6 a). The strategy was further promoted at conferences and disseminated on the SANBI website. The strategy was adjusted when necessary (approximately annually) to incorporate feedback until the fifth (current) version was produced (Appendix 8) and subsequently published in hard copy (Victor et al. 2015b).

3.9 Implementation of the strategy and evaluation of results

The draft strategy including the initial priority lists for taxonomic research was first implemented at SANBI in 2011. This was done through the Biosystematics Research Committee which is mandated to ensure that the research related targets in the Corporate Strategic Plan are achieved and that a strategic approach is used to identify research projects undertaken by the Division. The Committee consists of staff members of the Biosystematics Research and Biodiversity Collections division of SANBI, namely: the Chief Director, Deputy Director of Research, curators of the three SANBI herbaria, one scientist representing the National Herbarium and one scientist representing Compton. The Committee meets twice a year to review all proposed research projects in an attempt to raise standards of research by giving constructive feedback and support to enhance the quality of proposals and subsequent outputs. Results of implementation were monitored by tracking progress of research conducted and published on priority lists of taxa.

Case studies of certain prioritised taxa were conducted and presented in this thesis as Appendices 9–11. The implementation and subsequent evaluation of the initial results of implementation of the strategy is presented in Chapter 6.

3.9 Summary of procedure for developing the strategy

a) Develop a method for identifying taxonomically problematic plant taxa in conservation assessments.
b) Interrogate PRECIS and BRAHMS databases and taxonomic literature to develop methods for prioritising taxa in need of taxonomic research.
c) Develop draft strategy and lists of priority taxa requiring taxonomic research.
d) Circulate draft strategy and priority lists to specialists and stakeholders for input.
e) Implement the strategy at SANBI.
f) Make list of taxa publically available on SANBI website for consultation by prospective researchers and for regular updating.
g) Conduct and evaluate case studies.
h) Analyse results and impact.
i) Revise and finalise the strategy.
j) Update lists of priority taxa in need of taxonomic research.

CHAPTER 4

ASSESSMENT OF PLANT TAXONOMIC CAPACITY IN SOUTH AFRICA

4.1 Introduction

South Africa is a megadiverse country with more than 20 000 species and infraspecific taxa of vascular plants and bryophytes comprising its flora. This exceptionally rich and diverse flora faces challenges in terms of management and conservation. Careful planning, sufficient human capacity and financial resources, and efficient use of capacity and resources are required to ensure that the demands of these tasks are appropriately and comprehensively met. This chapter focuses on assessing the current (as at December 2014) capacity in South Africa for conducting taxonomic research on plants of the country, to determine whether there are sufficient resources in terms of: (1) human capacity, (2) research material and (3) financial or other resources, to implement and monitor a strategy for plant taxonomic research in the future. Thus the principal purpose of this chapter is to determine whether South Africa has the human capacity and resources to conduct taxonomic research that is required to support end users of plant taxonomic information, and to identify shortages of capacity or resources that might prove to be an obstacle in implementing a taxonomic research strategy. Taxonomists working abroad have made significant contributions to taxonomic research on South African flora, and their role is discussed in section 4.6.

The most recent comprehensive assessment of the state of taxonomy in South Africa was initiated by the South African National Committee for the International Union of Biological Sciences in 1979. The resulting report (Du Plessis 1985) concluded that the state of taxonomy was "gloomy", and deteriorating. It was recommended that an effort be made to stimulate plant taxonomy, which led to the formation of a National (Stimulation) Programme for Plant Systematics along with the Working Group for Plant Systematics within the then Foundation for Research and Development, now the National Research Foundation (NRF). This working group arranged a variety of activities to promote and stimulate plant taxonomy in the country. From 1988 to 1996, 18 training workshops, five symposia and five joint inter-institutional collecting trips were conducted (Smith et al. 1996). Following on from this, South Africa and colleagues from nine other southern African countries established the Southern African Botanical Diversity Network (SABONET) project in 1996, funded by the Global Environment Facility-United Nations Development Programme. This project had as a primary aim of improving the human resource capacity and infrastructure of herbaria in southern Africa (Smith & Willis 1997), strengthening and developing botany in southern Africa through workshops, courses and plant expeditions. Reviews of the project concluded that SABONET had been very successful in attaining its goals of building capacity through training, purchase of equipment, digitisation of plant specimen collections in herbaria, production of informative literature and creation of Red Lists throughout the countries involved.

4.2 Plant taxonomists in South Africa

Most of the expertise in plant taxonomy in South Africa is concentrated at the South African National Biodiversity Institute (SANBI) and at universities that offer taxonomy in the curriculum. There are approximately 35 professional plant taxonomists employed in academic posts as lecturers and/or researchers in South Africa, 19 of whom are with SANBI, and 16 at universities (see Tables 1 and 2; exact names and details are available from the author on request). In addition to taxonomic researchers, there are many trained taxonomists employed as herbarium curators or technical support staff, both at SANBI and at universities; at least five of these staff members conduct research as well. At SANBI, managers have also made a significant contribution to taxonomic research, as most managers were career scientists before assuming management roles.

Table 1. Universities of South Africa (excluding universities of technology) and academic (teaching) staff that do research in plant taxonomy as at December 2014. Universities of technology are excluded as none of them employ taxonomists or offer taxonomic training. W=White; F=Female; M=Male; B=Black

University	Herbarium	Academic staff (including curators that also lecture)		Capacity for postgraduate training in taxonomy
		Number	Population group	
University of KwaZulu-Natal	Pietermaritzburg: Bews (NU) Westville: Ward (UDW)	3	3xWM	Yes
Rhodes University	Selmar Schonland (GRA)	1	WM	Yes
University of Cape Town	Bolus (BOL)	2	WM BM	Yes
University of Pretoria	H.G.W.J. Schweickerdt (PRU)	1	WM	Yes
University of the Western Cape	University of the Western Cape (UWC)	1	WM	Yes
University of the Free State	Geo-Potts (BLFU)	1	WF	Yes
North-West University	AP Goossens (UNWH)	1	WM	Yes
University of Johannesburg	University of Johannesburg (JRAU)	2	WM BF	Yes

University of the Witswatersrand	CE Moss (J)	2	WM WF	Yes
University of Limpopo	Larry Leach (UNIN)	0	0	No
University of Zululand	University of Zululand (ZULU)	0	0	No
Stellenbosch University	Stellenbosch University (STEU)	1	WF	Yes
Nelson Mandela Metropolitan University	Ria Olivier (PEU)	0	0	No
University of Fort Hare	Giffen (UFH)	0	0	No
University of Venda	None	0	0	No
Walter Sisulu University	Walter Sisulu University (KEI)	1	WF	Yes
University of South Africa	Unregistered herbarium	0	0	No

Table 2. Taxonomic researchers employed at SANBI (as at December 2014). W=White; B=Black; F=Female; M=Male.

Herbarium	**Researchers**		**PhDs**	
	Number	**Population group**	**Number**	**Population group**
Compton Herbarium (NBG)	3	1 WF; 2 WM	3	1 WF; 2 WM
National Herbarium (PRE)	15	4 WM; 5 WF; 6 BF	4	2 WF; 1 WM
Natal Herbarium (NH)	1	1 BF	0	

There is an unequal distribution of taxonomic researchers at universities, for example in December 2014 there were three lecturers employed in the field of taxonomy at the University of KwaZulu-Natal, whereas six universities in South Africa had no plant taxonomists in academic posts as researchers and lecturers. Of greater concern is that very few full time students study taxonomy at postgraduate level at universities, as there has not been even one PhD student per year over the past 10 years graduating with overt specialisation in plant taxonomy. Mostly those that do qualify in taxonomy, emphasise phylogenetics, and not traditional alpha-taxonomy, in their studies. Paradoxically though, most have found employment as taxonomists, but the persisting perception that there are few employment opportunities for graduates in the field of plant taxonomy may be a deterrent to students choosing taxonomy as a career. There are numerous complex social aspects influencing the path of a student to becoming a professional taxonomist, however these fall outside of the scope of the thesis. Such factors include the competence of teachers of botany and taxonomy; their ability to attract students to taxonomic research programmes that will lead to postgraduate specialisation in taxonomy; and the provision of postdoctoral research fellowships to retain investment into taxonomy graduates. An in depth analysis of these aspects at each university over a number of years could provide further insight into the deficiency of training taxonomists in South Africa.

In addition to the currently employed taxonomists in South Africa, there are at least nine professionals who are not employed as plant taxonomists but conduct plant taxonomic research, as indicated by taxonomic research published in peer-reviewed journals in the five years preceding December 2014. A very important contribution to taxonomic research is made by retired professionals, of which the number actively contributing in the past five years, to December 2014, is six from universities and seven from SANBI.

Three SANBI plant taxonomists, and two based at universities, will retire from formal employment within the next five years. More than half of the plant taxonomists in the workforce are under the age of 50, which indicates that there should not be a sudden drop in capacity of plant taxonomists in the short to medium term future. The main obstacle to maintaining or increasing capacity at SANBI and other government-funded institutions such as universities and museums, is the Employment Equity Act, number 55 of 1998 which discourages recruitment of researchers from the white population group. In the past five years, six plant taxonomist posts have been advertised at SANBI's three herbaria, and it was possible to fill only two of these with candidates meeting the Employment Equity targets. Posts had to be re-advertised, sometimes on multiple occasions, due to the lack of qualified candidates meeting the Employment Equity targets. As a result, two posts have not been filled and one was filled with a candidate who did not meet the Employment Equity targets.

4.3 Current state of taxonomic research

The current state of taxonomic research on South African plants can be ascertained in terms of the availability of up to date literature for all taxa; trends in taxonomic research in South Africa; and productivity of South African plant taxonomic researchers.

4.3.1 Progress with taxonomic treatments of South African plants

The main sources of information for plants are family treatises, Floras for geographically delimited areas, and taxonomic revisions of genera. For species level information, various internet web pages frequently provide information on species, particularly if they are of horticultural or economic value. While classic revisions, and to a lesser extent, Floras, consist of complete species descriptions and geographical distribution (and sometimes habitat) information, web pages tend to offer additional information on plants such as how to grow them or their medicinal uses.

The *Flora of southern Africa* (FSA) project was initiated in 1955 aiming to document more than 20 000 species of 180 angiosperm families in South Africa, Botswana, Lesotho, Swaziland and Namibia over a period of 40 years. Progress with the FSA project was not as rapid as expected, and after 40 years only about 18% of the taxa had been treated (see Appendix 12). A decision to de-emphasise the FSA in favour of publishing manuscripts in *Bothalia* under the banner of 'FSA contributions' was taken in 1995. Although the FSA project does not currently exist as a formal project, volumes may still be published in future in *Strelitzia*, an in-house journal of SANBI.

There are approximately 931 currently recognised genera of indigenous plant species in South Africa. Revisions of taxonomic groups are scattered throughout various national (e.g. *Bothalia* and *South African Journal of Botany*) and international (e.g. *Opera Botanica* and *Kew Bulletin*) journals. A compilation of all taxonomic revisions for South African plant genera reveals that there are 50 genera that were last revised prior to 1900. Revisions published prior to 1900 are mostly *Flora capensis* treatments, which are, as one would expect, outdated. This is because new species have since been discovered and existing taxonomic concepts have changed as more information becomes available, which in turn leads to better understanding of concepts and relationships between and among species. Also, an additional 100+ years of fieldwork have resulted in more comprehensive habitat and distribution information becoming available, for example from herbarium specimens.

Apart from Flora treatments and classical revisions, additional major sources of taxonomic information for South and southern Africa have been published in *Strelitzia*. A series of in-country regional Floras for South Africa have been published or are still in progress, with the eventual aim of providing coverage of the whole country. Floras for the northern provinces (comprising Gauteng, Limpopo, Mpumalanga and North-West and covering over 5 700 species) and the 'Greater Cape Floristic region' covering Western Cape and parts of the Northern and Eastern Cape ('Core Cape Subregion' covering approximately 9 200 species and 'Greater Cape Subregion' covering about 3 700 species) have recently been published (Retief & Herman, 1997; Manning & Goldblatt 2013; Snijman 2013); and those for the Free State (almost 3 000 species) and Eastern Cape (over 7 300 species) have been completed and are being processed for publication. A volume on the parts of the Northern Cape not treated in the *Plants of the Greater Cape Floristic Region* is in preparation, covering an estimated 3 200 species, and will be submitted for publication in 2016.

Completion of a Flora of KwaZulu-Natal would result in regional treatises covering the flora of the entire country (Victor et al. 2013b).

4.3.2 Trends in taxonomic research

The number of new taxa of South African plants described per year over the past 34 years was investigated to determine the research output productivity of taxonomists in South Africa, and thus their capacity to undertake and publish research. This provides an indication of how much new information is still being discovered, and from this it is possible to extrapolate to predict whether there is still more to be discovered. The capacity for taxonomic research to be conducted by South African taxonomists is also reflected in the contributions by South African taxonomists relative to non-South African taxonomists.

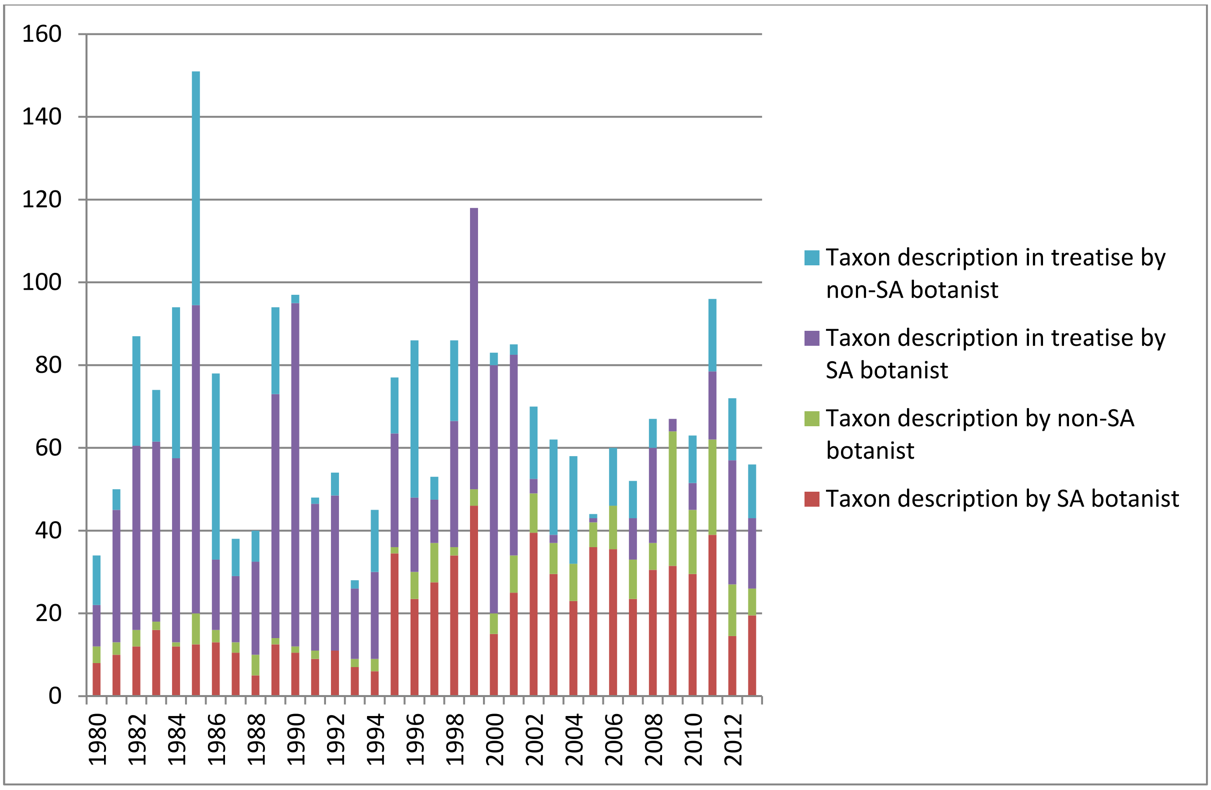

Figure 5. Number of plant taxa in South Africa described per year from 1980 to 2013 by South African (SA) and non-South African (non-SA) botanists, in revisions or as stand-alone papers.

There is no definite trend in the number of plant taxa described per year over the past 34 years (Figure 5). Numerous factors contribute to year-on-year variations and it would be mere speculation to attempt to explain these. For example, the slight reduction in the number of species described by South African botanists from 1991 to 1994 could be attributed to the time when the majority of SANBI taxonomists, and some university collaborators, were engaged with compilation of the comprehensive plant species checklist of South Africa (Arnold & De Wet 1993). The timing of the drop in number of new species described in revisions by South African botanists correlates with the establishment of the Leslie Hill Molecular Laboratory at the Kirstenbosch Research Centre in 2002, and the emphasis placed by SANBI research managers on conducting phylogenetic (mainly macrotaxonomic) research utilising molecular techniques (as discussed in Chapter 2). Another aspect of the description of new taxa that is worth noting is that in the 1980s (1980 to 1989), 102 taxa (14% of total) described were infraspecific taxa; in the 1990s, 57 (8%) were infraspecific taxa; and between 2000 and 2009, 72 (11%) were infraspecific taxa.

There is an apparent increase in number of taxa described in stand-alone (i.e. not part of a taxonomic treatise of a genus or family) scientific papers from 1995 onwards both by national and international scientists, with consistently fewer than 20 new taxa per year being described before 1995 and consistently more than 20 taxa being described each year from 1995 onwards. There is a corresponding reduction in the number of species described in taxonomic treatises (mainly generic revisions) of groups from 2002. The effect of publishing more individual species descriptions and fewer taxonomic treatises of groups would be an increased output of number of papers by scientists. The timing of this increase in numbers of stand-alone papers describing species correlates with the increasing tendency towards measuring productivity in terms of output of number of papers after the introduction of Corporate Strategic Plans at SANBI in 1991, and at universities, the measurement of academic productivity became increasingly, at least to some degree, based on number of papers, as were the formulae for funding research.

Opportunistic discoveries of new taxa in the field account for a small proportion of all taxa described, e.g. *Callilepis corymbosa* P.P.J.Herman & M. Koekemoer, discovered during the course of general fieldwork (Herman & Koekemoer 2014). Its recognition as a new species happened when the specialist in this group was unable to satisfactorily determine its identity in the herbarium. However, most new taxa are discovered in the course of conducting revisions, when examining existing and often unnamed specimens in herbaria, for example Kupicha (1984) described 10 new taxa in a revision of the genus *Schizoglossum*. In addition, a large number of the stand-alone taxon descriptions that have appeared recently resulted from discoveries made in the course of curatorial herbarium work (doing identifications and working through collections), but were published separately rather than as part of a revision. The genus *Ixia*, a member of the Iridaceae with 68 taxa indigenous to South Africa, makes an interesting case study to illustrate this. *Ixia* was first treated as a genus in *Flora capensis* (Baker 1896), and later revised by Lewis (1962) with 32 new taxa described. De Vos (1999) conducted the next revision of the genus for the Iridaceae contribution to the FSA project, adding two new varieties. Between 1993 and 2015, 39 new taxa of *Ixia* were published (including those by De Vos), of which eight species were published in seven stand-alone papers (Goldblatt & Manning 1993, 1999, 2004, 2010, 2012b; Goldblatt et al. 2015; Manning & Goldblatt 2006). In addition, three revisions covering four sections of *Ixia* were published (Goldblatt & Manning 2008, 2011 & 2012a), with 29 new taxa described. The advantage of describing new species as they become available rather than as part of a comprehensive revision is that the information is then immediately available for use by end users, especially conservation planners for example; the disadvantage is that the information is fragmented throughout the literature rather than being available in one consolidated source.

It is challenging to estimate what proportion of the flora of South Africa is currently undescribed, because of the variability in proportion of new taxa uncovered per genus during revisions conducted over the past 35 years. Revisions of relatively large genera (more than about 15 taxa) of small plants (small shrubs, succulents, geophytes, and herbs) since 1980 have elucidated numerous new species (excluding re-instated taxa and those that have subsequently been taken into synonymy). Since 1993, 57% (39) more taxa of *Ixia* have been described, which suggests that the potential for discovering more new species during revisions of plant genera is very high. In the 1970s revisions were conducted in genera of the subtribe Diosminae of the Rutaceae, which are characteristically sclerophyllous dwarf shrubs. Within this group, 7% (2) more taxa of *Diosma* were described; 15% (5) more *Acmadenia*; and 52% (12) more *Euchaetis*. In contrast, no new members of the local tree genera in the family have been described for over 50 years. From personal experience in the Rutaceae it is believed that only the genus *Agathosma* (135 taxa), last revised in 1950, harbours yet undescribed species. It is estimated that a revision of *Agathosma* should reveal at least 10%, but probably closer to 20%, more species than is currently known. In the geophytic Iridaceae, 39% (14) more *Dierama* infrageneric taxa have been described since 1980; 16% (27) more *Gladiolus* and 46% (47) more *Geissorhiza.* According to John C. Manning (personal communication, 2015), there are now only four currently known new species of Iridaceae in South Africa awaiting publication, and it is unlikely that many more will be discovered. One species in each of *Bobartia* and *Watsonia* have emerged from a treatment of these genera for a Flora account, and one in each of *Aristea* and *Tritoniopsis* emerged from general study in the field.

The conclusions that can be drawn from these estimates are that there are likely to be on average about 20% of new taxa in South African plant genera that have not been revised since 1980, particularly those with a predominantly small habit. It is unlikely that further study of recently revised genera would yield large proportions of undescribed taxa. Therefore, of the approximately 5500 taxa in South Africa not revised since 1980 (according to survey of the literature, see Chapter 3), there are probably about 1100 taxa (at a rate of 20% undescribed) yet unknown to science. This equates to about 5% of the current known flora of South Africa.

4.3.3 Publication output by taxonomists

For the following analysis of publication outputs of taxonomists, only numerical results are provided, but names and further details of individual taxonomists are available from the author on request. Data was collected mostly from personal communication, but in some cases where available, information was obtained from websites. Where no information was available for a researcher, or if employment term had been less than two years, the analysis excluded those researchers.

During a total of 153 person years worked between 2 000 and 2014, 15 university-based taxonomists (as at December 2014) published 779 papers. Of these, 131 (16.8%) were first-authored, or very rarely, sole-authored, publications. Whereas the average number of papers per year is 5.1 per person, of these, the average number of first-authored papers per year is 0.86 per person. During 171 person years of totalled employment, 17 of the SANBI taxonomists published 431 papers, of which 242 (or 56%) were first-authored. Therefore the average number of papers per year for SANBI staff members is 2.5 papers per person, of which 1.4 papers per person are first-authored. A direct comparison between the total number of papers published per person at SANBI and the universities would not give an accurate measure of relative productivity, because of the large number of duplications of counting due to the large numbers of co-authors from multiple institutions, especially for papers published by university-based taxonomists. The only truly reflective comparison available is therefore the number of first-authored papers.

A review of the titles of the papers published by taxonomists at both universities and SANBI show that the subject matter is very variable, and not limited to plant taxonomy, particularly in the case of university-based taxonomists. Where authors are not the sole or first author of a paper, the subject matter is usually not within that researcher's area of primary expertise, and particularly at universities, these papers are frequently (e.g. 50% of the papers of one author) not in plant taxonomy but in related (e.g. ecology) or sometimes very unrelated fields such as microbiology, chemistry, soil analysis, and zoology. Furthermore, co-authored articles are published in a variety of journals seemingly unrelated to plant taxonomy e.g. *Nuclear Instruments and Methods in Physics Research*; *Journal of the South African Veterinary Association*; *Forensic Science International* and *Journal of Fish Biology*.

An analysis was conducted by the Threatened Species Programme of SANBI to determine what proportion of South Africa's flora has been revised recently enough to provide sufficient information for conservation assessments (Von Staden et al. 2013). This analysis shows that 54% of the South African flora had been treated in generic or family taxonomic treatises published between 1970 and 2011. During this time most treatises were published in the 1980s and 1990s, with a significant decline in the last decade of the analysis. A reduction in generic or family taxonomic treatises between 2002 and 2011 can be inferred from the data presented in Figure 5, but this can not necessarily be attributed to a lower productivity of taxonomists considering the marked increase in the number of species described in stand-alone publications. This decade (2000–2010) also corresponds with an increase in numbers of papers in molecular phylogeny being published, leading to changes at the suprageneric (or macrotaxonomic) level owing to greater understanding of evolutionary relationships. Increasing numbers of modern revisions also include a phylogeny to circumscribe the group of interest, identify nearest relatives, and identify patterns of character evolution. Understanding of evolutionary relationships can assist in understanding more complex characteristics of an organism, such as the causal factors for its rarity as an example, leading to enhanced ability for priority setting by conservationists and development of management plans. Additional benefits of a phylogenetic classification are the following:

- It enables the focus of a search for species of economic importance to a smaller group (e.g. crop relatives and potential crops, biological control agents, or medicinal species).
- It provides a framework for measuring rates of extinction and patterns of global change.

- It furnishes the scientific context for understanding processes of extinction, speciation and adaptation that have given rise to present diversity.
- It creates a predictive framework for management of biological knowledge and a basis for communication across sciences.
- It provides a basis for comparative studies across all groups of organisms.

Peer-reviewed publications remain an important yardstick for measuring productivity of taxonomists. However, some of the most important products to end users often include those that are published in other forms. Among the more important local products is the checklist of South African plants, which has been published in hard copy e.g. Arnold & De Wet (1993), and subsequently Germishuizen et al. (2006) and is available online under the title Plants of Southern Africa (POSA) on the SANBI website (http://posa.sanbi.org/searchspp.php). Another critical product is the Brahms database (previously National Herbarium, Pretoria [PRE] Computerised Information System [PRECIS]) of specimen information and dissemination of this online. In addition, certain products generated predominantly by SANBI taxonomists, some with valuable contributions from university-based taxonomists, have been very popular, e.g. *Seedplants of southern Africa: families and genera* (Leistner 2000); *Herbarium essentials* (Victor et al. 2004); *Guide to the plant families of southern Africa* (Koekemoer et al. 2015); *Plants of the Greater Cape Floristic Region volume 1: the Core Cape flora* (Manning & Goldblatt 2013); and *Plants of the Greater Cape Floristic Region 2: the Extra Cape flora* (Snijman 2013). University taxonomists produce books to a lesser extent, but notable are publications such as *Medicinal plants of South Africa* (Van Wyk et al. 2009); *Field guide to trees of southern Africa* (Van Wyk & Van Wyk 2013); and *Field guide to the wild flowers of the Highveld* (Van Wyk & Malan 1997).

A discussion forum was held by SANBI staff members (D. Raimondo in collaboration with L. von Staden, M. Hamer and J.E. Victor) at the Southern African Society for Systematic Biology conference in Arniston, July 2012, to determine ways to stimulate the production of taxonomic revisions. The participants were asked, inter alia, what obstacles prevented them from carrying out taxonomic revisions, and answers are summarised as follows:

a) There is a perception that the academic merit system and funding allocation at South African universities inadvertently discourage publication of revisions as they are time consuming to conclude and thus reduce publication output. Shorter taxonomic publications which lead to a higher number of papers are therefore favoured. Criteria for career advancement and promotion take into account the impact factor of journals in which papers are published, and citation record for papers published. Because taxonomic journals tend to have lower impact factor and revisions are not cited often, publishing only descriptive revisions can have a negative impact on these criteria (Krell 2002).

b) There are limited opportunities for students to study traditional taxonomy at universities where the focus of taxonomic research projects is more on phylogenetic studies than revisions, especially considering that it often takes less time to complete such investigations and publish results. Phylogenetic studies can be published in higher impact factor journals and receive higher citation ratings. Therefore, taxonomic research is mostly carried out by more experienced researchers with accumulated knowledge of the groups in which they specialise.

c) Lack of information about research priorities was regarded as an obstacle to doing taxonomic revisionary work, and the need for an integrated source of information on what taxonomic research has been done, who is busy with what research projects, and what the priorities are for further research, was emphasised.

In further discussions during the workshop, it was suggested that funding should be directed towards projects that would contribute towards specific priority research targets, rather than putting out general calls for applications where researchers can choose their group of study.

4.4 South African herbaria

Herbaria are indispensable resources for taxonomic research. South Africa has at least 72 herbaria, housing more than 3.2 million plant specimens, of which over 80% are in the eight largest herbaria (Table 3) (Smith & Willis 1999). Most of these herbaria were established between 1970 and 1990. Between 1970 and 1980, 17 new herbaria were founded in South Africa, and 13 more up to 1990. In contrast, in the decade before 1970 only nine new herbaria were established, and eight in the decade after 1990. Very few were established at any time before or after this 50 year period (Smith & Willis 1999). The top 10 herbaria and the numbers of specimens they contain is shown in Table 3, and for all other herbaria in South

Africa there is a comprehensive review for the southern African region (Smith & Willis 1999). Each of the other herbaria in South Africa has fewer than 25 000 specimens.

Table 3. Number of herbarium specimens in the 10 largest herbaria in South Africa.

Herbarium	**Acronym**	**Number of specimens**
National Herbarium, SANBI	PRE	1 200 000
Compton Herbarium (incorporating SAM & STE), SANBI	NBG	500 000
Bolus Herbarium, University of Cape Town	BOL	300 000
Selmar Schönland Herbarium, Albany Museum	GRA	200 000
Bews Herbarium, University of KwaZulu-Natal	NU	120 000
H.G.W.J. Schweickerdt Herbarium, University of Pretoria	PRU	110 000
Charles E. Moss herbarium, University of Witwatersrand	J	100 000
KwaZulu-Natal Herbarium, SANBI	NH	100 000
Kimberley Herbarium, McGregor Museum	KMG	32 600
Bloemfontein Herbarium, National Museum	NMB	25 000

Although there are a large number of specimens in herbaria around South Africa, the representation of specimens geographically is unequally distributed. Figure 6 shows that there are certain parts of the interior of the country that are represented by fewer than 10 specimens per quarter degree grid square (representing roughly 25×25 km, or 625 km^2). In many cases this can be attributed partly to lower levels of diversity but even if this is the case, the number of specimens should be higher than 10 per quarter degree grid to be representative of the flora for the area.

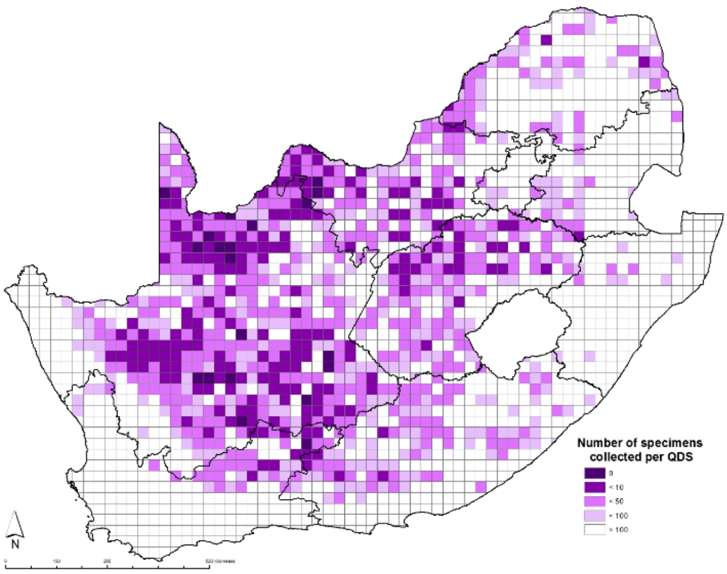

Figure 6. Map of South Africa showing the collecting intensity for South Africa, as reflected by the BRAHMS database of specimens in SANBI herbaria. Source: Biodiversity Information Management & Planning, SANBI.

One of the main reasons for the lack of collections from certain grids is poor accessibility, the bulk of the existing herbarium collections being from near major roads. Privately-owned farms in the arid interior of the country tend to be quite large and because a deliberate attempt must be made to survey them floristically, relatively few have been visited by plant collectors. The poor collecting record for parts of the northern Free State and central parts of North-West is in part due to extensive transformation of the natural vegetation by agronomy (this area is part of the so-called 'maize triangle').

SANBI, then as the NBI, had a National Plant Collecting Programme to improve regional coverage of South Africa in terms of plant specimens, and free identifications (whereas a handling fee is charged for all other collections) were provided to non-SANBI collectors who provided good quality specimens for donation to SANBI and that targeted under-represented areas. The advantage was that amateur botanists ('parataxonomists') could contribute herbarium specimens to the collections. However, in practice, amateur botanists did not specifically target areas identified as 'under-collected', and therefore specimens submitted from collectors were not always from under-represented areas, and for this reason the programme was not as effective as anticipated. According to the current coverage of specimens shown in Figure 6, there is still much to be done to fill the gaps in data. Although no longer a formal programme, SANBI still offers an informal service to have collections identified for free for collectors who apply and meet the requirements (i.e. donating good quality, fertile specimens from priority areas to SANBI), and this is evaluated on a case by case basis. More strategic identification of important areas to target for expanding herbarium specimen holdings, for example areas earmarked for development, may be an efficient way of improving coverage of under-represented areas.

In SANBI herbaria there are more than 3 800 taxa that are represented by five or fewer specimens (see Table 4 at the end of this chapter). This is an indication of how representative the herbarium collections are of the South African flora. Table 4 shows that the most under-represented family in this respect is the Aizoaceae (including Mesembyanthemaceae), which has the highest number of genera with fewer than five specimens per taxon (see Chesselet et al. 1995). Taxa represented by few specimens are characteristically rare and often distributed in inaccessible or hard to access localities. Another reason for lack of specimens is that some are awkward to collect and press due to for example the size or degree of succulence of the plants. Collecting to specifically target these taxa would provide vital foundational biodiversity information not only for taxonomic purposes, but also for providing information for end users, e.g. conservationists.

Only 6 276 plant specimens (out of a current total of about 1.8 million specimens in SANBI herbaria) collected in South Africa by early explorers before 1850 are presently in SANBI herbaria, after which the number of collectors and collections in South African herbaria accelerated rapidly as the interior of the country became more accessible and increasingly populated. Improvement of rail and road transport infrastructure resulted in the intensified botanical exploration of the country, eventually peaking in 1976 according to specimen accession records of SANBI's herbaria. In the decade 1975 to 1985, more specimens were collected and lodged in SANBI herbaria than in any other decade and since then numbers have dropped steadily for various reasons. Reasons that can be attributed to the decline in number of specimens collected as represented in SANBI herbaria include, inter alia, the introduction of handling fees for identification of plant specimens at the end of the 1980s; increased security risks, and subsequent reduced and more strictly controlled access to land from owners; increasingly onerous permitting requirements for plant collecting; increasing costs of fieldtrips; and reduced safety of carrying out fieldwork. In addition, the establishment of 17 new herbaria between 1970 and 1990 may have had an impact by attracting some specimens that otherwise would have populated SANBI herbaria.

4.5 Financial resources

A survey of opinions amongst South African botanical researchers (Bredenkamp & Smith 2008) revealed that two-thirds of respondents regarded inadequate funding as a "significant impediment to progress in botanical research." However SANBI and universities provide funding for research, and there is currently no obstacle to research at SANBI due to inadequate funding although this is subject to change depending on government budget allocations. Vehicles are available for fieldwork at SANBI and some universities, although research grants are used to hire vehicles when appropriate. Most universities have laboratories with facilities for conducting molecular analyses, as well as specialised equipment such as scanning electron microscopes, and SANBI staff frequently work in collaboration with university staff members to make use of these facilities. In addition, SANBI herbaria and universities provide access to libraries and inter-library loans, and has subscribed to JSTOR Global Plants, and there is therefore no shortage of access to 'old' and current literature. Additionally, access to older literature has been made considerably easier with the availability of open access online facilities such as the Biodiversity Heritage Library, Botanicus, and the Digital Library of the Spanish Royal Botanic Garden. All SANBI and university taxonomists have personal, computers and access to the internet.

A comprehensive needs assessment that was conducted for southern African herbaria (Smith et al. 1999b) as part of the South African Botanical Diversity Network (SABONET) project revealed that herbaria in the region had a shortage of dissecting and compound microscopes, computers and herbarium cabinets. These four items comprised the majority of the capital item budget expenditure that was required. At present the majority of taxonomists at SANBI and universities of South Africa do not have a shortage of these items. This positive development may indicate that budget allocation at the various institutions was indeed influenced by the report.

At SANBI, taxonomic researchers have access to a limited amount of governmental funds that cover some costs of research. This is usually sufficient to cover most running costs of research projects (e.g. fieldwork or specialised microscopy services), but staff members are encouraged to source additional funds from funding agencies so that the budget can stretch further. As a result of many successful applications to funding agencies, taxonomists at SANBI are able to conduct taxonomic work with sufficient financial resources available to them.

Funding for South African taxonomic research is provided by the Department of Science and Technology (DST) via the NRF. In 2002 the DST established a South African Biosystematics Initiative (SABI) to enhance taxonomic research of all organisms in South Africa. SABI was established following the compilation of a report (Herbert et al. 2001) that pointed out dire challenges faced by taxonomy and collections in South Africa. Between 2005 and 2012, about R96 million has been invested by the DST in South African taxonomy (not just plants), and in particular research projects with a phylogenetic/molecular component. There are few additional sources of local funding mainly aimed at promoting taxonomic research, for example the Botanical Education Trust, which operates under the auspices of the KwaZulu-Natal branch of the Botanical Society of South Africa (http://www.botsoc-kzn.org.za/html/botanical_education_trust.html).

4.6 Discussion and conclusions

From this review we can conclude that there is a severe shortage of capacity available to manage the country's rich and diverse flora in terms of taxonomy and provision of foundational biodiversity information. In general, taxonomists in South Africa are productive and are not limited by financial and infrastructural resources. However, there are still vast areas of the country that remain under-collected, and many taxa under-represented in herbarium collections, which indicate that taxonomists are partially limited by lack of plant material for research as well as from which to compile specimen data records for end users. In addition, the example of research on *Ixia* over the years reveals that intense study of one group generates a large amount of information over a long period of time. There are not enough taxonomists generating that level of information because it is clearly not happening for all of the 931 plant genera in South Africa. With approximately 20 000 species in South Africa and around 40 researching taxonomists (including technicians appointed in non-academic posts), the ratio of number of species to taxonomist is about 500 species to one. Table 4 paints a dire picture of how little is known for a large portion of the South African flora. It can therefore be concluded that more human capacity for taxonomic research in South Africa is urgently required. For now, to maximise the effectiveness of existing human capacity for taxonomy, prioritised activities need to be identified and efforts redirected towards these (Victor et al. 2015b).

Many taxonomists living and working outside of South Africa have made significant contributions to better understanding the taxonomy of the country's flora. A large number of these taxonomists originate from South Africa and have emigrated recently (ca. 30–50 since 1970), having found employment abroad. Although some continue to conduct taxonomic research on the South African flora and make valuable contributions, this 'brain drain' has undoubtedly had a significant negative impact on plant taxonomic capacity. Other taxonomists contributing from abroad have developed an interest in the flora of the country and furthered knowledge of many taxonomically problematic groups (e.g. Aizoaceae) immeasurably. A register of taxonomists detailing families and/or genera in which they are conducting taxonomic research and country of residence, is provided on the SANBI website (accessible on the link 'Register of taxonomic research' at http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies) as a way of stimulating further interest amongst taxonomists abroad. In addition it serves to coordinate taxonomic research of South Africa's flora on an international level.

A future potential problem for plant taxonomic capacity in South Africa is addressing employment equity targets. As shown in Table 1, not all universities have the capacity to offer post-graduate training in plant taxonomy, whereas some universities have two or even three taxonomists. The lack of capacity for postgraduate students to study taxonomy at the traditionally black universities is a severe impediment to successful transformation of the workforce in South Africa. More universities could undertake postgraduate training of students in taxonomy with external assistance in the form of a taxonomist co-supervisor from SANBI or another university. SANBI has at least 12 senior plant taxonomic researchers who have the ability to co-supervise research projects, but only four are currently involved in this activity. Bursaries offered to students at universities that currently do not have capacity to supervise postgraduate studies in taxonomy could stimulate the interest in this field amongst previously disadvantaged population groups. A solution to this would be for SANBI to more actively promote collaboration with these universities to offer skills for co-supervising postgraduate students, and facilitate (or offer) bursaries for this purpose, especially targeting universities currently without taxonomists. However with only about 40 positions for plant taxonomic researchers in the country, there is limited opportunity for employment and therefore the number of bursaries offered should be calculated carefully to ensure a steady supply for the availability of posts. To provide a choice of quality taxonomists the pool of candidates needs to be competitive, therefore it is essential to train more taxonomists than posts being or becoming available. Because of the specialist nature of taxonomy, which limits career opportunities, taxonomists need to have skills in other fields as a back-up so that they can find careers in for example environmental consulting or conservation, two fields in which trained taxonomists have successfully found employment in South Africa.

An alternative solution to providing future capacity for taxonomic research is for scientists to mentor interested and talented support staff employed in technical positions in herbaria, provided such candidates have an interest in, and aptitude for, taxonomic research. At least 11 senior SANBI plant taxonomists are actively mentoring junior scientists, graduates conducting internships or technicians, or have done so in the past five years. Many staff members employed by SANBI, frequently as junior taxonomists, enrol for postgraduate studies in taxonomy, which contributes to the development of institutional taxonomic expertise, in association with university and in-house experts leading the studies. SANBI also offers postdoctoral fellowships, of which one has been assigned to taxonomy in 2014 and has not yet been successfully filled because of the lack of graduates with PhD degrees available in South Africa. Postdoctoral fellowships also exist on occasion for taxonomy at some universities, but these mostly concentrate on phylogenetic work. These posts are essential to prevent loss of the investment into plant taxonomy and to facilitate the further career development of graduates. Early-career postdoctoral researchers can play a crucial role in advancing the scholarly mission of the host institution by bringing in new thinking and theories, as well as new methodologies. In a South African context postdoctoral researchers should have a responsibility to collaborate with and possibly mentor both junior staff as well as senior colleagues.

Traditionally black universities urgently need to create taxonomy posts so that equity can be redressed. In the meantime it would be beneficial for SANBI to produce more text-book type resources (for example Victor et al. 2004; Koekemoer et al. 2015), where the need exists, so that universities that do not employ taxonomists can still offer the course in a suitably stimulating manner so as to captivate potentially interested taxonomists. SANBI taxonomists have a history of offering training courses in aspects of taxonomy (especially identification of certain plant groups) to interested members of the public, including students, which has the benefits of creating awareness of and stimulating interest in taxonomy. These courses should be additionally promoted amongst botany students at traditionally black universities.

Although the conclusions reached by Von Staden et al. (2013) that taxonomic output in terms of 'revisions' has declined is supported, this cannot be extrapolated to taxonomic research output as a whole but rather to changes in emphasis of research topic. The output by taxonomic researchers in terms of numbers of papers published in ISI-rated journals shows that there is potential capacity to conduct and publish taxonomic research, although much of the research output effort is not spent on taxonomic research. The needs of most end users are for information of a microtaxonomic nature, but molecular phylogenetic work often supplies information of a macrotaxonomic nature. Using advanced modern analytical techniques to create phylogenies is useful, and indeed often necessary to resolve difficult taxonomic groupings, such as clarifying delimitation of genera. In the past, certain authors claimed that advances in molecular biology and phylogenetic reconstruction were driving taxonomic research to the detriment of 'traditional' taxonomy based on morphological studies (Wortley et al. 2002). It is therefore important not to overemphasise phylogenetic studies at the expense of alpha-taxonomy, but rather support comprehensive taxonomic revisions making use of datasets from other sources (including molecular) where necessary. It should, however, be noted that classifications produced by the phylogenetic school of classification are, in contrast to those of the evolutionary school, often less informative to end users of plant names (e.g. Van Wyk 2007).

Fragmentation of publications into units describing new taxa or revising small sections of a genus enables the information to be available for use in checklists and by end users much faster than working for years to consolidate all information and publish it when the revision is complete. An electronic means of dissemination, such as a single-portal online Flora, would solve the problem of fragmented information and enable all published literature to be available in a consolidated source. Taxonomic research should focus efforts on prioritised genera or even subdivisions of genera to uncover undescribed species, which can only be determined through comprehensive investigation, as illustrated by the example of *Ixia* (see 4.3.2). As is often the case globally, consolidation of information into Flora-type products can be done concurrently or after the primary research is conducted and published.

There appears to be a split between taxonomists doing molecular phylogenetic work (mainly at universities; supported by excellent laboratory facilities) and those doing more traditional alpha-taxonomy (mainly at SANBI; supported by excellent herbarium collections), and possibly not enough collaboration exists to unite those two ends of the spectrum. Fostering collaboration to ensure that phylogenetic work is not the end product but rather, is incorporated into revisions, would be of great benefit to taxonomic research products, because although end users do not directly require the results of macrotaxonomic studies, it is still a vital component of research. Qualifying scientists at SANBI are encouraged to become research associates at universities as one way to improve and expand collaboration between scientists who follow a more 'traditional' alpha-taxonomic approach and those who more easily use and incorporate molecular phylogenetic methodologies in their research. Likewise, scientists at tertiary institutions and elsewhere with access to molecular facilities are encouraged to forge partnerships with those taxonomists at SANBI who are well-versed in plant revisionary studies. Where practicable, this way of encouraging closer alliances between long-established and more modern research approaches will be increasingly emphasised in future as a way to strengthen inter-institutional and inter-personal collaboration. An added incentive for SANBI researchers to follow this approach is the possibility of indirectly benefitting from government subsidy paid to universities, museums and similar institutions for peer-reviewed material published in qualifying science media.

Such fund-sharing has the potential to expand the research budget allocation of both SANBI and university researchers.

Even if the human capacity to conduct plant taxonomic research in South Africa was doubled, there would still be work for taxonomists to do. The need for more taxonomists can clearly be justified but may not be prioritised in a country that already has such shortages of capacity in pre-primary, primary, secondary and tertiary education and social services, such as an effective police force, for example. Therefore aside from lobbying for more jobs to be created, there is an urgent need to utilise available resources (human and other) effectively, and develop a strategy to ensure that priority activities are conducted.

Table 4. Genera with number of taxa represented by five or fewer herbarium specimens in SANBI herbaria.

Genus	Family	Number of taxa indigenous to SA	% of taxa with ≤ 5 specimens
Arenifera	AIZOACEAE	4	100
Calamophyllum	AIZOACEAE	3	100
Cerochlamys	AIZOACEAE	3	100
Deilanthe	AIZOACEAE	3	100
Dinteranthus	AIZOACEAE	4	100
Emplectanthus	APOCYNACEAE	3	100
Ophionella	APOCYNACEAE	3	100
Phiambolia	AIZOACEAE	10	100
Polydora	ASTERACEAE	4	100
Woodia	APOCYNACEAE	3	100
Delosperma	AIZOACEAE	142	99
Ruschia	AIZOACEAE	206	92
Astridia	AIZOACEAE	10	90
Lithops	AIZOACEAE	29	90
Rhinephyllum	AIZOACEAE	10	90
Stomatium	AIZOACEAE	39	90
Aloinopsis	AIZOACEAE	8	88
Conophytum	AIZOACEAE	166	88
Corpuscularia	AIZOACEAE	8	88
Schwantesia	AIZOACEAE	8	88
Dicrocaulon	AIZOACEAE	7	86
Pectinaria	APOCYNACEAE	7	86
Anderbergia	ASTERACEAE	6	83
Argyroderma	AIZOACEAE	12	83
Glottiphyllum	AIZOACEAE	16	81
Hereroa	AIZOACEAE	27	81
Clematis	RANUNCULACEAE	5	80
Odontophorus	AIZOACEAE	5	80
Rhombophyllum	AIZOACEAE	5	80
Cheiridopsis	AIZOACEAE	32	78
Octopoma	AIZOACEAE	9	78
Lampranthus	AIZOACEAE	194	77
Antimima	AIZOACEAE	96	76
Gibbaeum	AIZOACEAE	17	76
Faucaria	AIZOACEAE	8	75
Grammatotheca	LOBELIACEAE	4	75
Myosotis	BORAGINACEAE	4	75
Pleiospilos	AIZOACEAE	8	75
Sceletium	AIZOACEAE	8	75
Larryleachia	APOCYNACEAE	7	71
Leipoldtia	AIZOACEAE	14	71
Albuca	HYACINTHACEAE	123	70
Bergeranthus	AIZOACEAE	10	70
Haworthia	ASPHODELACEAE	191	70
Trieenea	SCROPHULARIACEAE	10	70

Marasmodes	ASTERACEAE	13	69
Amauropelta	THELYPTERIDACEAE	3	67
Bacopa	SCROPHULARIACEAE	3	67
Berula	APIACEAE	3	67
Chenopodiopsis	SCROPHULARIACEAE	3	67
Coelanthum	MOLLUGINACEAE	3	67
Cynorhiza	APIACEAE	3	67
Eustegia	APOCYNACEAE	6	67
Glia	APIACEAE	3	67
Hammeria	AIZOACEAE	3	67
Herniaria	CARYOPHYLLACEAE	6	67
Jacobsenia	AIZOACEAE	3	67
Juttadinteria	AIZOACEAE	3	67
Lidbeckia	ASTERACEAE	3	67
Microcodon	CAMPANULACEAE	3	67
Mucuna	FABACEAE	3	67
Najas	NAJADACEAE	3	67
Nananthus	AIZOACEAE	6	67
Oeceoclades	ORCHIDACEAE	3	67
Peersia	AIZOACEAE	3	67
Rabiea	AIZOACEAE	6	67
Tanquana	AIZOACEAE	3	67
Villarsia	MENYANTHACEAE	3	67
Drosanthemum	AIZOACEAE	107	66
Cephalophyllum	AIZOACEAE	31	65
Ornithogalum	HYACINTHACEAE	82	65
Cyphia	LOBELIACEAE	83	64
Chasmatophyllum	AIZOACEAE	8	62
Gasteria	ASPHODELACEAE	40	62
Riocreuxia	APOCYNACEAE	8	62
Adenogramma	MOLLUGINACEAE	10	60
Clerodendrum	LAMIACEAE	5	60
Cylindrophyllum	AIZOACEAE	5	60
Esterhuysenia	AIZOACEAE	5	60
Ledebouria	HYACINTHACEAE	35	60
Nervilia	ORCHIDACEAE	5	60
Resnova	HYACINTHACEAE	5	60
Sarcostemma	APOCYNACEAE	5	60
Wimmerella	LOBELIACEAE	10	60
Trichodiadema	AIZOACEAE	32	59
Tylecodon	CRASSULACEAE	49	59
Phyllopodium	SCROPHULARIACEAE	26	58
Astroloba	ASPHODELACEAE	7	57
Dasispermum	APIACEAE	7	57
Drimiopsis	HYACINTHACEAE	7	57
Oscularia	AIZOACEAE	23	57
Stenoglottis	ORCHIDACEAE	7	57
Vellereophyton	ASTERACEAE	7	57
Aneilema	COMMELINACEAE	9	56
Lichtensteinia	APIACEAE	9	56
Brachystelma	APOCYNACEAE	85	54
Quaqua	APOCYNACEAE	28	54

Restio	RESTIONACEAE	165	54
Wahlenbergia	CAMPANULACEAE	177	54
Centella	APIACEAE	63	51
Acanthopsis	ACANTHACEAE	8	50
Acrodon	AIZOACEAE	6	50
Alchemilla	ROSACEAE	16	50
Angraecum	ORCHIDACEAE	6	50
Apodolirion	AMARYLLIDACEAE	6	50
Bulbophyllum	ORCHIDACEAE	4	50
Capnophyllum	APIACEAE	4	50
Cleretum	AIZOACEAE	4	50
Hyobanche	OROBANCHACEAE	8	50
Jordaaniella	AIZOACEAE	6	50
Killickia	LAMIACEAE	4	50
Lyperia	SCROPHULARIACEAE	6	50
Machairophyllum	AIZOACEAE	4	50
Mitrophyllum	AIZOACEAE	6	50
Monilaria	AIZOACEAE	6	50
Ophioglossum	OPHIOGLOSSACEAE	16	50
Pimpinella	APIACEAE	6	50
Ruschiella	AIZOACEAE	4	50
Sansevieria	RUSCACEAE	6	50
Stapeliopsis	APOCYNACEAE	8	50
Thamnea	BRUNIACEAE	8	50
Bulbine	ASPHODELACEAE	70	47
Curio	ASTERACEAE	15	47
Dyschoriste	ACANTHACEAE	9	44
Alepidea	APIACEAE	28	43
Annesorhiza	APIACEAE	14	43
Braunsia	AIZOACEAE	7	43
Cynoglossum	BORAGINACEAE	7	43
Gethyllis	AMARYLLIDACEAE	30	43
Microdon	SCROPHULARIACEAE	7	43
Cineraria	ASTERACEAE	36	42
Lobelia	LOBELIACEAE	66	41
Prismatocarpus	CAMPANULACEAE	34	41
Struthiola	THYMELAEACEAE	34	41
Callilepis	ASTERACEAE	5	40
Silene	CARYOPHYLLACEAE	10	40
Trifolium	FABACEAE	5	40
Buchnera	OROBANCHACEAE	8	38
Ceratocaryum	RESTIONACEAE	8	38
Ceropegia	APOCYNACEAE	52	38
Gymnostephium	ASTERACEAE	8	38
Lepidium	BRASSICACEAE	16	38
Maytenus	CELASTRACEAE	13	38
Mesembryanthemum	AIZOACEAE	21	38
Plantago	PLANTAGINACEAE	8	38
Selago	SCROPHULARIACEAE	176	38
Syringodea	IRIDACEAE	8	38
Euphorbia	EUPHORBIACEAE	251	37
Lotononis	FABACEAE	145	37

Helictotrichon	POACEAE	14	36
Sarcocornia	CHENOPODIACEAE	14	36
Thesium	SANTALACEAE	173	36
Cliffortia	ROSACEAE	150	35
Lessertia	FABACEAE	54	35
Oedera	ASTERACEAE	17	35
Schizoglossum	APOCYNACEAE	37	35
Arctotis	ASTERACEAE	59	34
Agathisanthemum	RUBIACEAE	3	33
Bassia	CHENOPODIACEAE	3	33
Ceraria	PORTULACACEAE	3	33
Cerastium	CARYOPHYLLACEAE	6	33
Christella	THELYPTERIDACEAE	6	33
Cyathocoma	CYPERACEAE	3	33
Duvalia	APOCYNACEAE	12	33
Ebracteola	AIZOACEAE	3	33
Freylinia	SCROPHULARIACEAE	9	33
Heterolepis	ASTERACEAE	3	33
Hippia	ASTERACEAE	9	33
Lachnostylis	PHYLLANTHACEAE	3	33
Linconia	BRUNIACEAE	3	33
Mariscus	CYPERACEAE	3	33
Mestoklema	AIZOACEAE	6	33
Nebelia	BRUNIACEAE	6	33
Oxalis	OXALIDACEAE	240	33
Polyarrhena	ASTERACEAE	6	33
Polycarena	SCROPHULARIACEAE	18	33
Sisyranthus	APOCYNACEAE	12	33
Spermacoce	RUBIACEAE	3	33
Steirodiscus	ASTERACEAE	6	33
Trianoptiles	CYPERACEAE	3	33
Tylophora	APOCYNACEAE	9	33
Vepris	RUTACEAE	3	33
Manulea	SCROPHULARIACEAE	73	32
Othonna	ASTERACEAE	94	32
Phylica	RHAMNACEAE	182	32
Schoenoxiphium	CYPERACEAE	19	32
Cuscuta	CONVOLVULACEAE	13	31
Malephora	AIZOACEAE	16	31
Psammotropha	MOLLUGINACEAE	13	31
Tripteris	ASTERACEAE	16	31
Pelargonium	GERANIACEAE	257	30
Pseudoselago	SCROPHULARIACEAE	27	30
Rotheca	LAMIACEAE	10	30
Senecio	ASTERACEAE	290	30
Agathosma	RUTACEAE	152	29
Cephalaria	DIPSACACEAE	14	29
Festuca	POACEAE	7	29
Galium	RUBIACEAE	18	28
Galenia	AIZOACEAE	30	27
Muraltia	POLYGALACEAE	121	27
Pachycarpus	APOCYNACEAE	26	27

Tetraria	CYPERACEAE	42	26
Anacampseros	ANACAMPSEROTACEAE	36	25
Anthoxanthum	POACEAE	4	25
Diclis	SCROPHULARIACEAE	4	25
Elephantorrhiza	FABACEAE	8	25
Erythrococca	EUPHORBIACEAE	4	25
Garuleum	ASTERACEAE	8	25
Gnidia	THYMELAEACEAE	101	25
Harpagophytum	PEDALIACEAE	4	25
Harveya	OROBANCHACEAE	16	25
Hydrocotyle	ARALIACEAE	4	25
Ifloga	ASTERACEAE	4	25
Lachenalia	HYACINTHACEAE	126	25
Limosella	SCROPHULARIACEAE	8	25
Lithospermum	BORAGINACEAE	8	25
Lopholaena	ASTERACEAE	8	25
Massonia	HYACINTHACEAE	8	25
Nymphoides	MENYANTHACEAE	4	25
Oncosiphon	ASTERACEAE	8	25
Ruellia	ACANTHACEAE	8	25
Anisodontea	MALVACEAE	21	24
Cotula	ASTERACEAE	45	24
Diascia	SCROPHULARIACEAE	63	24
Hebenstretia	SCROPHULARIACEAE	25	24
Hypoxis	HYPOXIDACEAE	41	24
Cullumia	ASTERACEAE	22	23
Ficinia	CYPERACEAE	70	23
Marsilea	MARSILEACEAE	13	23
Nemesia	SCROPHULARIACEAE	69	23
Roella	CAMPANULACEAE	22	23
Spiloxene	HYPOXIDACEAE	22	23
Acalypha	EUPHORBIACEAE	23	22
Aeschynomene	FABACEAE	9	22
Aizoon	AIZOACEAE	9	22
Clutia	EUPHORBIACEAE	40	22
Hoodia	APOCYNACEAE	9	22
Melinis	POACEAE	9	22
Osteospermum	ASTERACEAE	46	22
Phymaspermum	ASTERACEAE	18	22
Platycaulos	RESTIONACEAE	9	22
Salvia	LAMIACEAE	27	22
Stylapterus	PENAEACEAE	9	22
Tetragonia	AIZOACEAE	32	22
Zantedeschia	ARACEAE	9	22
Dicoma	ASTERACEAE	14	21
Erica	ERICACEAE	943	21
Zaluzianskya	SCROPHULARIACEAE	52	21
Afrosciadium	APIACEAE	5	20
Barleria	ACANTHACEAE	46	20
Carpha	CYPERACEAE	5	20
Cassine	CELASTRACEAE	5	20
Chamarea	APIACEAE	5	20

Conium	APIACEAE	5	20
Danthoniopsis	POACEAE	5	20
Eleocharis	CYPERACEAE	10	20
Hemimeris	SCROPHULARIACEAE	5	20
Isoglossa	ACANTHACEAE	15	20
Lippia	VERBENACEAE	5	20
Macowania	ASTERACEAE	10	20
Ranunculus	RANUNCULACEAE	5	20
Rhoicissus	VITACEAE	10	20
Staavia	BRUNIACEAE	10	20
Thesidium	SANTALACEAE	5	20
Vigna	FABACEAE	20	20
Cotyledon	CRASSULACEAE	16	19
Rhynchosia	FABACEAE	64	19
Dimorphotheca	ASTERACEAE	22	18
Juncus	JUNCACEAE	17	18
Zyrphelis	ASTERACEAE	11	18
Aridaria	AIZOACEAE	6	17
Aspidoglossum	APOCYNACEAE	23	17
Cannomois	RESTIONACEAE	12	17
Cyphostemma	VITACEAE	29	17
Dolichos	FABACEAE	12	17
Haplocarpha	ASTERACEAE	6	17
Kleinia	ASTERACEAE	6	17
Melanospermum	SCROPHULARIACEAE	6	17
Olinia	OLINIACEAE	6	17
Pteronia	ASTERACEAE	71	17
Schizachyrium	POACEAE	6	17
Sclerochiton	ACANTHACEAE	6	17
Strelitzia	STRELITZIACEAE	6	17
Sutherlandia	FABACEAE	6	17
Tetradenia	LAMIACEAE	6	17
Vahlia	VAHLIACEAE	6	17
Eriosema	FABACEAE	32	16
Limonium	PLUMBAGINACEAE	19	16
Pharnaceum	MOLLUGINACEAE	25	16
Agrostis	POACEAE	13	15
Dianthus	CARYOPHYLLACEAE	20	15
Eugenia	MYRTACEAE	13	15
Stapelia	APOCYNACEAE	39	15
Aptosimum	SCROPHULARIACEAE	14	14
Asystasia	ACANTHACEAE	7	14
Cissus	VITACEAE	7	14
Clivia	AMARYLLIDACEAE	7	14
Dierama	IRIDACEAE	36	14
Indigofera	FABACEAE	189	13
Raspalia	BRUNIACEAE	15	13
Brunia	BRUNIACEAE	8	12
Epischoenus	CYPERACEAE	8	12
Indigastrum	FABACEAE	8	12
Thereianthus	IRIDACEAE	8	12
Elytropappus	ASTERACEAE	9	11

Portulaca	PORTULACACEAE	9	11
Psoralea	FABACEAE	44	11
Scabiosa	DIPSACACEAE	9	11
Schistostephium	ASTERACEAE	9	11
Abutilon	MALVACEAE	20	10
Crotalaria	FABACEAE	51	10
Pentzia	ASTERACEAE	20	10
Syncarpha	ASTERACEAE	31	10
Jamesbrittenia	SCROPHULARIACEAE	58	9
Pavonia	MALVACEAE	11	9
Ozoroa	ANACARDIACEAE	14	7
Vernonia	ASTERACEAE	14	7
Setaria	POACEAE	17	6
Hibiscus	MALVACEAE	44	5
Serruria	PROTEACEAE	56	5
Hermannia	MALVACEAE	140	4
Panicum	POACEAE	33	3

CHAPTER 5

DEVELOPMENT OF STRATEGIES FOR TAXONOMY IN SOUTH AFRICA

5.1 Introduction

In this chapter the results of the needs analysis for end users of taxonomic information are presented, and the development of the methodology and application thereof for prioritising taxonomic research in South Africa are presented in a series of papers that have been published or as manuscripts that have been submitted for publication. These contributions are summarised in this chapter, and in each case reference is made to the full versions presented in the Appendices of the thesis. Each paper has its own discussion and therefore no discussion is included in this chapter. However, an overview of all papers and manuscripts is presented and discussed in the general discussion, Chapter 7.

5.2 Needs analysis

An analysis of the needs of end users conducted during this study shows that the most frequent external users of plant identification services at SANBI are (in no particular order):

- university researchers and students;
- herbaria;
- environmental consultants;
- members of the public;
- Agricultural Research Council (especially veterinary institutions) of the Department of Agriculture of the South African government;
- Council for Scientific and Industrial Research of the Department of Science and Technology of the South African government;
- natural history museums (national and international);
- local interest groups, e.g. the Botanical Society of South Africa;
- commercial plant nurseries and garden centres;

- conservation agencies e.g. South African National Parks, South African provincial nature conservation bodies; and

- SANBI staff from other divisions and programmes e.g. the Millennium Seed Bank project; Invasive Aliens Early Detection and Rapid Response Programme; Threatened Species Programme; and horticulturalists.

Requests for data from the database of herbarium specimen information addressed to SANBI herbaria include information such as species lists for geographical areas, and geographical distribution ranges of species. In order of frequency these end users are: taxonomists at SANBI herbaria; researchers at universities; scientists from other SANBI divisions (e.g. the Threatened Species Programme); environmental decision makers (e.g. consultants); environmental policy makers; conservationists; veterinarians and agronomists (Pieter J.D. Winter, personal communication, 2012). These end users all require accurate taxonomic information and data derived from herbarium specimens and their associated labels to enable correct recommendations on, for example, proposed land use, and informed decisions that take the occurrence of threatened taxa into account.

The five most important requirements for end users of taxonomic products determined as part of the outcomes of a National Workshop for Stakeholders and End users of Botanical Information and Herbaria (Steenkamp & Smith 2002, 2003), in descending order of priority, were:

- updated, accurate checklists of all South African plant species;

- species lists for specified geographical areas enriched with additional information such as Red List status or residential status (e.g. aliens);

- a centralised information database system with all associated information on the plants that is factually accurate and freely accessible to all;

- fully representative herbarium collections; and

- an efficient and affordable plant identification system.

A review of enquiries, data requests, visitors and services requested from SANBI's herbaria from 2010 to 2014, shows that there is still continuous pressure on herbarium staff for these activities to be prioritised, and the results of the workshop conducted in 2002 therefore remain current. These requirements largely depend on accurate specimen identifications, which in turn rely on precise species demarcation and comprehensive information that is generated through taxonomic research. Taxonomists are well placed to provide this information to enable the work in virtually all other fields of biological endeavour, such as to assist conservationists to assess the extinction risk of the species, and to determine how to manage them.

It is therefore important not to overemphasise phylogenetic studies at the expense of alpha-taxonomy (Wortley et al. 2002), but rather support comprehensive taxonomic revisions making use of datasets from a diversity of sources, including molecular analyses, where necessary. It should, however, be noted that classifications produced by the phylogenetic school of classification are, in contrast to those of the evolutionary school, often less informative to end users of plant names (e.g. Van Wyk 2007; Brummitt 2014).

5.3 Development of a method for highlighting taxonomic problems in conservation assessments

The first step towards developing taxonomic priorities was taken when plant taxa that were taxonomically problematic were highlighted during conservation assessments and flagged accordingly (Victor 2006; Raimondo et al. 2009). This method of highlighting taxa of conservation concern enabled a prioritisation process for taxonomically problematic groups of plants requiring research attention (Victor & Smith 2011). These two developments are discussed below.

5.3.1 Data Deficient Flags for use in the Red List of South Africa

Published contribution (see Appendix 2): Victor, J.E. 2006. Data Deficient flags for use in the Red List of South African plants. *Bothalia* 36: 85–86.

Compilation of the most recent Red List of plants for South Africa was heavily reliant on taxonomic information such as that derived from taxonomic revisions (Raimondo et al. 2009). In many cases lack of recent revisions was an obstacle to assessing the extinction risk faced by these taxa. In the South African Red List there are potentially threatened plant taxa that have not been adequately assessed because of lack of sufficient data to determine the conservation status. These were classified as Data Deficient (DD), since, according to IUCN (2001), a taxon qualifies for this category when “there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status".

The flag 'T' (from Taxonomy) proposed to highlight taxa listed as DD due to unclear taxon demarcation was used in the subsequent publication of Red List of South African plants (Raimondo et al. 2009). This enabled use of the taxa flagged as such to aid in prioritising families (Victor & Smith 2011), genera, species, and infraspecific taxa for taxonomic research.

5.3.2 The conservation imperative and setting plant taxonomic research priorities in South Africa

> Published contribution (see Appendix 3): Victor, J.E. & Smith, G.F. 2011. The conservation imperative and setting plant taxonomic research priorities in South Africa. *Biodiversity & Conservation* 20: 1501–1505.

As discussed in Chapter 4, South Africa suffers from a lack of human and other resources to adequately address its taxonomic research needs. This inevitably calls for a process of priority setting to ensure the wise use of available funding and other resources. The list of threatened indigenous South African plant taxa identified in the Red List of plants of South Africa (Raimondo et al. 2009) provides a significant opportunity for taxonomists to align their work with national priorities, in this case, conservation. Plant families most urgently in need of attention in this regard were identified (Victor & Smith 2011) and recommendations made to conduct research on taxa that are classified as DDT.

5.4 A method for establishing taxonomic research priorities in a megadiverse country

> Published contribution (see Appendix 4): Victor, J.E., Smith, G.F. & Van Wyk, A.E. 2015. A method for establishing taxonomic priorities in a megadiverse country. *Phytotaxa* 203: 55–62.

A coordinated strategy for taxonomy is needed in South Africa, to address the needs of end users and improve the relevance and impact of research products. The basic types of information that taxonomists provide, common to all organisms, are the names, descriptions, and a mechanism for identifying components of biodiversity, and associated data such as geographical distribution information. This information depends on and is provided through taxonomic research. A strategy for taxonomy that focuses on the main gaps in taxonomic knowledge is therefore required. This paper details the prioritisation process developed for South Africa to facilitate this process and its application to plants, but it can potentially be used for all organisms and be equally applicable to other parts of the world.

The methodology for the development of the taxonomic priorities to formulate a research strategy is described, and selected results are presented as examples. Determining priorities for taxonomic research and for informing the development of the strategy will facilitate bridging the gaps among compilers, users and implementers of taxonomic information, and streamline the taxonomy-conservation impediment.

5.5 Strategies for taxonomy in South Africa

The *Biosystematics research strategy* comprises a series of strategies for taxonomic research on all living organisms: the algae, animals, bacteria and archaea, fungi and plants of South Africa (Victor et al. 2013a; 5.5.2). In this publication, the word 'biosystematics' is used to infer taxonomy of various groups of organisms, and inclusive of associated data from other sources e.g. palynology and cytology (Stuessy et al. 2014).

The SANBI website can be consulted for the full strategies for taxonomic research for the algae (http://www.sanbi.org/sites/default/files/documents/documents/algal-systematics-research-strategy-south-africa.pdf) and bacteria and archaea (http://www.sanbi.org/sites/default/files/documents/documents/bacterial-biosystematics-research-strategy.pdf). The plant taxonomic component of the *Biosystematics research strategy* has been covered in two published documents (Victor et al. 2013a; Victor et al. 2013b), one submitted contribution that has subsequently been published (Victor et al 2015b), and one submitted but yet unpublished document, discussed below.

5.5.1 Creating an online World Flora by 2020: a perspective from South Africa

Published contribution (see Appendix 5): Victor, J.E., Smith, G.F., Turland, N.J., Le Roux, M., Paton, A., Figueiredo, E., Crouch N.R., Van Wyk A.E., Filer, D. & Van Wyk, E. 2013. Creating an Online World Flora by 2020: a perspective from South Africa. *Biodiversity & Conservation* 23: 251–263.

Target 1 of the Global Strategy for Plant Conservation (GSPC) aims to produce an online Flora for all the plants of the world by 2020. Governments that have ratified the CBD will have to report over the next several years on progress towards achieving this challenging target. Floras are still widely regarded as a means of providing descriptive information and identification tools for the plants that occur in a specified region. Historically, Floras have included taxon concepts with diagnostic characters, accepted scientific names with authorship for all taxa known to occur in the area; synonymy; descriptions; identification keys; geographic distributions within the region in question; specimen citations; habitat; literature references; and illustrations. Of these, taxon (notably species) concepts, nomenclature, descriptions, identification tools, illustrations and distributions are critical components. The approach being taken by South Africa, a biodiversity-rich country, in working towards achieving Target 1 of the GSPC by 2020 is presented and discussed, outlining a methodology that may well be of practical use to other countries. Other countries are urged to consider how they might monitor progress with, and ultimately meet, this challenging conservation-driven target.

5.5.2 A biosystematics research strategy for the algae, animals, bacteria and archaea, fungi and plants of South Africa 2013–2018

Published contribution (see Appendix 6): Victor, J.E., Hamer, M. & Smith, G.F. 2013. A biosystematics research strategy for the algae, animals, bacteria and archaea, fungi and plants of South Africa 2013–2018. SANBI Biodiversity Series 23. SANBI, Pretoria.

This is the first ever comprehensive national research strategy produced for South Africa that deliberately emphasises taxonomy as an important research component. However, taxonomic research is inextricably linked to collections of preserved biological collections typically held in natural history museums and herbaria, as well as to the datasets (databases) that are derived from specimens held in these collections. Although this document deliberately addresses the research component of taxonomy in South Africa, collections, and data capture and dissemination, are identified as co-priorities for attention because of the dependence of research on these resources. This strategy recognises the challenges faced by collections, and derivative datasets are seen as a major output from taxonomy that is needed by users of taxonomic information.

The purpose of the *Biosystematics research strategy* is to provide clear guidelines to taxonomic researchers in South Africa and elsewhere as to where to direct research effort and resources to maximise the benefits of research to society. The *Biosystematics research strategy* also clarifies the coordinating role with which SANBI is mandated.

The *Biosystematics research strategy* deals with the taxonomy of living organisms. Three domains of life are recognised: the Bacteria, Archaea and Eukarya. Whereas Bacteria and Archaea each comprise a Kingdom of their own, they are treated together in a strategy. Although now classified in a Kingdom together, strategies for animals and fungi have been developed separately, as well as plants and algae which here refer to brown algae (now classified in a separate Kingdom) as well. Viruses and subviral agents (e.g. prions) are not classified in a Kingdom as they are not considered to be living organisms, and for this reason they are excluded.

Priority objectives for the research strategies across taxa were identified as establishment of the following:

- an online and updated taxonomic checklist of South Africa's biodiversity (algae, animals, bacteria and Archaea and fungi);
- an online platform for species information, linked to literature and specimen data (all taxa);
- an online resource for the identification of priority species (algae, animals, bacteria and Archaea); and
- networks of experts to promote information sharing, collaboration and communicating the importance of taxonomic research and data (bacteria and Archaea and fungi).

In summary, points raised by the different individuals and groups who commented on components of the *Biosystematics research strategy* highlighted the following considerations:

- SANBI's focus on plants but the need for a coordinating body for other taxa;
- funding to support the implementation of many of the objectives;
- shortage of capacity to carry out many of the activities identified, with many experts also having other research interests and responsibilities; and
- the need for all taxonomists to support the objectives and use the strategy to guide the actions, approaches and research work.

5.5.3 Strategy for biosystematics research in South Africa: overview of the plant systematics component

Submitted contribution (see Appendix 7): Victor, J.E., Smith, G.F. & Van Wyk, A.E. (in press). Strategy for biosystematics research in South Africa: overview of the plant systematics component. Proceedings of a UNESCO International Conference, Botanists of the 21st Century: Roles, Challenges and Opportunities, 22–25 September 2014, UNESCO Headquarters, Paris, France.

A strategy for plant taxonomic research has been developed by SANBI as part of the *Biosystematics research strategy* to provide guidance to institutions and individual researchers that are involved in research on the South African flora. Users of taxonomic information require the names, demarcation and descriptions of species and identification tools such as keys, along with information on diagnostic characters, distributions and habitats, various plant properties, and evolutionary relationships. The basis of this information is provided via taxonomic research mainly at species level, which has battled to attract sufficient funding in the last few decades. A prioritisation process was used as guideline for establishing taxonomic research priorities. Such a process is an effective way to clearly and unambiguously justify the use of resources (either derived from funding agencies or taxpayers) to carry out taxonomic research.

5.5.4 Strategy for plant taxonomic research in South Africa 2015–2020

Submitted contribution (see Appendix 8): Victor, J.E., Smith, G.F. & Van Wyk, A.E. 2015. Strategy for plant taxonomic research in South Africa 2015–2020. SANBI Biodiversity Series 26. SANBI, Pretoria.

The National Environmental Management: Biodiversity Act (NEMBA) No. 10 of 2004: Section 11 gives SANBI the mandate for leadership in South African taxonomy through coordination and promotion of the discipline in the country. The *Strategy for plant taxonomic research in South Africa 2015–2020* (hereinafter referred to as the Strategy) therefore provides guidance to South African institutions that are involved in plant taxonomic research. A coordinated strategy for plant taxonomic research that addresses the needs of end users improves the relevance, image and impact of research products.

The end users of taxonomic research comprise all users of plant names in scientific, commercial, policy-making, educational, and civil society spheres. Their requirements include having rapid and free access to reliable species names and descriptions, along with identification tools, information on their distributions and habitats, diagnostic characters, properties and evolutionary relationships. The basis of this information is provided mainly via alpha-taxonomic research, which has battled to attract funding in the last few decades. Global trends towards electronic publication of taxonomic data and databases and the use of innovative technologies for identifying species facilitate the dissemination of taxonomic information to end users.

The capacity as at December 2014 for conducting taxonomic research in South Africa was assessed to determine whether there are sufficient resources in terms of: (1) human capacity, (2) research material and (3) financial (and other) resources, to implement and monitor a strategy for plant taxonomic research in the future. Amongst other factors, the current state of taxonomic research was reviewed, as well as the resources available for research (herbarium specimen collections and databases of associated label information). This enabled identification of shortages of capacity or resources that might prove to be an obstacle in implementing a strategy. The need for more taxonomists in South Africa is clearly justified. Recommendations are made to address transformation in terms of population representation.

Three research programmes are proposed to focus on the main gaps in taxonomic knowledge, namely, (1) the e-Flora programme, (2) the revisions of plant genera programme, and (3) the Data Deficient plant programme. Because of the ongoing work conducted on priority taxa the lists are dynamic; current lists of priority taxa are not in this document but are available on the SANBI website as indicated. In addition, a plant collecting programme is proposed to improve coverage of foundational biodiversity information for South African plants. Collecting of specimens should routinely incorporate sampling for comparative DNA studies, including DNA barcoding, with links to correctly identified voucher specimens. These programmes collectively cover the strategic objectives identified, addressing priority areas of research and aiming to produce the most useful products for end users. It is critical that the quality of data derived from herbarium specimen labels and disseminated to end users is accurate, and data validation and detailed checking is therefore not a separate programme but rather a key activity of all taxonomists and support staff at SANBI. Recommendations for addressing data quality are given in the Strategy. All herbaria that disseminate electronic specimen label information to end users should adhere to these.

CHAPTER 6

IMPLEMENTATION AND EVALUATION OF THE STRATEGY

6.1 Introduction

The development of the *Strategy for plant taxonomic research in South Africa 2015–2020* (Appendix 8) was initiated in 2011. The first draft was circulated for additional input to university and SANBI taxonomists, some end users, and international partners, and revised four times between 2011 and 2015. The initial version included the first three strategic objectives of the Strategy, as well as the first three corresponding research programmes which were implemented at SANBI in 2011 through the Biosystematics Research Committee (see Chapter 3). From that point all taxonomic research conducted at SANBI was directed towards addressing priorities identified in the Strategy. Results of implementation were monitored by tracking progress of research conducted and published on priority lists of taxa. The Strategy was revised and adjusted when necessary to incorporate feedback until the fifth (current) version was produced (Appendix 8) and subsequently published (Victor et al. 2015b). This most recent version will be revised in 2020, incorporating any future feedback from scientists, and evaluating changes in needs of end users and priorities. Aspects of its implementation are presented in this chapter, along with an evaluation of the effectiveness of the Strategy to date.

6.2 Programme 1: e-Flora

On the basis of the e-Flora programme (see Appendix 8), SANBI's Biosystematics Research and Biodiversity Collections Division motivated in 2013 to fill four vacant positions dedicated to running this programme and achieving the goals. A Plant Checklist Coordinator and a support officer are managing the list of names, synonyms and associated literature for all South African plants. The e-Flora Coordinator and a support officer are responsible for ensuring that the e-Flora of South Africa is completed by 2020, in collaboration with as many taxonomists as possible from around the country, as described in Victor et al. (2013b). The e-Flora Coordinator is responsible for ensuring that the project is completed and contributed to the World Flora Online by 2020, to ensure that South Africa meets its obligation to the Convention on Biological Diversity's Global Strategy for Plant Conservation.

The first deadline for the e-Flora of South Africa project is to have 40% of the Flora published online by July 2016. To achieve that, all SANBI taxonomists associated with its three herbaria, as well as some technical support officers employed in the herbaria, are contributing by collating existing information (latest published literature for use in the checklist) and supplying it to the Coordinator. After the Coordinator has received necessary permission from copyright holders, the literature is scanned and the collaborators then mark-up and edit the text. The Coordinator ensures that the text is incorporated into the database. One obstacle to progress is the time-consuming process of obtaining permission from copyright holders. For this reason the contingency plan of incorporating existing information from regional Floras of South Africa is concurrently being implemented, so that even if it is not possible to have the latest available Flora-style information (see Victor et al. 2013b) for each taxon, at least there will be as complete a coverage of the country as possible.

6.3 Programme 2: revisions of plant genera

The first priority list of genera to be revised consisted of 159 genera (available from the authors on request). The uptake of this list has been very gratifying, with 81 of the prioritised genera currently under revision e.g. *Acanthopsis*, *Delosperma*, *Lessertia*, *Rhynchosia*, and *Vernonia* (see http://www.sanbi.org/sites/default/files/documents/documents/priority-plant-genera-revision_0.pdf for complete list), and eight that have been completed (*Aloinopsis*, *Garuleum*, *Spiloxene* [now *Pauridia*], *Micranthus*, *Nananthus*, *Ranunculus*, *Silene* and *Steirodiscus*) since the list was first circulated in 2011.

A review of recent research on genera prioritised by the Strategy and how the resulting revisions have impacted on society can be illustrated by considering the change in conservation status after a revision has been conducted. Increase in information accumulated during the course of a revision frequently leads to changes in conservation status as more information becomes available, such as during the course of a revision of *Garuleum* (Swelankomo 2013), a genus of eight species of which two were listed as Data Deficient (DD) according to the IUCN (2001) categories and criteria for evaluation of conservation status, and flagged ‘T’ (Victor 2006). The remaining members are categorised, according to IUCN (2001) criteria, as Least Concern (LC). As a result of investigation during revision of the genus, *Garuleum album* S.Moore was recognised to be Vulnerable; and *Garuleum tanacetifolium* (MacOwan) Norl. is now known to be not threatened with extinction.

Bruyns (2012) made numerous nomenclatural changes to the genus *Euphorbia*, which were published without an accompanying revision of the genus. However the nomenclatural changes resulted in a number of conservation status changes, particularly where species listed as DD, threatened, or of conservation concern were subsumed into species that are listed as LC. Some examples of changes to conservation status are as follows:

a) *Euphorbia crassipes* Marloth: a number of taxa were taken into synonymy (e.g. *E. fusca* Marloth which was LC; *E. inornata* (Dressler) Radcl.-Sm. was DDT and *E. hopetownensis* Nel was DDT) and thus the distribution range is enlarged and two DDT species removed from list.
b) *Euphorbia flanaganii* N.E.Br.: a number of species were subsumed (*E. gatbergensis* N.E.Br., LC; *E. ernestii* N.E.Br., LC; *E woodii* N.E.Br., Endangered). Because of medicinal use of the taxa that were previously recognised as separate, and that it is declining on the whole, was formerly LC but now known to qualify as Vulnerable.
c) *Euphorbia jansenvillensis* Nel: *E. tubiglans* Marloth ex R.A. Dyer was taken into synonymy, and distribution range is therefore now bigger; in addition *E. tubiglans* was LC whereas *E. jansenvillensis* was DDT.

6.4 Programme 3: Data Deficient plants

The first list of taxa prioritised for research included 272 taxonomically problematic taxa, and the latest update has 246 (see http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies and click on link to ‘priority plant species for revision’ for latest update). Three examples of taxonomic problems investigated without conducting a taxonomic revision of the genus are given below. Progress is relatively slow in comparison to that of the revisions of plant genera programme, perhaps because of the difficulty of some of the taxonomic problems of the taxa concerned. These taxa are frequently little-known and under-represented in herbaria, and require extensive fieldwork to gather sufficient information for study.

The following case studies are examples of research projects targeting DDT plants conducted by the author in conjunction with newly qualified graduates conducting their internships at SANBI, and/or junior staff members.

6.4.1 Case study 1: taxonomic problem impacting on conservation and development

Published contribution (see Appendix 9): Victor, J.E., Mashau, A.C. & Ngobeni, V.J. 2012: The taxonomic and conservation status of *Agrostis eriantha* var. *planifolia*. *Bothalia* 42: 202–204.

This is an example of a taxon with a historical distribution in the Gauteng province of South Africa. Considering the rarity of this taxon, having only been collected once in what is now a highly transformed habitat, nature conservation officials were unsure of how to manage and protect it. Potential economic development, including inevitable urban expansion in the areas where this species could occur was at risk as development would have been disallowed had this apparently rare taxon been proven to be at risk of extinction. This problem was compounded by the inability to distinguish between the two subspecies, which lead to questions about the taxonomic status of this taxon. In collaboration with Gauteng Nature Conservation, fieldwork was conducted to relocate the species growing in or near its former habitat, and a subsequent investigation was carried out on material collected at the type locality to determine whether or not the taxon was a good entity. The results of the study concluded that the taxon could not be recognised as separate, and *Agrostis eriantha* Hack. var. *planifolia* Gooss. & Papendorf was therefore regarded as not warranting varietal status.

This case study illustrates the benefit of the Strategy in channelling taxonomic work to focus on the Data Deficient plant programme. This benefited both economic development, which was no longer hindered by a taxonomically problematic and potentially threatened taxon, and conservation, which no longer had to expend resources on a species that was not worthy of special conservation effort.

6.4.2 Case study 2: unknown species potentially of concern to conservation

Published contribution (see Appendix 10): Baloyi, O., Victor, J.E. & Swelankomo, N. 2013. Gentianaceae. The taxonomic and conservation status of *Sebaea fourcadei*. *Bothalia* 43: 225–230.

Sebaea fourcadei Marais was known from only two specimens prior to this study. This species is superficially similar to *S. ramosissima* Gilg and their ranges are parapatric, which lead to uncertainty in demarcation of the two species and resulted in assignment of a conservation status of DDT to *S. fourcadei*. Further material located during the investigation confirmed the distinction between the two species, and facilitated a proposed new conservation status, following comprehensive assessment.

This example illustrates how a species that is not clearly taxonomically demarcated and understood, due to lack of herbarium specimen material (see Chapter 5 and the plant collecting programme), can escape notice and become lost to conservation and biodiversity.

6.4.3 Case study 3: medicinally important taxa with taxonomic uncertainties

Published contribution (see Appendix 11): Victor, J.E. & Aphane, M. 2014. Taxonomic status of *Pelargonium reniforme* Curt. *Bothalia* 44: Art. #173, 3 pages. http://dx.doi.org/10.4102/abc.v44i1.173

Pelargonium reniforme Curt. is a morphologically variable species that many authors have attempted to split or combine. Confusion relating to the differences between the two subspecies that were included under *P. reniforme* impeded attempts to assess their conservation status, which is of concern considering that this species is being harvested for use in traditional medicine (Motjotji 2011). The investigation showed that the morphological characters used to distinguish the two subspecies of *P. reniforme* are too variable to separate them. Variation in some morphological characters may be related to environmental conditions. The recognition of the two subspecies of *P. reniforme* as distinct taxa is no longer justified, and the species has been assessed as Near Threatened due to declining populations.

6.5 Discussion

Progress on the priority areas addressed in the first draft of the *Strategy for Plant Taxonomic Research in South Africa* has been more rapid than expected. At this rate, it is anticipated that within 10 years after initial implementation of the Strategy, i.e. by 2020, South Africa will have a centralised electronic resource, the e-Flora of South Africa, comprising a checklist and associated nomenclatural information, links to other useful information, and a specimen information database; in addition the number of genera that are urgently in need of revision will have halved, dropping from 159 to an estimated 80, and it is expected that the number of taxa listed as DDT will be reduced by 20%, from 272 to about 214. The large number of priority genera being researched since the initial list was developed is testimony to the success of the Strategy so far. Progress to date indicates that channelling of resources towards priority activities and appointments of new staff members in SANBI (Checklist & e-Flora co-ordinators) have been worthwhile. Furthermore, strategic planning of taxonomy is benefiting conservation by facilitating conservation assessments, as well as the economy by way of streamlining the interface between taxonomy and end users.

CHAPTER 7

GENERAL DISCUSSION

7.1 Introduction

South Africa is one of the most biologically diverse countries in the world, with one of the richest floras. According to its mandate, the South African National Biodiversity Institute (SANBI) is responsible for exploring, revealing, celebrating and championing biodiversity for the benefit and enjoyment of all South Africans. SANBI must coordinate and promote the taxonomy of South Africa's biodiversity. As a Schedule 3A government institution (public entity), SANBI is primarily funded by the taxpayers of South Africa, thus its policies and strategies ultimately stand in the service of society. The development of a strategy to promote biodiversity research extends much more widely than the institution itself. SANBI, with its regional network of herbaria, botanical gardens and most comprehensive plant collections in South Africa, is an indispensable resource to be consulted by anybody studying the botanical diversity of the country, and southern African subcontinent. To this end, the main intention of the thesis was to provide an objective method for prioritising taxonomic research that informs the development of a strategy and that meets the needs of end users, and to make efficient use of scarce and dwindling resources (financial and human capacity) in South Africa. In this chapter, the outcomes of the study are presented, and whether or not strategic planning has benefitted taxonomic research thus far is discussed.

Most of the development of plant taxonomic research in South Africa in the past 400 years happened in the 20th century, stimulated by creation of posts at local universities and within the government, first of the Union of the country, later in the Republic, for botanical research. The search for useful plant species triggered early exploration of South Africa's flora, which gradually grew into a quest for new species and increasing organisation of accumulated knowledge in the form of preserved herbarium accessions and taxonomy. As formal botany and taxonomy developed in South Africa, ecological and economic interests further influenced research, and modernisation in terms of technological advances in analytical techniques, research methods and electronic communication pushed taxonomy into the modern era. Thus taxonomic research priorities in South Africa have been driven by personal fascination in plant diversity, by organisation and formalisation of taxonomy as a science, by external influences, such as searches for economically important plants, and lastly by the advent of electronic communication and information dissemination technology and resultant increasing global connectivity (see 1.8 b & c). Modern taxonomic research frequently incorporates phylogenetic studies and employs more objective and quantitative methods of analysis including statistical/numerical techniques and cladistics. Information that is essential for the practice of taxonomic research, such as texts, images, journals and datasets, are becoming more easily accessible as such content is increasingly disseminated on the World Wide Web. In addition, taxonomic outputs are being reported (e.g. via Scratch pads) and disseminated electronically for the benefit of a diverse range of end users, ranging from scientists to lay people. This influences the way in which taxonomic research is conducted and the type of products that are delivered. Thus product delivery is streamlined and fast tracked using available global electronic connectivity tools. The advantages of this 'connectivity phase' of taxonomy need to be utilised to maximise on the rapid and efficient manner in which taxonomic information can be disseminated, at least in some instances at comparatively low cost, and to improve the relevance and impact of research products derived. Further discussion of what the future may hold for plant taxonomy as a discipline is provided below (see 7.8).

7.2 Capacity for plant taxonomic research

It was demonstrated that South Africa lacks sufficient human capacity for plant taxonomic research, which can be an obstacle to effective management of the wealth of plant diversity in the country. The objective of the Global Taxonomic Initiative (GTI), to remove the taxonomic impediment through development or strengthening of human capacity to generate information (UNEP 2010a), is an obligation of South Africa as a signatory to the Convention on Biological Diversity (CBD). The first strategic action of the capacity building strategy for the GTI (adopted at COP 11, Hyderabad, India in 2012) is to "review taxonomic needs… and set priorities to implement the Convention and the Strategic Plan for Biodiversity 2011–2020." SANBI is mandated to fulfil this obligation.

One of the major challenges to taxonomy worldwide is a lack of dedicated, trained, skilled, and experienced taxonomists available to replace those retiring or leaving employment, as recruitment of young scientists into taxonomy is not keeping pace with needs of countries to adequately study their biodiversity (Cotterill, 1995; Simonetti, 1997). This is linked to, amongst other factors, a zoocentric approach when children are raised, little or diminishing attention to plants and their significance in school curricula, a lack of taxonomy programmes at training institutions worldwide, and these are also all applicable to South

Africa. Priorities that have been identified through the review on capacity for plant taxonomic research in South Africa are (1) an urgent need for more taxonomy posts in South Africa, particularly at universities that do not currently have lecturers in plant taxonomy; and (2) a need to train more taxonomists at universities. It needs to be recognised by the government of South Africa that these actions must be taken to fulfil the country's obligation to the CBD. SANBI has certain obligations under the GTI, including capacity building, and should therefore demonstrate that an effort is being made to fulfil the capacity component of its responsibility to these international conventions.

7.3 Organisational structure of SANBI

The organisational structure of SANBI is shown in Figure 7. Within SANBI, all personnel involved in biodiversity (from research, monitoring planning and policy advice, to publishing and disseminating data) fall within the Biodiversity Science and Policy Advice branch. Within the branch there are four divisions which operate independently but collectively, on the institutional Corporate Strategic Plan. The divisions are managed by senior staff members (usually chief directors) who report to the head of the branch.

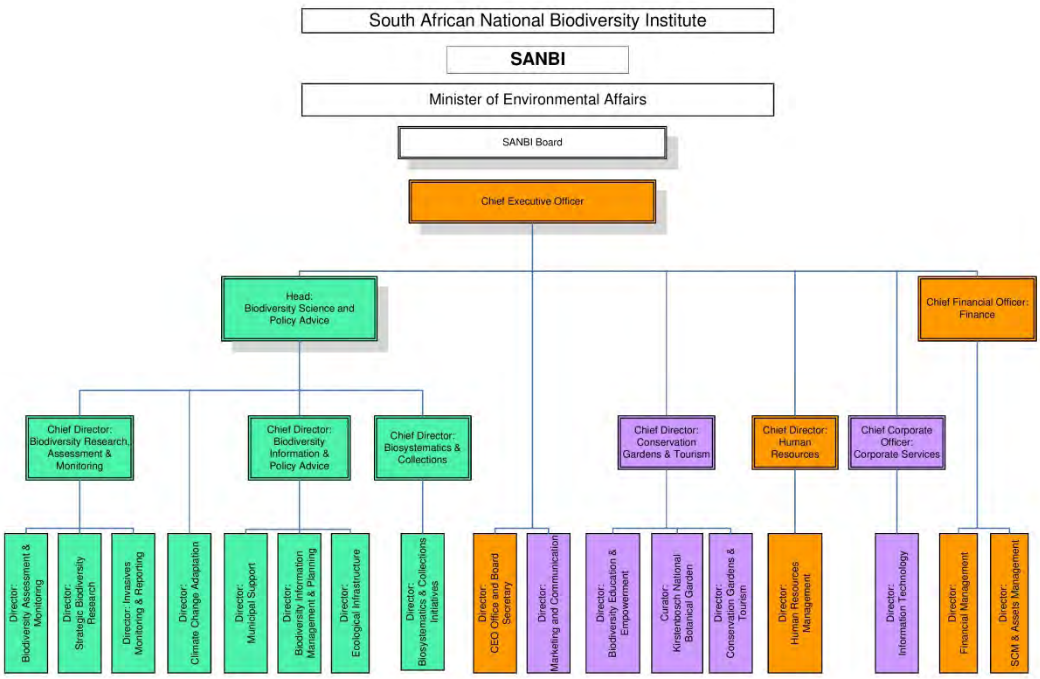

Figure 7. Organisational structure of SANBI.

A weakness of the current organisational structure of SANBI is that it promotes segregation between divisions. This has the result that the taxonomic researchers in the Biosystematics Research and Biodiversity Collections Division (Biosystematics Division) relies on cooperation from Biodiversity Information Management and Planning (BIM), situated in a different division, to fulfil their mandate. BIM are the interface between Biosystematics Division and the public, disseminating information generated by the Biosystematics Division to end users. This information generated by Biosystematics Division is in the form of data in the herbarium specimen collection database (BRAHMS), online resources e.g. the Plants of southern Africa checklist, and in-house research publications, e.g. the regional Floras, produced by the scientists. Online production of the e-Flora of South Africa is also dependent on the cooperation of BIM. The Biosystematics Division does not have autonomy in influencing whether deadlines can be met on time; and management of the BRAHMS dataset is in control of BIM. This situation is counterproductive because the quality and speed at which these products are delivered are not in the ultimate control of the Biosystematics Division, and yet the Biosystematics Division is held accountable for delivery of the products. Control of the database, data and dissemination thereof should be ideally situated within the Biosystematics Division to be effectively managed and to enable the Biosystematics Division to be accountable for their mandate. The current structure should be revisited by management to take these considerations into account. One way in which the current structure could be improved is by transferring the key personnel involved in the management and dissemination of the data to the Biosystematics Division.

SANBIs three herbaria fall within the Biosystematics Division. The National Herbarium (PRE) situated in Pretoria has a national and international focus in terms of specimen representation, housing plant specimens from throughout the country, from neighbouring countries, as well as from Africa and abroad. Researchers in the National Herbarium carry out studies on plants in the geographical region in which the herbarium situated as well as in other parts of the country, whereas scientists from the Compton Herbarium (NBG) in Cape Town have traditionally focussed on plants of the southern, Western and Northern Cape (Cape Floristic Kingdom); and herbarium collections were intentionally built up to be representative of the southern and western regions of the country. The KwaZulu-Natal Herbarium's (NH) collections have been mostly restricted to plants of South Africa's eastern seaboard.

Taxonomic expertise is unevenly distributed among the herbaria. Most of SANBIs taxonomists are situated in the National Herbarium in Pretoria, with only three currently in Compton Herbarium in Cape Town (and a vacant post), and one in the KwaZulu-Natal Herbarium. A scientist post at Compton Herbarium has within the past year been converted to a technician post after an unsuccessful attempt to recruit a scientist as a result of lack of applicants meeting Employment Equity requirements. It is critical that a suitable applicant is recruited to fill the current vacant scientist post at Compton Herbarium, otherwise human capacity for taxonomic research on the exceptionally rich Cape Floral Kingdom will be severely constrained. Having only one SANBI taxonomist in KwaZulu-Natal poses certain constraints to implementation of the Strategy, as taxonomic research of plants occurring in the floristically diverse eastern region of the country is in risk of being neglected; furthermore, the ability of one scientist to complete the Flora of KwaZulu-Natal in isolation is limited. Sharing of expertise between different centres is vital to ensure that the eastern region is given due attention, as well as to ensure completion of the KwaZulu-Natal Flora.

To optimise the spread of taxonomic expertise around the country, there should be at least one more scientist at a senior level in KwaZulu-Natal, so that the existing scientist can benefit from collaborative research, and the Flora of KwaZulu-Natal completed. If it is not possible to create a new scientist post in SANBI for this purpose, it is vital that a post-doctoral position is established at the KwaZulu-Natal Herbarium.

7.4 Priorities for taxonomic research

Kirschner & Kaplan (2002) ascertained that a “substantial proportion of the names listed on the IUCN Red List represent synonyms, often belonging to widespread taxa, or remain doubtful taxonomically”. A comparison conducted by these authors on Red List taxa showed that after monographs of Juncaceae and Potamogetonaceae were produced, only 10–25% of the taxon names that had been used before, were correct. This clearly illustrates the importance of up-to-date, reliable taxonomic work for conservation. Conservationists are reliant on the knowledge of professional taxonomists to guide the assignment conservation status to taxonomically problematic species. One of the most important products that will be disseminated as an outcome of the *Strategy for plant taxonomic research in South Africa* is the e-Flora of South Africa, which will make taxonomic information for all plants in the country accessible to end users in a single electronic portal (Victor et al. 2013b).

The *Strategy for plant taxonomic research in South Africa* (hereinafter referred to as the Strategy) has been developed using gaps in information, and areas and taxa lacking sufficient taxonomic endeavour, to inform research priorities (see Chapter 1.8 e). Existing taxonomic data derived from databases were analysed, and the literature interrogated (see Chapter 1.8 f), using an objective methodology that was developed to determine taxonomic priorities. This methodology can be applied not only to plants, but also to most other groups of organisms (Victor et al. 2013a). The Strategy was implemented in SANBI in 2011 and the progress and results monitored on an ongoing basis. The SANBI website hosts a list of plant taxonomic research interests of botanists, both professional and amateur, from herbaria and universities countrywide, as well as priority species and genera for research (http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies). These lists will be updated regularly and act as a resource to stimulate interest in the Strategy, in this way coordinating taxonomic research on the South African flora. Being online enables it to be accessible to international botanists interested in studying South African flora. Thus the Strategy serves the additional purpose of promoting taxonomy, both nationally and internationally.

One of the primary objectives of taxonomy is to develop a natural and predictive classification system that reflects evolutionary relationships among plants. To achieve this, results from molecular studies are integrated with other sources such as anatomical, cytological, physiological, and palynological studies. This can be efficiently achieved by fostering collaborative relationships between researchers, especially when facilities for particular technologies are lacking at certain institutions. Although alpha-taxonomic work should be prioritised, it is best enhanced with a variety of information from other sources to produce the best possible research products.

Further exploration of South Africa’s biodiversity is needed so that improved foundational biodiversity information can be provided to end users. Hindrances to exploration of the country are legislation around permitting requirements for collecting plants, difficulty, costs, time and complexity of obtaining permits (Kruger et al. 2007), high costs of accommodation and transport, restricted access to land, and security issues. The solution to overcoming obstacles in obtaining collecting permits is to have one central permitting body operating from a central office. Applicants should apply for a single collecting permit that is applicable for collecting or transport of plant material in the whole country. SANBI could facilitate the permitting process by assessing and registering all projects nationally, so that permit-issuing staff would be required to spend less time assessing individual applications to determine what the impact on biodiversity would be. However because factors such as this example are beyond the control of the current Strategy, exploration therefore needs to be carefully targeted towards under-collected taxa and under-collected areas. Imposition of handling fees for identification could be a further obstacle to collecting new information, and waiving this fee for good quality specimens collected from prioritised areas would provide an incentive to collectors who are interested in contributing specimens for these purposes.

7.5 Evaluation of the Strategy for plant taxonomic research

The hypothesis presented in Chapter 1 (8 d) was that targeted taxonomic research would improve the relevance and impact of derivative research products (such as Floras) that are delivered to the benefit of end users. An assessment of the effectiveness of the initial priority setting exercises (Chapter 6) has demonstrated that taxonomic research targeted towards priority endeavours can indeed be effective, as the projected clarification of the taxonomy of at least a half of the priority genera (revisions of plant genera programme) in a decade (2011 to 2020) reflects the value of having the Strategy in place. Secondary objectives of developing strategies, for example to reduce numbers of taxonomically problematic plants to aid conservation or sustainable economic use of plants; and to assist end users by producing revisions so as to enable more accurate plant identifications, are of direct benefit to end users. Thus taxonomic research benefits from having a coordinated Strategy in place, to benefit the needs of end users (see Chapter 1.8 h). It has therefore been demonstrated that SANBI can better fulfil its mandate by providing a coordinated framework for taxonomic research on plants (see Chapter 1.8 a), and other organisms.

7.6 Future of the Strategy for plant taxonomic research in South Africa

Within SANBI, existing capacity in taxonomic research is and will continue to be utilised towards addressing the priorities identified in the Strategy. The e-Flora of South Africa, once delivered online in 2020, will continue to be maintained by the Biosystematics Division of SANBI, and further developed to include more aspects (e.g. links to conservation status, inclusion on CITES appendices, medicinal and other uses), and existing data will be continuously updated and improved (e.g. improved taxon descriptions as they become available through research). The global explosion of media, and information and communication technology, is moving the world from an industrial economy to a knowledge-based one. Disseminating comparatively costly taxonomic research outputs as efficiently and effectively as possible by utilising the Internet is of paramount importance. The future of revitalising taxonomy as a science lies in optimising the interface between the electronic media and the science, and in so doing, making taxonomy freely accessible to the public.

The Strategy will be promoted amongst university researchers to stimulate their involvement by selecting projects highlighted for research for themselves and students, and in particular to stimulate interest of potential taxonomists embarking on honours (fourth-year) studies in projects from the Data Deficient plants programme. Such projects have the additional advantage of being cross cutting between taxonomy, population biology, ecology and conservation, and are therefore ideal for students who have not yet specialised in a particular field of research. Projects from this programme are also ideal for newly qualified graduates conducting internships, who need research projects that can be accomplished in under one academic year, or junior scientists who require mentorship and training.

Strategic prioritisation for expanding plant specimen collections in herbaria through a systematic and efficient approach to target geographical and information gaps will significantly improve the knowledge base of plant diversity in South Africa. This will provide vital foundational biodiversity information not only for taxonomic purposes, but also for end users. Quality control of information in any existing, or anticipated, databases (including for example the e-Flora) must be subjected to constant scrutiny to ensure information is as accurate as possible.

At regular (five year) intervals, updated needs and gap analyses will be used to inform new priorities for the next strategy cycle. Although the long term monitoring of the success of the Strategy falls beyond the scope of this study, from projections of initial results the overwhelming success of this project is predicted. It is anticipated that the experiences, methodologies, approaches, and outcomes of this study will provide guidance to decision makers managing and leading taxonomic networks and institutions, and the funders of taxonomic research, in other parts of the world beyond South Africa, especially in the so-called megadiverse countries.

7.7 The Strategy for plant taxonomic research in South Africa in a global context

Few taxonomic research strategies exist in institutions similar to SANBI in other parts of the world, and only one example intimating at such a strategy was located in this study. The Natural Environment Research Council (NERC) in the United Kingdom (UK) set up a committee to ascertain whether and how to develop a national strategy for taxonomy, although to date the strategy itself has not yet been produced. The emphasis of the NERC report (Godfray et al. 2011) on taxonomy of Overseas' Territories highlights the contrast between a biodiversity-poor country with an advanced economy country in comparison to a biodiversity-rich country with a developing economy, where resources need to be directed towards national (rather than overseas) priorities. To put South African taxonomic research in a global context, the following points that were suggested by the NERC as to what research programmes might entail (see Chapter 1) are compared with the current priorities for taxonomic research in South Africa.

a) Major digitisation campaigns: South Africa commenced with digitisation of specimen information in the 1970s. In SANBI herbaria, 100% of the South African specimens of the National Herbarium are digitised; about 17% of the specimens in the Compton Herbarium are digitised; and about 60% of the KwaZulu-Natal herbarium specimens are digitised. Other major herbaria in South Africa have been attempting to digitise all specimens, most notable of which is the Bews Herbarium of the University of KwaZulu-Natal with 100% of its specimens digitised. It is also the first major institutional herbarium in the country to convert to the BRAHMS database. Digitisation is an ongoing process at SANBI and some other herbaria, and has not been specifically highlighted in the current Strategy as a priority, which rather focusses on improving coverage and quality of existing data.

b) Establishment of web-based taxonomies of significant taxa: a programme has been established at SANBI to provide an e-Flora of all plants, notably not only of 'significant' taxa, of South Africa (Victor et al. 2013b).

c) Completion of significant taxonomic resources: the regional Floras of South Africa will cover the flora of the country by 2018 and will be consolidated in the e-Flora programme (Victor et al. 2013b). The e-Flora aims to contain links to identification keys, and to literature and other references.

d) Assembling key branches (phylogenies) of the Tree of Life: this has not been directly specified as a priority in the short term in South Africa, although contributions to this are made by South African taxonomists. It is a consideration for prioritisation in future research strategies when provision of primary taxonomic information is no longer an obstacle to management of biodiversity of the country.

e) DNA barcoding campaigns: currently underway in South Africa (see 7.8). Although collection of samples for DNA barcoding is encouraged as a routine part of fieldwork for taxonomic research, it is not currently prioritised as an independent exercise in the Strategy. In the long term this is envisaged as a possible solution to identification of plants in the scenario in which human capacity and expertise in plant taxonomy are declining, but in the short term, DNA barcoding cannot provide identification for taxa where the reference taxa are not yet confidently demarcated, identified and classified. Until gaps in taxonomic information are filled, taxonomic researchers and experts in plant identifications will not become redundant.

f) Taxonomic inventories of selected United Kingdom Overseas Territories: not applicable to South Africa; however inventories of South African species are established; continuing research is underway to provide updates and target taxonomically problematic taxa and groups; and updating and maintenance of the South African plant checklist is a priority.

g) Major micropalaeontological resources to reconstruct climate change: not currently specified as a priority in the short term in South Africa.

These comparisons between a country with an advanced economy but impoverished biodiversity and a biodiversity-rich country with a developing economy indicate that South African plant taxonomy is relatively well balanced.

7.8 Forecast for the future of plant taxonomy in South Africa

The current priorities for taxonomic research in South Africa focus on gaps and needs of end users, to attain the scenario of being able to competently manage the country's rich biodiversity. In future when this ideal is achieved, and provision of foundational biodiversity knowledge is no longer a limitation to management of biodiversity, it will be feasible to shift focus from alpha-taxonomy to creating resources and utilise taxonomic knowledge in novel ways. This could include creation of micropaleontological resources to reconstruct climate change, contributions towards assembling the phylogenies for the Tree of Life, and increase focus on assembling data for DNA barcoding and development of associated rapid and automated identification techniques (see Godfray et al. 2011).

Hebert et al. (2003) proposed that a database of DNA barcodes linked to named specimens would provide an identification tool as an alternative to human taxonomic expertise as taxonomists as professionals are on the decline. DNA barcoding is thus a recent development in the field of molecular studies, but is yet a long way from replacing taxonomists in biodiversity-rich countries where taxonomic problems remain and much of the flora is still to be discovered. When a sufficiently comprehensive library of DNA barcodes has been accumulated on the flora of South Africa, DNA barcoding will be able to play an important role in identification of specimens. However if an unknown specimen is not able to be closely matched to an existing reference specimen, a barcode sequence cannot qualify the taxon as a new species, but can flag it for further taxonomic analysis, in this way aiding species discovery (Hajibabaei et al. 2007). DNA barcoding therefore holds great potential in prioritisation processes for future taxonomic research strategies, once sufficient data has been accumulated on the existing flora.

There is sentiment that DNA barcoding, along with associated automated identification tools that could feasibly be developed, will make taxonomists redundant as scientists (Figueiredo & Smith 2015). According to these authors, the role of taxonomists could consequently be increasingly technological rather than scientific, with emphasis on technological identification tools and maintenance of information in electronic portals, such as the e-Flora of South Africa. In the long term future it would fulfil the current vision and purpose of the Strategy if taxonomic problems of the South African flora were all resolved, and the flora of the country was adequately managed with availability of a wealth of fully representative, high quality data. However it is the view of this author that whereas DNA barcoding and electronic information dissemination portals will lead to enhanced ability in species identifications, taxonomic expertise will remain vital for the naming, description, classification, and evolutionary and phylogenetic interpretation of biodiversity. Making sense of biodiversity has always been at the core of what taxonomists do, and whereas the advent of DNA barcoding might facilitate the identification aspect of taxonomy, human interpretation based on expertise will be in demand for centuries to come.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

- The development, implementation and monitoring of a Strategy has greatly benefited biodiversity research and conservation in general.
- The Strategy coordinates taxonomic research on the South African flora and promotes taxonomy nationally.
- Initial implementation of the Strategy (2011) has been successful and effective, as taxonomic research targeted towards priority endeavours will, inter alia, lead to the establishment of an e-Flora and a projected halving of prioritised taxonomically problematic plant genera by 2020.
- Taxonomic research is therefore benefiting from having a coordinated Strategy to address the needs of end users.
- The South African National Biodiversity Institute (SANBI) is better fulfilling its mandate by providing a coordinated framework for taxonomic research on plants and other organisms.
- Taxonomic research priorities in South Africa have been driven by personal fascination in plant diversity, by organisation and formalisation of taxonomy as a science, by external influences, such as searches for economically important plants and lastly, by the advent of electronic communication and information dissemination and resultant increasing connectivity.
- South Africa lacks sufficient human capacity for plant taxonomic research, which can be an obstacle to effectively manage the wealth of plant diversity in the country.
- There is an urgent need for more taxonomy posts in South Africa, particularly at universities that do not currently have lecturers in plant taxonomy.
- There is a critical need to train more taxonomists at universities, especially among previously disadvantaged groups.
- An objective method for prioritising taxonomic research in plants and other organisms has been developed and informed the development of a *Strategy for plant taxonomic research in South Africa* (Strategy).

- As the future remains unpredictable in some respects, the Strategy was based on current trends in taxonomic research, but with a view of future, increased scientific connectivity globally.
- The Strategy aims to meet the needs of end users, making efficient use of limited resources (especially financial and human capacity) in South Africa.
- The e-Flora of South Africa project established as part of this study will make taxonomic information for all plants in the country accessible to end users in a single portal by 2020.
- The Strategy has been developed using gaps in information, areas under-represented in collections, and taxa lacking sufficient taxonomic endeavour, to inform the research priorities.
- A comparison between the United Kingdom, a country with an advanced economy but impoverished biodiversity, and South Africa, a biodiversity-rich country with a developing economy, indicates that South African plant taxonomy is relatively well balanced in a global context, although priorities are slightly different.
- It is anticipated that the experiences, methodologies, approaches, and outcomes of this study will provide guidance to decision makers who manage and lead taxonomic networks and institutions, and the funders of taxonomic research, in other parts of the world beyond South Africa.
- This study provides a potential solution for taxonomists in South Africa to facilitate the work of biodiversity scientists who focus on competently managing the country's rich biodiversity.
- It is anticipated that this thesis will be of benefit internationally, especially in other megadiverse regions, as well as locally.

8.2 Recommendations

- SANBI has certain obligations under the Global Taxonomic Initiative, including capacity building, and should therefore actively demonstrate an effort to fulfil the capacity component of its responsibility to these international conventions.
- The current structure of SANBI should be revisited by management with consideration given to transferring the key personnel involved in the management and dissemination of taxonomic data to the Biosystematics Division.

- Within the three research centres in the Biosystematics Division, sharing of expertise between different centres is vital to ensure that the eastern region is given due attention, as well as to ensure completion of the KwaZulu-Natal Flora.
- To optimise the spread of taxonomic expertise around the country, increased capacity, in the form of creating another scientist post, is required in KwaZulu-Natal; and it is urgent that the vacant post at Compton Herbarium in Cape Town is filled with a suitable scientist.
- SANBI needs to more actively promote collaboration with universities that have no taxonomists to offer skills for co-supervising postgraduate students, and facilitate (or offer) bursaries for this purpose.
- Experienced taxonomists should mentor interested and talented support staff employed in technical positions in herbaria, provided such candidates have an interest in, and aptitude for, taxonomic research.
- It would be beneficial for SANBI to produce more text-book type resources so that universities that do not employ taxonomists can still offer the course in a suitably stimulating manner so as to captivate potentially interested taxonomists.
- Taxonomists should focus research on taxa or groups of taxa prioritised in the *Strategy for plant taxonomic research in South Africa 2015–2020*.
- Although alpha-taxonomic work should be prioritised, it is best enhanced with information from a variety of other sources of taxonomic evidence to produce the best quality research products and most predictive classifications.
- The e-Flora of South Africa should be completed and launched in 2020.
- Further exploration of South Africa's biodiversity is needed to improve representation of the flora in areas of the country that are under-collected, and for specimens of taxa that are under-collected, to enhance the quality of foundational biodiversity information provided to end users.
- Dedicated plant collecting trips must be targeted towards under-collected taxa and under-collected areas.
- To further expand specimen collections in under-collected areas or of under-collected taxa, SANBI should offer, as an incentive to plant collectors targeting prioritised taxa or areas, to waive handling fees for identification in return for donation of good quality specimens.

- There should be a single, central permitting office in South Africa, to which applicants could apply for a single collecting permit that is applicable for collecting or transport of plant material in the whole country; and SANBI should further facilitate the permit-issuing process by assessing and registering projects on behalf of the permit-issuing office.
- The *Strategy for plant taxonomic research in South Africa 2015–2020* should be kept in place in SANBI and revised at a minimum of five year intervals, so that it can be continuously applicable and current.

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SUMMARY

South Africa is one of the most biologically diverse countries in the world, and harbours one of the richest floras. According to its mandate, the South African National Biodiversity Institute (SANBI) must coordinate and promote the taxonomy of South Africa's biodiversity. Unresolved taxonomic problems, problematic classifications, and lack of a clear strategy for developing plant taxonomy hinder management of biodiversity, and hamper opportunities for the management and sustainable use of species for economic purposes. To this end, the main intention of the thesis was to provide an objective method for prioritising taxonomic research that informs the development of a strategy. The strategy will meet the needs of end users, and make efficient use of scarce and dwindling resources, including financial and human capacity, in South Africa.

There is a severe shortage of human capacity and resources available to manage and study the country's diverse flora in terms of taxonomy and provision of foundational biodiversity information. There are vast areas of the country that remain under-collected, with many taxa under-represented in herbarium collections, which indicates that taxonomists are partially limited by lack of plant material for research as well as from which to compile specimen data records for end users. There are currently almost 160 plant genera in urgent need of revision, and more than 270 taxonomically problematic taxa. To maximise the effectiveness of existing human capacity, prioritised activities need to be identified and research efforts redirected towards these.

An objective method of prioritising taxa in urgent need of taxonomic research was developed and can potentially be used for all organisms and be equally applicable to other parts of the world. This methodology informed the development of a *Strategy for plant taxonomic research in South Africa 2015–2020* (Strategy). Three research programmes are proposed to focus on the main gaps in taxonomic knowledge, namely, (1) the e-Flora programme, (2) the revisions of plant genera programme, and (3) the Data Deficient plant programme. In addition a plant collecting programme is suggested to improve foundational biodiversity data. The importance of data quality is emphasised and recommendations are made for addressing this aspect.

Since implementation of the Strategy at SANBI in 2011, evaluation of progress on the priority areas shows that progress has been more rapid than expected. It is anticipated that by 2020, South Africa will have a centralised electronic resource, the e-Flora of South Africa,

comprising a checklist and associated nomenclatural information, links to other useful information, and a specimen information database; in addition the number of genera that are urgently in need of revision will have halved, and the number of taxonomically problematic taxa reduced by 20%. Strategic planning of taxonomy is benefiting conservation by facilitating conservation assessments, as well as the economy by way of streamlining the interface between taxonomy and end users.

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CURRICULUM VITAE

Janine Elizabeth Victor

Janine Victor was born in Grahamstown on 10 July 1969, and educated at Kingswood College, matriculating in 1987. She went to Rhodes University and qualified for her BSc in 1990, majoring in botany and microbiology. In 1991 she received her Honours in plant taxonomy and plant physiology. She then enrolled for a Higher Diploma in Journalism at Rhodes, qualifying in 1992. In 1993 she was employed by the National Botanical Institute (now South African National Biodiversity Institute) and commenced with research on the fynbos genera of the Rutaceae. She obtained her MSc (cum laude) from the University of Pretoria in 1997, with a dissertation on the palynology of *Acmadenia*. She then became involved in conservation research, and was the national coordinator for the Red List of South African plants until 2007. Following her return to systematics, she continued with research, focussing her interest on taxonomically problematic plants of conservation importance. In 2011 she was appointed as a Deputy Director of Research, where she became involved in developing strategies for taxonomic research. She is the author/co-author of 30 peer-reviewed papers, and 25 other scientific articles, chapters in books or books.

APPENDICES

APPENDIX 1: List of experts consulted

Staff members of the South African National Biodiversity Institute (SANBI) consulted

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T. Jaca

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E. Campbell, Nelson Mandela Metropolitan University, Port Elizabeth

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A. da Castro, plant taxonomist and consultant, Johannesburg

A.P. Dold, Schonland Herbarium, Rhodes University, Grahamstown.

L. Dreyer, Stellenbosch University, Stellenbosch

G. Goodman, University of the Witwatersrand, Johannesburg

D.B. Hoare, ecologist and consultant, Pretoria

K. Immelman, Walter Sisulu University, Umtata

L. Joubert, University of the Free State, Bloemfontein

J. Kirschner, Academy of Sciences of the Czech Republic, Průhonice

H.P Linder, University of Zurich, Zurich

R.A. Lubke, Rhodes University, Grahamstown

R. Mackenzie, Nisc, Grahamstown

R. Mesibov, Queen Victoria Museum & Art Gallery, Launceston

A. Moteetee, University of Johannesburg, Johannesburg

M. Muasya, University of Cape Town, Cape Town

A. Nicholas, University of KwaZulu-Natal, Durban

A. Paton, Royal Botanic Gardens, Kew

M. Potgieter, University of Limpopo, Pholokwane

S. Ramdhani, University of KwaZulu-Natal, Durban

S. Siebert, University of the North-West, Potchefstroom

P.M. Tilney, University of Johannesburg, Johannesburg

T. Trinder-Smith, University of Cape Town, Cape Town

N. Turland, Berlin Botanische Garten und Botanisches Museum, Berlin

C. Walker, The Open University, Milton Keynes

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A.E. van Wyk, University of Pretoria, Pretoria

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APPENDIX 2: Data Deficient flags for use in the Red List of South African plants

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DATA DEFICIENT FLAGS FOR USE IN THE RED LIST OF SOUTH AFRICAN PLANTS

The first Red Data List for southern African plants was published in 1980 (Hall *et al*. 1980), and was followed 16 years later by an update (Hilton-Taylor 1996). These publications classified plants as Rare, Vulnerable, Endangered, Indeterminate or Insufficiently Known. Since then the Species Survival Commission (SSC) of IUCN—World Conservation Union has introduced a new system with improved methods of assessing extinction rates of taxa. This system makes use of prescribed quantitative criteria to place taxa into different categories according to their extinction risks (IUCN 1994, 2001). Many taxa that were previously classified as Rare are now in the category Least Concern (LC) since they are not facing increased extinction risk. However, they may still require conservation attention. For this reason, Victor & Keith (2004) introduced the Orange List concept and proposed a quantitative system of assessing, recording and documenting taxa that should be considered for legal protection and conservation. The Orange List includes taxa that are rare but not declining, as well as taxa that are declining but not fast enough to trigger a threatened listing according to the IUCN Red List Criteria. Two other categories that are considered under the Orange List are Data Deficient (DD) and Near Threatened (NT).

According to IUCN (2001), a taxon qualifies for the category Data Deficient when 'there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status'. Although this usually applies to taxa that are poorly known, this category might also contain well-known taxa that lack sufficient data required for using the IUCN Red List Criteria. Whereas DD is not considered to be one of the categories of threat, listing of taxa in this category acknowledges the possibility that future research may show that threatened classification is appropriate.

During the seven years of compilation of South Africa's Red List of threatened plants according to the revised Red List assessment process, it has become apparent that there is a need to distinguish between different scenarios for listings within the DD category. A set of flags is proposed to distinguish between the different reasons for listing, with the aim of facilitating conservation planning and highlighting research needs for the taxa.

Three main reasons for listing taxa in the DD category are apparent. In the first scenario, taxa have been listed as Data Deficient but are suspected to have taxonomic problems (such as being indistinguishable from closely related taxa) that make it difficult for them to be accurately assessed. Only once these taxonomic problems are sorted out, can a proper assessment be made of the taxon. It is proposed that the taxa that are unable to be assessed due to unclear taxonomic delimitation, or suspected to be synonymous with other taxa, are listed as DD with a flag of 'Taxonomically uncertain' (abbreviated as DDT). Because these taxa are often thought to be synonymous with more widespread taxa, they are usually unlikely to warrant conservation attention. An example is *Erica obconica*, which is probably conspecific with the widespread *Erica mucronata*. However, this has not yet been formalized so the species is classified as DDT for now.

The second flag deals with taxa that could very well qualify for a category of threat but have insufficient information required for the assessment process (such as distribution or rate of decline). It is proposed that such taxa are classified as DD with the flag 'Distribution and/or other information lacking' (abbreviated as DDD). Taxa classified as DDD are likely to be of high conservation importance and high research priority. An example is *Phylica apiculata*, a shrub found on mountain slopes of the Caledon District. Since much of the natural land in the Caledon area is transformed, it is likely that this species is threatened with extinction. It is therefore classified as DDD until more information becomes available.

A third flag is proposed for taxa that are so poorly known that it is impossible to determine whether or not they could be classified as threatened. Whereas most DD taxa are suspected to be threatened, some taxa have so little information that it is not known whether they are undercollected, rare, taxonomically problematic or poorly known; but there is no cause to suspect that they are threatened with extinction. These taxa are represented by very few collection records in herbaria and have insufficient information about them in the literature. These taxa are flagged to indicate that they are of high research priority, but low conservation priority until such time more information becomes available. These taxa are flagged DDX. An example is *Anderbergia fallax*, which is known from a single collection made from Goedgeloof Peak in the Langeberg near Swellendam. It is likely to be undercollected as it is a fairly inconspicuous plant; furthermore it is unlikely to be threatened on the high mountain peaks where it grows.

The advantage of flagging subsections of the Data Deficient category is that conservationists will no longer have to divest efforts into the taxa in the DDT and DDX categories. The DDT flag will serve to highlight those taxa that need taxonomic attention; whereas DDD and DDX flags would serve to highlight those taxa in need of more field work and research attention.

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APPENDIX 3: The conservation imperative and setting plant taxonomic research priorities in South Africa

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ORIGINAL PAPER

The conservation imperative and setting plant taxonomic research priorities in South Africa

Janine E. Victor · Gideon F. Smith

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Abstract For more than a decade it has been internationally recognised that efforts should be made to remedy the concern that taxonomy is an endangered discipline in the grips of rapid decline. In acknowledgement of the perceived continuing marginalisation of taxonomy, the Darwin Declaration recognised the need to enhance the taxonomic capacity of members who are party to the CBD, and beyond. South Africa is one of the most biodiversity rich countries globally, and the unique and rich flora of the country brings with it a significant conservation imperative. Although the country, and southern African subregion for that matter, has a strong history of taxonomic endeavour, stretching back for over a century, it also suffers from a lack of human and other resources to adequately address its taxonomic needs. This inevitably calls for a process of priority-setting to ensure the wise use of available funding. As one example, it is shown that 1,009 indigenous South African plant taxa are regarded as Data Deficient for taxonomic reasons, following the completion of a recent comprehensive Red Listing exercise. Although not the only criterion to be considered when prioritising taxonomic research, efforts focused on these groups represent a significant opportunity for taxonomists to align their work with national priorities.

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Keywords Conservation · Priorities · Red List · Data deficient · Systematics · Taxonomy

Abbreviations

CBD	Convention on Biological Diversity
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice
GTI	Global Taxonomy Initiative
SANBI	South African National Biodiversity Institute
PRE	National Herbarium, Pretoria
PRECIS	National Herbarium, Pretoria (PRE) Computerised Information System
DD	Data Deficient
EIA	Environmental impact assessment
IUCN	International Union for Conservation of Nature

The importance of taxonomy, the science of detecting, describing, naming and classifying biological organisms, as a fundamental discipline requisite for all other fields of biological science is undisputed (Lowry and Smith 2003; Wilson 2003, 2004; Smith et al. 2008). However, despite the wide recognition and support expressed for taxonomy, a 'taxonomic impediment' referring to diminishing capacity to perform basic taxonomic research, has been recognised since the second meeting of the SBSTTA of the CBD held in 1997. Significantly, the Darwin Declaration (Environment Australia 1998) called for investment by governments in biological collections in terms of development of capacity and infrastructure. The importance of taxonomy in conservation and management of the world's biodiversity therefore has the support of the Conference of Parties to the CBD, which resulted in the establishment of the GTI at the fourth meeting in 1998. Despite this admirable development, there are growing concerns that the discipline is struggling (Lowry and Smith 2003), weakened by the increasing difficulty in procuring funding for research and for maintaining collections (Wilson 2004). This is in part due to the nature of taxonomy as an established and fundamentally descriptive science. Adding to this, products of taxonomic work, such as scientific publications, are widely used without being cited, resulting in taxonomic publications being measured as of low impact (Agnarsson and Kuntner 2007). More prestigious and fashionable fields of study are preferentially given funding, in spite of many essays and papers justifying why there is a critical need to prioritise constant updating of taxonomic knowledge (see for example Khuroo et al. 2007, Cresswell and Bridgewater 2000).

At several institutions with a proud history of taxonomic research there has been a steady decline in the number of employees over the past few years, as aged taxonomists retire or younger employees depart for improved prospects and their posts are not filled. This trend has been reported in the literature for many countries that are signatories to the CBD (Cogalniceanu et al. 2007), yet it is in conflict with the operational objective of the programme of work of the GTI, i.e. developing or strengthening human capacity to generate information (operational objectives 2 and 3, see CBD website at http://www.biodiv.org/convention/result.aspxid=7182).

With the recent completion of a Red Listing initiative that covered the entire South African flora, it was shown that for over 1,000 plant taxa insufficient data are available to accurately assess their conservation status. We confirm the importance of taxonomy, and argue that increased relevance for the discipline can be derived from a focus that, among other things, comprehensively embraces taxa that require taxonomic resolution to improve knowledge of their conservation.

Callmander et al. (2005) appeal for plant taxonomists to mobilise to identify threatened species using available distribution data and include preliminary Red List assessments in taxonomic works. As a result of extensive field experience, taxonomists almost invariably have the knowledge to do this. Justifiably therefore staff of the Threatened Species Programme of SANBI placed heavy reliance on taxonomic expertise in conducting Red List assessments (Raimondo et al. 2009; Victor 2002). Without primary data, no comparison between the current and historical status of species is possible, and the task of assessing threat status, and subsequently, informing conservation management, would be insurmountable. This is the case in Brazil (Brito 2004), and in India and Sri Lanka, where taxonomic research has also declined (Pethiyagoda et al. 2007).

The Red List status of many taxa indigenous to South Africa has not been adequately assessed because of uncertainties in their taxonomic status. These were classified as DD, since, according to IUCN (2001), a taxon qualifies for this category when "there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status". However, there was a need to distinguish taxa that were DD for taxonomic reasons from those that were DD for other reasons. The use of the letter "T" was therefore adopted to flag those species, while those entities that were DD due to insufficient information regarding threats or population statistics were flagged with the letter "D" (Victor 2006).

There are currently 1,009 plants, or about 9% of the South African flora, that are recorded as DDT on the Red List (Raimondo et al. 2009). Furthermore, taxonomic problems have been identified in some threatened and DDD plant species. This is partly a result of the nature of the process for assessing the threat status. Taxonomically problematic species are often known from only one or very few localities, and such apparently rare species are selected via the assessment process as being of conservation concern. It can be difficult to distinguish between truly rare and threatened species from those that simply appear to be very rare or threatened due to lack of taxonomic and other information. When taxonomically problematic species are listed as threatened or DD, conservation authorities have inadequate information to ensure the conservation and future survival of the species, and may neglect them in favour of better known species to justify the financial outlays. Conversely, conservation organisations have too little financial resources to spend on species that are taxonomically problematic when resources could be allocated to higher priority species. In addition to this, taxonomically problematic species that are threatened or DD still need to be taken cognizance of during EIA processes, often having significant fiscal implications for both conservation departments and developers, and hampering or delaying EIAs. If the taxonomic status is in doubt, this can lead to unnecessary wastage of financial resources. One of many such examples in South Africa is a rather obscure milkweed that had sunken into obscurity for 109 years. It was rediscovered in an area targeted for housing development. The plant in question, now known as *Stenostelma umbulleliferum*, resulted in a moratorium being put on development whilst taxonomists and conservationists collaborated to clarify both the taxonomic status and conservation status of the species (Bester and Victor 2005).

Taxonomic research targeted towards taxa with taxonomic problems, would have significant impacts on conservation of South Africa's biodiversity, particularly in regions of high economic development. The results of such studies are of great significance to the conservation community, in that their financial resources can be more effectively allocated to species of conservation priority. The outcomes of taxonomic research targeted to DD

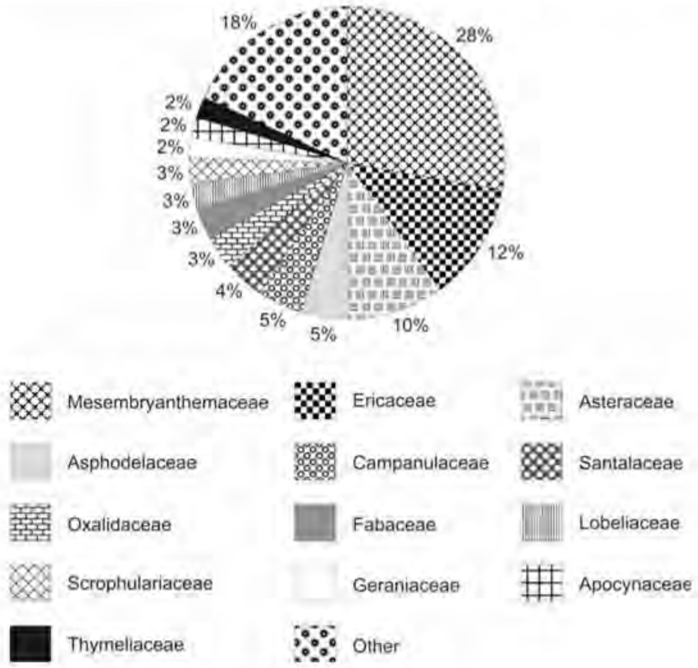

Fig. 1 Proportion of total of number of DDT species per family

and threatened species furthermore have significance and importance to developers and the South African economy, in improving the Red List and clarifying issues that could otherwise hinder both conservation and development, thus informing the science–policy interface.

One way to prioritise which plant families should receive focused taxonomic attention is therefore to analyse the proportion of species listed as DDT in each indigenous South African family. For the purposes of these analyses we have expressed the results as a percentage of the total number of DDT species. This provides information on which families have the most DDT species and are therefore most in need of taxonomic attention.

An analysis of DDT species on the current Red List (Fig. 1) shows that of the 254 plant families indigenous to South Africa, 13 have more than 20 members classified as DDT. Thus, these families are regarded as being priorities for focussed taxonomic attention. The family that contains the highest number of DDT species, and therefore is most in need of taxonomic attention, is the Mesembryanthemaceae, a family of succulent plants. A further 46 families contain fewer than 20 members classified as DDT, and 221 families out of 254 have no species classified as DDT.

One way to ensure that accurate and complete taxonomic information is available for end users in the face of diminishing resources is to concentrate efforts on two main foci of research: targeting specific taxonomic problems that have implications for other fields e.g. conservation; and compilation of accurate inventories for undercollected areas. Specifically there is an urgent need to focus taxonomic research on the families highlighted in the current paper. Taxonomists are required to keep abreast with existing thrusts (such as red listing) and new technologies and skills that can enhance understanding of species and their interrelationships.

The taxonomic community has to maximise on this international recognition of the crucial importance of taxonomy if, among other things, conservation and related research is to succeed. In this regard taxonomists need to document and synthesize all knowledge and make it easily available to end users. Integrating taxonomic products with other fields of research will improve taxonomy-based products as well as improve potential funding opportunities (Agnarsson and Kuntner 2007). Ultimately, a sound taxonomic framework encompassing an understanding of phylogenetic relationships will "facilitate scientifically informed policies in conservation efforts and bioresource management" (Wheeler 1995). If South Africa is serious about preserving biodiversity and maximising on benefits that can be derived from it, the country cannot afford to neglect its taxonomists.

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APPENDIX 4: A method for establishing taxonomic research priorities in a megadiverse country

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A method for establishing taxonomic research priorities in a megadiverse country

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Abstract

A coordinated strategy for biosystematics research that addresses the needs of end-users can improve the relevance and impact of research products. The basic types of information that taxonomists provide, common to all organisms, are the names, descriptions, and a mechanism for identifying components of biodiversity, and associated data such as distribution information. This information is provided through taxonomic research.

A biosystematics research strategy has been developed in South Africa to focus on the main gaps in taxonomic knowledge. A prioritisation process has been developed and applied to plants, but can potentially be used for all organisms. The methodology for development of the taxonomic priorities to formulate a research strategy is described. Determining priorities for taxonomic research and development of the strategy will facilitate bridging the gaps among compilers, users and implementers of taxonomic information, and streamline the taxonomy-conservation impediment.

Introduction

Biosystematics research underpins biodiversity and all other organismal-related studies. Such studies involve the discovery, naming, description and classification of biological organisms. In this paper, the term taxonomy is used in the broad sense to include the organisation and classification of information about organisms. The recognition and interpretation of genetic variation in organisms is at the heart of taxonomy (Van Wyk 1996). Taxonomists collect and organise foundational biodiversity data, which is built upon by other fields of science. If the foundational information is lacking, flawed or unstable, it not only impedes all other fields of biological research, but also hampers and frustrates the work of the many other end-users of taxonomic information.

The critical importance of taxonomy in the field of conservation, all other areas of biological science, as well as society at large, is well established and has been recognised in the Global Strategy for Plant Conservation (GSPC) (Lowry & Smith 2003, Smith *et al.* 2008, Victor & Smith 2011, Ebach *et al.* 2011). At the Conference of the Parties to the Convention on Biological Diversity (COP 11), held in Hyderabad, India, in 2012, a capacity building strategy for the Global Taxonomic Initiative (GTI) was adopted with the aim of identifying gaps and prioritising capacity-building needs, and to generate and maintain taxonomic information to meet the identified taxonomic needs. The first strategic action proposed in this regard is to "review taxonomic needs … and set priorities to implement the Convention and the Strategic Plan for Biodiversity 2011–2020" (COP 2012). Development of a national biosystematics research strategy will contribute to a government's obligations to fulfil the aims of the capacity building strategy for the GTI.

A Biosystematics Research Strategy was developed by the South African National Biodiversity Institute (SANBI) covering all living organisms of the country (Victor *et al*. 2013). This Strategy provides guidelines for research priorities; communicates the value of taxonomic research to the public, academic institutions and funding agencies; makes the most strategic use of limited time and resources; guides future decisions on capacity development, staff recruitment and training; stimulates dissemination of priority taxonomic information to end-users; and provides a shared vision to guide research.

During the development of the research strategy for South Africa, the authors consulted taxonomists from local universities, as well as abroad, to share, and where appropriate, incorporate views beneficial to strategy development

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and implementation. Key to the development of a research strategy, especially in a megadiverse country such as South Africa, is the implementation of a method to rank taxa in a way that reflects taxonomic priority. In this contribution we present and elucidate the method for prioritising biosystematics research that was developed and adopted for South Africa. This method can be applied to most groups of biological organisms in any country.

Methods

To prioritise taxonomic research, the critical first step is to identify gaps in taxonomic knowledge by comparing available information with urgent knowledge needs. This then informs where priority research activities should be aimed. The three main products required by users of biological names are an inventory of the taxa of a geographical region or political area; a means to identify the taxa, i.e. descriptions of species and identification keys; and an inventory of herbarium specimen records in the area, from which information such as distribution ranges or areas of occurrence can be collated. These three requirements drive the prioritisation process for the research that is required to provide, improve, complete and disseminate these products.

Strategic objectives for taxonomic research should be developed in such a way as to improve the main outputs of taxonomic research. Within any group of biological organisms, one of the ideal end products of taxonomic research would include an electronic database of names linked to descriptions of the organisms that is accessible online. For example, the first strategic objective of the plant component of the Biosystematics Research Strategy for South Africa (Victor *et al*. 2013) is to produce an online electronic Flora (e-Flora) of plants for the country by 2020, which will contribute to the first target of the Global Strategy for Plant Conservation (GSPC). The approach that will be followed by SANBI for development of the e-Flora has recently been published (Victor *et al*. 2014), and involves collaborating with contributors countrywide to achieve the target.

To meet this strategic objective, it is necessary to fill the gaps of information available for establishing such a resource. This would be accomplished through research on groups that are in need of taxonomic revision. For plants as well as other organisms, taxonomic research of greatest practical relevance to society can be aimed at three different levels in the hierarchy: family, genus and species (including infraspecific taxa). Research aimed at addressing questions above the family level tends to be more academic.

Approach at family level

Prioritisation of the research that is required to target plant families most in need of attention was done by using two resources: the Red List of South African Plants (http://redlist.sanbi.org/) and taxonomic literature.

The IUCN Red List can be a useful resource to elucidate taxa that are in need of revision. The process of assessing the Red List status of a species can be hindered because of uncertainties in its taxonomic status. This frequently leads to an assessment of Data Deficient (DD) on the Red List (IUCN 2001). The need to distinguish taxa that were DD for taxonomic reasons from those that are DD for other reasons resulted in the use of the letter ‘‘T’’ being adopted to flag such species in the South African Red List of Plants (Victor 2006). It is recommended that this flag be adopted for conservation assessments of all organisms in all countries so that the taxonomic priorities can be flagged for the attention of taxonomists. By doing so, families with large proportions of taxa classified as DDT can be prioritised for research. However if the taxa classified as DD are not flagged, using a proportion of DD species as an indicator is an acceptable alternative, as they are lacking in information often as a result of inadequate or incomplete information (particularly distribution information) provided in taxonomic literature.

When prioritising taxonomic groups for research, it is important to have access to a dataset of all the literature associated with the group in order to identify gaps. Treatments of large groups (e.g. families containing more than 100 species) that are understudied (e.g. with more than 50% of taxa last revised prior to 1960), particularly those with taxa that present challenges to identify, are of particular importance and should be prioritised. In South Africa, an example of such a plant family would be Cyperaceae.

Approach at genus level

Taxonomic research on genera that are in need of revision will contribute to filling gaps in knowledge, enhance the information content and predictive value of species names, and improve information available for checklists, information databases and associated taxonomic products. To provide an objective list of genera requiring revision, indicators are used as criteria for prioritisation. Seven criteria are suggested here, but the methodology can be adapted to use more or fewer criteria depending on the particular group of organisms and according to available information. Ideally, at least three criteria should be used, one of which should be the date of the last revision.

Genera are listed in the first column of a Microsoft Excel spreadsheet, and the percentage values of each criterion (C) for each genus are listed in separate columns, as shown in the example provided in Table 1.

TABLE 1. Example showing selected results of prioritization analysis for South African plant genera (column A) based on four criteria (columns B–E). The higher the score (column F), the more pressing the need for taxonomic study of a group in the presented method. "DDT" refers to taxa that are Data Deficient (DD) for taxonomic (T) reasons. A to F refer to columns as in a Microsoft Excel spreadsheet.

A	B	C	D	E	F
Genus	**Date (% of range)**	**Proportion of taxa DDT (%)**	**% unidentified taxa**	**% of genus endemic**	**Score**
Acanthopsis Harvey (1842: 28)	69	13	4	75	40
Acrosanthes Ecklon & Zeyher (1837: 328)	32	0	0	100	33
Delosperma Brown (1925: 412)	100	13	74	69	64
Lessertia De Candolle (1802: 37)	55	19	13	61	37
Nananthus Brown (1925: 433)	100	17	14	50	45
Riocreuxia Decaisne (1844: 640)	0	0	4	42	12
Senecio Linnaeus (1753: 866)	47	12	8	12	20
Steirodiscus Lessing (1832: 251)	0	0	0	100	25
Stomatium Schwantes (1926: 175)	94	5	14	100	53
Trichodiadema Schwantes (1926: 187)	94	25	17	94	58

Criterion 1: Taxonomic information out-of-date/up-to-date

The date of publication of the last revision of a genus is a useful indicator of whether the information is outdated or not, and therefore, whether the genus should be revised. This can be used alone if no other information is available.

The dates should be converted to a percentage as follows, where C_1 = Criterion 1, Y = Year of last revision, and the oldest date subtracted from the most recent date (established in advance; see below) or alternatively, the current date, is the range (Y_{range}):

$$C_1 = Y/Y_{range} \times 100$$

However, if the genus has never been revised (i.e. Y = 0), then C_1=100 (because such a genus has the highest priority).

In the example provided in the results (Table 1), the range of dates used was from the first revision of the genus until 1970, and all dates higher than 1970 are regarded as equivalent. The justification for a cut-off date of 1970 being used in the analysis for South African plants is that university-trained botanists were rare in South Africa in the early days of colonisation (Rourke 1999, Figueiredo & Smith 2010) up until the 1960s, and revisions of South African plant groups were dominated by studies conducted by scientists outside of South Africa. In addition, use of advanced technology and multiple sources of data for revisions were in its infancy. The 1970s coincide with the advent of electronic databases, as well as increased incorporation of more modern techniques in systematics following international trends.

Criterion 2: Quality of most recent revision

Taxonomic treatments in existing (even relatively old) revisions may well be adequate in terms of species concept and nomenclature, in which case it might not be a priority to revise the group. Conversely, some groups having been relatively recently revised may be inadequate or already out of date. Quality of a revision is an important additional consideration, because even if a group has been revised very recently, if the rigor and scope of the work is not up to standard or acceptable to end-users of biological names, it would necessitate further work. For this reason it is advisable to further refine the list of priority genera by circulating it to specialists and considering and adopting expert advice. It is important to also canvas the opinions of end-users of biological names (e.g. horticulturists, ecologists, informed members of the public), even though most of these would not be professional taxonomists. A revision (whether old or new) may be inadequate due to many factors including: a lack of clear and unambiguous descriptions of species, adoption of a classification philosophy and species concept not enhancing the information content and predictive value of the resultant biological names (e.g. phylogenetic vs. evolutionary; lumping vs. splitting), lack of clarity of generic delimitations, keys that are difficult to use, and/or the presence of undescribed species. A questionnaire can be circulated to collections curators, researchers and end-users of names for each genus on the priority list to rate whether species descriptions are correct and species delimitations are clearly defined and a sound reflection of infrageneric variation, with 100% being all species, 50% half of the species, and 0% none of the species, or any amount in between converted to a percentage.

Criterion 3: Proportion of unidentified specimens in collections

A high proportion of unidentified herbarium/museum specimens within a genus can be an indicator of potential taxonomic problems resulting from inadequate revisions. The number of unidentified specimens in collections of organisms, for example herbaria, can be used to detect potential problematic genera that require prioritising for taxonomic research. The number of unidentified specimens should be calculated as a percentage of the total number of specimens for that genus.

Criterion 4: Proportion of DD or DDT species per genus

The most important factor in terms of bridging the taxonomy-conservation impediment is to identify and analyse the problems of deficiency of data for species. This information can be used as an alternative to the second criterion, quality of the revision.

The proportion of species listed as DD or preferably, DDT, in each genus provides a useful indication of potential need for taxonomic revision of a genus, and can therefore be used to determine priority groups for taxonomic research as discussed in Victor & Smith (2011). The percentage of taxa listed DD or DDT in each genus should be calculated as a percentage of the total number of taxa in the genus for the country.

Criterion 5: Economic importance

There are various alternative ways of determining the economic importance of a group. Ideally, the number of economically important species in each genus should be calculated as a percentage of the total number of species of the group, but this is time-consuming and potentially inaccurate in that it masks the potentially valuable wild relatives.

An alternative method is to prioritise all economically important genera or families. For South African plants, the top seven economically important families were determined by conducting a survey of the literature as well as seeking expert advice. Economically important plant families are considered to be those that have a higher proportion of indigenous taxa of importance in South Africa with respect to their status such as crop plants, food plants including fodder for livestock, medicinal value, horticultural value, timber or alien invasives. For example, in South Africa, two of the economically important families are Poaceae (frequently acknowledged as the most economically important plant family in the world) and Fabaceae (considered to be the most economically important dicotyledonous plant family in the world according to Harborne 1994).

If such data are available, the actual numbers of economically important taxa per genus can be calculated. However this may be subjective, and could negate the predictive value of other potentially economically important taxa in phylogenetic groups.

Criterion 6: Proportion of species occurring in the country

The proportion of species occurring in the country (either percentage of indigenous or percentage of endemic out of all species of the genus) can be an important factor to consider when prioritising groups for research. When the majority of the members of a genus do not occur in the country, the cost and complexity of doing a revision escalates when fieldwork is necessary to collect material for examination.

Criterion 7: Ecological importance

Management of biodiversity and rangelands can be hampered by a lack of knowledge of species composition, and how these species function in the ecosystem. The proportion of species in each genus that function as ecological keystone species, that are important for ecosystem function or integrity, is important from a conservation point of view, and it is therefore vital that the taxonomy of such taxa is clear.

The final score for each genus is calculated as follows: Where W = weight and C = criterion, Score = $C_1W+C_2W+C_3W+C_4W+C_5W+C_6W$…

And, where W_{count} is the number of criteria being used, W x W_{count} = 1 (Therefore, if for example four criteria are used, each will have a weight of one quarter, i.e. W = 0.25).

If the formula is put into a Microsoft Excel spreadsheet, with the top row (row 1) being the header row, the genus in the first column (column A) and each criterion in subsequent columns, the formula for calculation of the score in column F (in the case of four criteria of equal weight, as in Table 1) will be as follows: =SUM(B2:E2)/4

From these analyses, a list of genera to be prioritised for revision can be determined by choosing the top scoring candidates. Selection of different criteria due to data availability or deliberate prioritisation of certain criteria can affect the final priority list.

Approach at species and infraspecific levels

In genera that are not in need of revision, there are occasionally isolated members with taxonomic problems. These species are often of conservation concern or are economically important. Taxonomic problems impede the determination of conservation status of these species, and the species can therefore not receive appropriate conservation attention. It should be emphasised that, at least in the case of plants, the bulk of South Africa's biodiversity is at the infraspecific level, yet variants other than subspecies and varieties are rarely formally recognised (five infraspecific ranks are available for plants, McNeil *et al.* 2012: Art.4.2). As pointed out by Van Wyk (1996), the formal naming of such infraspecific units (morphological or otherwise), is perhaps the most urgent and daunting task facing the plant taxonomist in Africa. The provision of a name or other label attracts attention and would facilitate efforts to conserve a representative sample of genetic diversity, and hopefully prevent the loss of outstanding forms. Resolving taxonomically problematic species may sometimes be achieved without having to revise the entire genus. The opposite may also be true and clarifying the taxonomy of a species, or species complex, may of course necessitate revising the genus to which it belongs.

In South Africa, all plant taxa that are listed as DDT on the Red list but are not identified as priority candidates according to the above method are prioritised for taxonomic research.

Results

A prioritisation process conducted by Victor & Smith (2011) showed that in South Africa the Aizoaceae had the highest proportion of species listed as DDT, implying that it has the highest proportion of taxonomic problems and is therefore a research priority (Chesselet *et al*. 1995). Twenty plant families that have been prioritised in South Africa are therefore included in the Biosystematics Research Strategy.

Table 1 shows an example of ten South African plant genera that have been analysed using selected criteria according to the methods described here, and the full list of prioritised genera is available online (http://www.sanbi.org/sites/default/files/documents/documents/taxonomic-experts-sa-floramay2014_0.pdf).

In the example provided (Table 1), the genus *Delosperma* is one of the highest priority genera in South Africa, as it has never been comprehensively revised; a relatively high proportion of the genus has species that are taxonomically problematic; three quarters of specimens of the genus are unidentified in the SANBI herbarium collections; and the genus is largely endemic to South Africa. In contrast to *Delosperma*, the genus *Riocreuxia* is not considered to be a priority, as it achieved a low final score. The reason for this is that it was recently revised, and the lack of DDT species and very low proportion of unidentified species in the herbarium indicate that the most recent revision (Dyer 1983) was sound.

There are currently 980 species (5% of the South African flora) listed as DDT on the South African Plant Red List (http://redlist.sanbi.org/index.php) although this figure is updated annually, as new taxonomic revisions are incorporated into the Red List.

Discussion

The first attempt to prioritise plant groups in South Africa by Victor & Smith (2011) resulted in informed decisions being able to be made when employing new taxonomists at SANBI, for example the gap in Aizoaceae taxonomy was addressed by employing a taxonomist specifically to research this group in South Africa. This was followed by an attempt to prioritise a list of plant genera according to their conservation importance (Von Staden *et al*. 2013), of which many were in common with the priority list developed for the research strategy. We have successfully applied the methods outlined here in South Africa to compile lists of priority plant families, genera and species which are incorporated into the Biosystematics Research Strategy.

Priority lists are dynamic, changing as new information becomes available and new taxonomic works are published. Such lists are incorporated into the Biosystematics Research Strategy, which has been implemented in SANBI with all taxonomists employed by the Institute doing research on priority projects at different levels of the taxonomic hierarchy. SANBI is committed to ensuring that capacity exists for research to be undertaken in the plant families identified as priorities. For example, compilation of a conspectus of South African Cyperaceae is currently underway by a SANBI taxonomist with 35 years' experience, and a young scientist has been employed to be mentored and trained by this scientist so that capacity in this priority family is retained. All plant taxonomists within SANBI are currently undertaking revisions of priority genera such as *Acanthopsis* and *Delosperma*. Furthermore, since the priority lists are available online, they are consulted by researchers external to the Institute, such as those employed at universities.

Many of the DDT species are being targeted for research especially by SANBI's technical staff and interns. Examples of successfully completed projects on DDT species include the clarification of the taxonomic or conservation status of species such as *Agrostis eriantha* Hackel (1904: 172) (Victor *et al*. 2012) and *Sebaea fourcadei* Marais (1961: 463) (Baloyi *et al*. 2013). Projects to clarify the taxonomy of species are useful to students wishing to pursue undergraduate research projects in botany, whereas postgraduate students are able to select suitable projects from the list of genera requiring revision. Researchers working on priority genera are listed on the website so as to prevent duplication and foster collaboration. The Biosystematics Research Strategy is also available to funding agencies so that funding towards these priority research programmes can be stimulated, and it facilitates the choice of suitable projects eligible for preferential funding.

Conclusions

The three most useful resources for the development of the plant component of South Africa's Biosystematics Research Strategy were a database of herbarium specimen information, plant taxon information (names, synonyms and literature, including dates of publications) and the South African Plant Red List. Importantly, if these three resources are not available to a country, or for a particular group of organisms such as the algae, fungi, bacteria and archaea in the Biosystematics Research Strategy of South Africa, compilation of these resources should be prioritised. In South Africa, there are approximately 22,000 indigenous plant species and it has therefore not been possible to accurately compile information on ecologically or economically important species yet. As more information is gathered the priority list will be refined and improved in future.

The important point is that these methods provide a well-considered and defensible target list of taxa upon which to focus research attention, using criteria and a methodology that are objective. In addition, the criteria can be adjusted according to the level of the taxonomic hierarchy being studied, the group of organism being studied, and extent of information available in the country. The prioritisation of taxonomic research and development of strategies will facilitate bridging the gaps among compilers, users and implementers of taxonomic information, and streamline the taxonomy-conservation impediment.

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APPENDIX 5: Creating an Online World Flora by 2020: a perspective from South Africa

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COMMENTARY

Creating an Online World Flora by 2020: a perspective from South Africa

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Abstract At the 10th Conference of the Parties of the Convention on Biodiversity (CBD), which was held in Nagoya, Japan, in October 2010, an updated Global Strategy for Plant Conservation (GSPC) was adopted as part of the plan of work of the CBD. Target 1 of the GSPC aims to produce an online Flora for all the plants of the world by 2020. Governments that have ratified the CBD will have to report over the next several years on progress towards achieving this challenging target. Floras are still widely regarded as a means of providing descriptive information and identification tools for the plants that occur in a specified region. Historically, Floras have included identification keys; scientific names with authorship for all taxa known to occur in the area; synonymy; descriptions; distributions within the region in question; specimen citations; habitat; literature references; and illustrations. Of these, nomenclature, descriptions, identification tools, illustrations and distributions are critical components. The approach being taken by South Africa, a biodiversity-rich country, in working towards achieving Target 1 of the GSPC by 2020 is presented and discussed, outlining a methodology that may be of practical use to other countries. We hope this will urge other countries to consider how they might meet this challenging conservation target.

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Introduction

In 1999, the international botanical community attending the XVI International Botanical Congress in Saint Louis, MO, United States, resolved that plant conservation should be regarded as a priority in biodiversity conservation. This led to the development of the Global Strategy for Plant Conservation (GSPC) within the framework of the Convention on Biodiversity (CBD) in 2002 (COP 2002). The first target of the GSPC as then construed was for the plant taxonomists of the world to develop a working list of all known plant species by 2010. Through a collaborative effort between the Royal Botanic Gardens, Kew, the Missouri Botanical Garden and many contributors, a global plant checklist was placed online in December 2010 (The Plant List 2010). A second and updated version of this list is scheduled to be released soon, correcting errors detected in the first version, including further datasets, and reducing the number of unresolved names. Four years earlier than the target deadline, South Africa had published a comprehensive country-level checklist (Germishuizen et al. 2006), enhanced with primary biological information such as plant height, growth form, and altitudinal range occurrence. This volume was a successor to earlier regional floristic checklists that first appeared from the 1980s to the 1990s. These publications reflected the cumulative work of several generations of collectors, taxonomists, recorders and databasers and were built on extensive regional herbarium collections.

An update of the GSPC for the decade spanning 2011–2020 was adopted by the 10th Conference of the Parties of the CBD in Nagoya, Japan, in October 2010 (COP 2010). Sixteen outcome-orientated targets were specified to achieve five objectives by 2020. Target 1 of the updated GSPC is to build on the success of the 2010 Target 1 by creating "*an online flora of all known plants*" by 2020 (COP 2010). A resolution of the XVIII International Botanical Congress in Melbourne, Australia, in July 2011, called for "*botanical institutions worldwide to collaborate to achieve a comprehensive and authoritative 'online flora of all known plants' by 2020*" (IBC 2011). In this way, the international conservation and botanical communities have acknowledged that taxonomy

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provides essential baseline information that is a prerequisite to the success of all other targets. A widely accessible online Flora (with a capital 'F' denoting a hardcopy or electronic publication on the plants of a region) of all known plant species is critical in plant and ecosystem conservation efforts. South Africa, which is recognised as one of the megadiverse countries of the world, has a flora of about 20,000 indigenous and naturalised plant taxa (Steenkamp and Smith 2006). In this paper, we explore possible ways in which South Africa, and conceivably countries in the rest of the southern African subcontinent and elsewhere, can achieve Target 1 of the GSPC 2020, after having successfully responded to Target 1 of GSPC 2010.

End-users of Flora information

In the year before October 2013, the website of The Plant List (2010) was visited more than 2 million times by a large audience of 1.1 million users from all walks of life. Even though the list does not reflect a consensual, authoritative classification, it is used to provide immediate information on the status of plant names and as a tool to access further information on those names in 14 linked websites. This level of use is an indication of the potential success of a more comprehensive product such as an online Flora.

Given the scope of the 16 GSPC 2020 targets, the potential users of a World Flora Online (WFO) will have a broad range of interests and requirements for information (Paton 2009). The WFO therefore needs to provide the necessary taxonomic information, but also link to a broad range of other facts about plants. Names and synonymy, distribution data, identification aids and cross-referencing to sources such as the Encyclopaedia of Life (EOL) and the Global Biodiversity Information Facility (GBIF) are likely to be priorities for the implementation of biodiversity policies (Smith 2005). Policy implementation will require institutional support and collaborative taxonomic initiatives to deliver required information in appropriate formats (Kirkup et al. 2005; Smith et al. 2008).

Target 1 of the GSPC clearly underpins the other Targets. The most obvious example of this is that Target 2, "An assessment of the conservation status of all known plant species", cannot be achieved without a reliable list of species to build on. Achievement of other species-orientated targets such as Targets 7, 8, 9, 10, 11 and 12 will depend on knowing which species exist and where, while habitat-orientated targets such as Targets 4, 5 and 6 will require knowledge of the species within specific geographic areas to assist in conservation planning and monitoring. As the WFO is a collaborative endeavour, it will also support Targets 15 and 16 that deal with training and strengthened collaborations.

The WFO is not only important to achieve the GSPC targets, but also for implementing the CBD in general (CBD 2013), including broader biodiversity goals such as the Aichi Targets and the Millennium Development Goals (MDG). Within the CBD, the need for taxonomy and the taxonomic expertise necessary to implement the convention has been recognised as the Global Taxonomy Initiative (Klopper et al. 2002; Smith et al. 2008). The WFO, providing a taxonomic baseline for the plant components of biodiversity, needs to support the synthesis of information necessary to implement relevant CBD decisions and support broader biodiversity goals with specific emphasis on conservation.

Challenges in achieving a World Flora Online

Before building a WFO it is necessary to have or to compile a list of names to which floristic information can be linked. How to resolve the problem of nomenclatural consensus between countries at an international level is probably the most challenging obstacle faced by compilers of the WFO. For example, the South African National Biodiversity Institute (SANBI) has taken a decision to follow the Angiosperm Phylogeny Group (APG) II classification system, whereas a European and Australian consortium, the Vascular Plant Classification Committee, has taken a decision to follow the more recent APG III system (Wearn et al. 2013). At or below genus level this problem is not insurmountable, if all floristic information for the WFO is databased using the genus name as the searchable point of reference rather the than family name. Ideally the database should enable more than one family name to be linked to the genus name so that different countries can use alternative classification systems. For country endemics, data can be relatively easily incorporated into a global flora. For non-endemic species the task is much more complex, for example, there may be inconsistency in which genera or species are accepted in different areas. Such instances of incongruence between different taxonomic views can help prioritise further taxonomic work. National contributions, expertise and classificatory best-practise should inform global consensus taxonomy. The global overview provides information that is not available nationally, such as global context for species delimitations and distributions. This interplay between national and global levels is critical to the success of the GSPC (Paton and Nic Lughadha 2011).

In its most basic characterization, a Flora can be defined as a taxonomic treatment of the plants of a clearly delimited geographic area (Meyer et al. 1997). It has also been defined as an inventory of plants occurring in a particular geographic region, providing a means to identify these plants (Diggs and Lipscomb 2002; Kirkup et al. 2005). This broad meaning includes other, less information-rich products that are not strictly Floras (e.g. a conspectus, which is similar to a Flora but lacks detailed descriptions, or even a catalogue with identification keys; see Meyer et al. 1997). A challenge faced by compilers of the WFO is deciding what fields to include in an online Flora as mandatory, and which should be optional.

In the traditional sense Floras typically include information on a broad range of organismic and environmental elements. The data content of a Flora, and consequently, an online Flora, can vary from having only a name, synonyms, descriptive text and possibly images, to those which extend to basionyms, homonyms, distribution and habitat, endemism, identification keys, etc. (Smith 2005; eFloras 2008).

At the national level, countries will decide what floristic elements should be included and what the requirements of the end-users will be (Morin et al. 1988; Smith 2005; Victor et al. 2013). The floristic information provided by the independent institutions or countries will therefore not be consistent and not all regions would be able to provide the same level of information. Most regions will rely heavily on previously published literature. It is therefore necessary to decide at a global level which elements are rudimentary for each taxon to qualify as an entry into the WFO and which elements will enhance the quality of the product. At the 16th meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the CBD, certain core fields were suggested as being necessary to produce a WFO, with supplementary fields being regarded as optional (CBD 2012). These core fields included the accepted scientific name, family and synonyms, description, distribution, images, keys and references; supplementary fields included native status, habitat, altitude, conservation status, website links and vernacular names. This is, however, a work in progress, and the mandatory and optional fields are currently under discussion by the Technical Working Group of the WFO project.

The third challenge is to ensure that there are links to, and interoperability with, other databases. The framework of WFO should be created in such a way as to be compatible with the data standards used to share information with other platforms such as EOL and GBIF. The information that WFO will provide will have similarities to that provided by EOL and GBIF although, currently, these systems are not substantial in terms of the descriptive information provided. GBIF is somewhat more focused on spatial (locality) data than EOL (which obtains its maps from GBIF). The two systems share distribution information and are cross-referenced on both sites. WFO will also be able to share information if the same data standards are used throughout all these systems. Links from WFO to specimen data held in GBIF will be particularly valuable to users seeking more precise distribution data.

Methods for achieving a national online Flora

In a broad sense, the compilation of a national online Flora for South Africa will inevitably follow a similar methodology as used to produce a WFO. The process will be initiated by using SANBI's checklist of South African flora published by Germishuizen et al. (2006), that is maintained in an electronic database and continually updated, as the taxonomic backbone. South Africa is in a privileged position to have regional floristic treatments that have either been published or that are currently being compiled by a dedicated team of taxonomists. These treatments can be used to extract valuable floristic information that can be consolidated to form the major part of the online Flora of South Africa (e-Flora).

Compiling the e-Flora will involve the incorporation of all names from the checklist into a relational database where the synonyms are linked to the accepted names. Available floristic information will then be harvested from regional Floras through markup and stored in the database. A time-frame for the compilation of the e-Flora is provided in Table 1.

Certain elements are commonly included in floristic treatments (Smith 2005; eFloras 2008; Rilke et al. 2012). Therefore we have selected the following elements that are in agreement with the majority of Floras as fields that should and can be accommodated in order to provide authoritative information to support research and conservation that facilitates the implementation of the CBD. Including these elements in an online Flora for South Africa is regarded as a realistic target to achieve by 2020:

- up-to-date names with authorship for all taxa within South Africa (covering family, genus, species and infraspecific names);
- protologue citation;
- synonyms (including widely used taxonomically alternative names);
- descriptions;
- identification keys to the families, genera and where available to species—initially available text (dichotomous) keys should be referenced, but with an aim to move to multi-access keys and other options as technology, markup, and data parsing become available. Inclusion of keys may be facilitated by linkages to existing sources such as http://www.identifylife.org/ or online Flora projects;
- images—photographs and/or drawings of at least one species of each genus (ideally, linked to voucher specimens) should be included where available. Alternatively an imaged herbarium specimen or link to the URL of the type specimen (if available) should be provided.
- geographic scope—national-level geographic distribution ranges (with accompanying maps), or within floristic regions;

Table 1 Time-frame of activities for compilation of the e-Flora for South Africa by 2020

	2013	2014	2015	2016	2017	2018	2019	2020
Markup publications and incorporate descriptions for the gymnosperms and angiosperms of South Africa into the database	XXX	XXX	XXX	XXX	XXX	XXX		
Commence with possible collaborations to compile family, generic and species level treatments for the bryophytes and pteridophytes	XXX	XXX	XXX					
Incorporate images for families and genera represented in the database			XXX	XXX	XXX	XXX	XXX	
Commence with the compilation of dichotomous keys (include updates) for families, genera and where possible, to species level			XXX	XXX	XXX	XXX	XXX	
Produce maps					XXX	XXX	XXX	
Determine where the gaps in the floristic database are and collaborate with taxonomists to compile relevant floristic information					XXX	XXX	XXX	
Scan representative herbarium specimens for those families and genera that lack images							XXX	
Select the best description for each taxon to be published online							XXX	
Publish the e-Flora for South Africa online								XXX

- resident status—taxa will be flagged as, e.g., exotic/alien, indigenous/native, naturalised;
- endemic status—taxa that are endemic will be flagged; and
- literature references and credits—attribution of authors, sources of data and images included in the Flora.

Supplementary fields, which could be added subject to availability of resources and time, include:

- links to higher-level classification (such as order);
- categories of habit/life form
- categories of habitat and ecology, e.g. altitudinal range—although usually part of the description of a geographic range, general categories can be added to provide coarse sorting of plant species;
- specimen citations;
- links to digitised specimen information;
- conservation status;
- vernacular names—to be included if available;
- traditional, economic, and medicinal uses;
- trade statistics and non-detriment information for implementing the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES);
- invasiveness—potential or actual;
- online links—to external data and data sources about the species, e.g. DNA barcodes; and
- a system that enables submission of feedback that can be included or acted upon to correct or improve the content.

The technological resources available today have changed the emphasis of certain components in a Flora and there are several key advantages in publishing electronic Floras. Previously, descriptions and dichotomous identification keys were the bases for identification. Nowadays, emphasis can be given to visual data, such as specimen images, field photographs and multi-access keys (see Koekemoer and Steyn 2009). Electronic Floras are dynamic systems that can easily and continuously be improved without incurring the same costs as for paper-published Floras. Additionally, electronic Floras can be updated rapidly and dynamically in comparison to the time it takes to publish in hardcopy format. However, there will inevitably be costs involved in maintaining and updating an online Flora. Names of taxa change regularly for nomenclatural or taxonomic reasons and such changes must be incorporated and referenced to ensure that the content of the Flora is kept current. This requires the availability of broadly-based taxonomic expertise—a rare commodity—along with biodiversity informatics specialists who can develop and maintain a robust electronic shell into which content is cast and from which it is served on the worldwide web. Committing to producing an online Flora is not a once-off endeavour: it will require resources. As technology advances, e-Flora information can potentially be searched through multiple access points on a tablet computer or mobile phone whereas it is impractical to carry around numerous volumes of heavy weight Floras (Brach and Boufford 2011). In addition, there are increasing technological advances in using DNA barcoding as an identification mechanism, for example BOLD Systems (http://www.boldsystems.org/).

The compilation of a traditional Flora is time consuming and not achievable within the set timeframe of the GSPC 2011–2020. It generally takes approximately two days for an experienced taxonomist to compile a comprehensive species treatment for a known taxon, including related distribution and habitat information (Gómez-Pompa and Nevling 1988). Because of the short timeframe, it is not feasible to undertake new taxonomic revisions and write new keys and descriptions for the *c.* 20,500 plant species found in South African or for the world's *c.* 400,000 plant species. Therefore, initially the Flora aims to be synoptic, populated by pre-existing data on as many of the plant species of the world as possible (CBD 2012). Once this foundation is in place, it will be possible to identify gaps in the data. Filling these gaps will be a challenge that can be met at a national level by development of biosystematics research strategies and building capacity.

In response to SANBI's mandate to "coordinate and promote the taxonomy of South Africa's biodiversity", a national biosystematics research Strategy has been developed (Victor et al. 2013). The Strategy highlights taxonomic research priorities for algae, animals, bacteria and archaea, fungi and plants. The first objective of the plant systematics component of the Strategy proposes that an online Flora of South African plants can be achieved using existing species descriptions, in particular those that are available in recently published family treatises or generic revisions. Descriptions that are not published in family-level treatments or generic revisions can be extracted from regional Floras, published by SANBI, which will have covered the entire country before 2020. The South African National Plant Checklist will be updated by SANBI and lodged on the Institute's website, forming the backbone of the national e-Flora. The second objective of the Strategy identifies gaps in taxonomic information, in terms of revisions of plant genera that are outdated or inadequate, and prioritises which groups most urgently require attention (Victor and Smith 2011). These revisions can be used to populate the e-Flora on a continuous basis as they are produced. The third objective of the Strategy is to resolve taxonomic problems in plants of economic and conservation importance, where the genus to which the plant belongs is not necessarily in need of revision. The three strategic objectives should be met within a five-year time frame to provide a solid foundation for an online Flora.

The following procedure is a broad outline of SANBI's action plan to produce an e-Flora for South Africa by 2020, to contribute to the WFO:

Resources required

SANBI has appointed one full-time trained taxonomist (e-Flora Co-ordinator) to co-ordinate the South African component of the WFO, with the help of at least one full-time assistant. SANBI has to ensure that sufficient infrastructure and information technology resources are available to support this function. In addition to cost of employees, further financial input is required for travel both locally and internationally in order for the e-Flora Co-ordinator to liaise with external contributors to the project as well as the WFO Technical Working Group. External collaborators will be approached to contribute information at their own cost.

Selection of an appropriate data management system

It is important to decide on a system that will fulfil all the requirements to build an e-Flora. The system should be able to accommodate and manipulate information (core fields as well as supplementary fields) at different taxonomic levels (family, genus, species, etc.). It would be an advantage if the system could manage and incorporate information taken from individual herbarium specimens, e.g. for the production of maps. Other functions that should be considered when selecting an appropriate system include the ability to

(a) manipulate and update large sets of data and (b) to communicate with other information systems using biodiversity information standards such as Darwin Core Archive (Biodiversity Information Standards 2009) to export information into an appropriate format in order to contribute to projects such as the WFO.

The Botanical Research And Herbarium Management System (BRAHMS; Filer 2012) is capable of incorporating and manipulating inputs and delivering all the outputs necessary to build the e-Flora of South Africa. The software has the ability to combine information from many different fields, e.g. information gathered from herbarium specimens, botanical surveys, living collections, seed banks, literature from several sources with corresponding references, images, keys, etc. (Filer 2012). SANBI has recently adopted BRAHMS to house all specimen data, and will therefore also use BRAHMS to house all taxonomic data from where the floristic information will be parsed onto a website where the e-Flora of South Africa will be published.

The advantage of using BRAHMS is the interoperability of the database, which enables countries to share data. For example South Africa would be able to provide information to neighbouring countries with species in common. Another advantage of BRAHMS is that it is widely available and accessible online. For countries that are not able to use BRAHMS as their Floristic data management system, a simple database can be created using for example Microsoft Access or even Excel.

Populating the database

All core fields are populated for each taxon. Initially, descriptions from regional treatments will be incorporated; later on, they will be supplemented by descriptions from taxonomic revisions.

Family and genus descriptions are already available for most monocotyledons, dicotyledons and gymnosperms in South Africa, published by SANBI in *Seed plants of southern Africa* (Leistner 2000). In addition, SANBI is currently in the process of publishing regional floras for all provinces of South Africa: KwaZulu-Natal; Free State; Eastern Cape; Western Cape (Manning and Goldblatt 2013; Snijman 2013); Northern Cape; and the northern provinces comprising Gauteng, Limpopo, Mpumalanga and North West (Retief and Herman 1997, with plans to update by 2018). These regional Flora treatments will serve as the basis for the e-Flora (see Table 1 for the estimated time-frame of the project). Furthermore, almost 20 % of South Africa's flora has been treated at family level in a project initiated in 1955, The Flora of Southern Africa project. The aim was to document more than 20,000 species of 180 angiosperm families in South Africa, Lesotho, Swaziland, Botswana and Namibia. Due to slow progress, the project was de-emphasised in 1995 in favour of publishing family treatises in SANBI's in-house journal, Bothalia, a practice that is still currently active. Descriptions from these family treatises will be used in place of the regional Flora information where they are more recent or of a higher standard. Finally, recently published revisions of plant genera may be used if published in a SANBI journal, or if consent can be obtained from the publishing journal and authors (Sierra et al. 2013). Attribution is considered to be a very high priority for all data used, especially descriptions and images, considering that many taxonomists from around South Africa, and possibly internationally, are expected to contribute.

The technical process of populating the database includes the following steps:

a. Digitisation and markup

   Literature published only in hard copy format has to be converted to digital format

(Kirkup et al. 2005). Converting literature requires the scanning of each page, running it through optical character recognition (OCR) software (Pro-iBiosphere), converting the .pdf file into a Word document and editing the text for typos or unrecognised symbols and characters. Thereafter it has to be marked up for transfer into the database. Markup is mostly done manually where after the semantics has to be revised to ensure the import of data takes place correctly (Brach and Song 2006). It is time consuming and requires some basic botanical knowledge (Sierra et al. 2013).

b. Importing of data
Marked up literature is converted from .docx format, in Microsoft Word, to plain text after which it is imported into Microsoft Excel or Access. The best set of information (core elements) has to be evaluated from all literature resources of which the best quality data is imported into BRAHMS.

c. Inclusion of images
Images will be uploaded into BRAHMS through the Image Management System. Details of contributors or contributing institutions and any related copyright will clearly be linked to each image (whether these are photographs, illustrations or scans).

d. Keys
Keys to family and genus level will initially be taken from Leistner's publication (2000) and will be updated to the same classification system according to which the SANBI herbaria (NBG, NH and PRE) are arranged.

e. Updates to the taxonomic backbone
The taxonomic backbone for the South African flora will be held in BRAHMS and will be updated on an on-going basis. As updates are made, floristic information will be incorporated for the new taxa.

f. Quality control
Before any data are published online, they will be verified. Once published online, provision will be made for users to provide feedback in order to improve the quality of the data.

Disseminating and publishing the e-Flora

According to the 16th meeting of SBSTTA (CBD 2012), the primary technical challenge for the WFO is to develop an open-access web-based facility for data input, manipulation, storage, and delivery, with the functionality to tailor outputs as desired by end-users, e.g., for national or regional contexts, particular plant families or genera, specific kinds of organisms (such as trees, conifers, mosses), or threatened species. The database should be easily able to permit editing by approved specialists, and must be compatible with a wide variety of external hardware and software options (CBD 2012).

BRAHMS has the capability of exporting information directly to a word processor, which enables easy editing and proofreading of the text (Filer 2012).The Biodiversity Information Management Directorate (BIM) within SANBI will assist with the development of the e-Flora website in South Africa. All information relevant to the e-Flora will be exported from BRAHMS onto the website using the BRAHMS publishing function (BRAHMS online) and will be made available to the WFO accompanied by metadata.

Once the initial aim of Target 1 of the GSPC 2020 has been accomplished and all core fields are published online, supplementary fields will be populated with the relevant information. Given the dynamic nature of taxonomic work, often leading to changes in names and their status, and the steady accumulation and refinement of our knowledge of species (Constance 1964), it is important that both the database and the website are maintained and updated.

Future work

After the first phase of the development of the e-Flora is completed (with the aim of submitting a national Flora to WFO by 2020), attention can be given to improving detail and providing consistent high resolution information, e.g.

(a) Create comprehensive species descriptions for all taxa using a template.
(b) Provide at least one image for each species and where possible photos of taxa in situ showing diagnostic characters.
(c) Create interactive species-level keys.

Conclusion

In South Africa it will be possible to use existing resources to compile an online Flora. The availability of these current resources is a result of commitment and collaborative efforts over many years to enhance botanical knowledge in this country. All countries can benefit from data at regional or global level even where there has been no great national investment (as there has been in South Africa). In this way, national implementation can be greatly enhanced by use of existing material and judicious targeting of resources to fill the gaps that are most critical to the conservation priorities of the country.

The WFO will be a critical resource for management and conservation of plants by providing baseline information on plant diversity for each region or country, enabling effective identification, clearly documenting geographic distributions, and supporting all other GSPC Targets, including those likely to be set in the decades beyond 2020.

Achieving a World Flora describing some 400,000 species by 2020 may seem unrealistic, but there is an enormous body of usable data available, scientists with expertise, a formal recognition that such a Flora is a priority and urgently needed, and a broad-based enthusiasm to make it happen. Concerted efforts from many contributors in the world wide taxonomic community, along with leadership from key institutions, will be required to achieve this target, so that taxonomists are able to have a positive impact on global conservation efforts by providing the ultimate botanical resource. We urge other countries to consider how they might practically organise themselves to help deliver this challenging conservation target.

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APPENDIX 6: A biosystematics* research strategy for the algae, animals, bacteria and archaea, fungi and plants of South Africa, 2013–2018

*Biosystematics: in this publication, the term 'biosystematics' is used to refer to taxonomy of various groups of organisms, and as synonymous with taxonomy in the broad sense inclusive of alpha-taxonomy, phylogenetics and evolutionary studies. It should be noted, however, that the term has different meanings (see Stuessy 2014 for a full clarification).

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SANBI Biodiversity Series 23

A BIOSYSTEMATICS RESEARCH STRATEGY for the Algae, Animals, Bacteria and Archaea, Fungi and Plants of South Africa 2013–2018

J.E. Victor, M. Hamer & G.F. Smith

SANBI
Biodiversity for Life

Pretoria
2013

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Chapter 1
INTRODUCTION

What is taxonomy?

South Africa has a proud history of taxonomic research endeavour across all the indigenous and naturalised biota present in the country. In the 17th and 18th Centuries most biological specimens collected in South Africa for taxonomic work found their way to natural history museums and herbaria in continental Europe and the United Kingdom, but during the past 150 years the development of local specimen preservation facilities saw research in this area expanding in the country. However, taxonomic research is often conducted in an explorative manner with inadequate regard for the needs of end-users, and gaps in the existing knowledge framework have largely not been considered. Taxonomy remains fundamentally important in all downstream biodiversity research, including several serious environmental issues such as the sustainable use of natural resources and spatial planning to protect ecological infrastructure. Globally, the importance of taxonomy has been recognised by way of the Global Taxonomy Initiative (GTI), one of the thrusts of the Convention on Biological Diversity (CBD), to which South Africa is a signatory. The CBD describes taxonomy as "...the science of naming, describing and classifying organisms. Using morphological, behavioural, genetic and biochemical observations, taxonomists identify, describe and arrange species into classifications, including those that are new to science. Taxonomy identifies and enumerates the components of biological diversity, so providing basic knowledge underpinning management and implementation of the Convention on Biological Diversity". Usually more broadly defined, 'systematics' and 'biosystematics' are nevertheless sometimes used interchangeably with 'taxonomy'. Regardless, this sphere of science essentially provides a fundamental understanding of, and information about, components of biodiversity. Taxonomy contributes to and is indispensable for all biological research, including enabling effective decision-making in conservation and the sustainable use of biodiversity.

This is the first ever comprehensive National Biosystematics Research Strategy that deliberately emphasises the research component of taxonomy. However, taxonomic research is inextricably linked to collections of preserved biological collections typically held in natural history museums and herbaria, as well as to the datasets that are derived from specimens held in these collections. Although this document therefore deliberately addresses the research component of biosystematics in South Africa, collections and data capture and dissemination are here identified as co-priorities for attention, especially in the case of animals and fungi, because of the dependence of research on these resources. This research Strategy recognises the challenges faced by collections, and derivative datasets are seen as a major output from taxonomy that is needed by users of taxonomic information and so this has been included for animals. Additionally, both collections and datasets are included in the GTI list of priorities.

South Africa's biodiversity wealth

The latest estimate for the total number of species on Earth is 8.7 million, with 6.5 million species found on land and 2.2 million (about 25% of the total) dwelling in the ocean depths (Mora *et al*. 2011). The same study states that 86% of all species on land and 91% of those in the seas have yet to be discovered, described, and catalogued; even though over 1.2 million species have been described to date.

Why a strategy?

A co-ordinated Strategy for taxonomic research that addresses the needs of end-users will significantly improve the relevance and impact of research products delivered by taxonomists. The Strategy also serves as a basis for co-ordinating and promoting taxonomic research throughout South Africa, thereby providing leadership in this regard.

Further benefits of the Strategy are that it:

- Provides a shared vision to guide research.
- Sets and leads the biosystematics research agenda in South Africa by providing guidelines for research priorities.
- Communicates the value of taxonomic research to the public, academic institutions and funding agencies.
- Makes the most strategic use of limited resources for taxonomic research.
- Guides future decisions on capacity development, staff recruitment and training.
- Informs funding allocations for taxonomic research.
- Stimulates the implementation of and dissemination to stakeholders of priority research products.

Context for the strategy

At national level, the National Environmental Management: Biodiversity Act (NEMBA) No. 10 of 2004: Section 11, gives the South African National Biodiversity Institute (SANBI) the mandate to lead, through co-ordinating and promoting, taxonomy in the South African community. Internationally, governments of the world, through the CBD, have acknowledged the importance of taxonomy and the existence of a "taxonomic impediment" that frustrates the recording and sound management of biodiversity. This impediment refers to the knowledge gaps in our taxonomic system, the shortage of trained and skilled taxonomists and collections curators, and the crippling impact these deficiencies have on our ability to conserve biological diversity and to use and share the benefits derived from it.

Decision-makers need to know which species occur where to facilitate the establishment and wise management of protected areas and to enable sustainable land-use. It is also necessary to understand which species make up communities that collectively play an integral role in the functioning of ecosystems on which humankind and all life on Earth ultimately depend. Regulating and combating harmful invasive species is only possible if they can be distinguished from indigenous species. How can

the economic potential presented by the sustainable use of our biodiversity be unlocked if the diversity remains unknown? Taxonomy ultimately provides a fundamental understanding of the components of biodiversity that are necessary for effective decision-making about, among other things, conservation and sustainable use.

In this national and international context, this Strategy is intended to guide South African institutions that are involved in taxonomic research, aiming to ensure that the needs of end-users are addressed, so improving the relevance and impact of research products. At a broader national scale, the Strategy forms part of the National Biodiversity Research Framework that SANBI is developing for the country.

This is the first comprehensive Strategy produced for the major biota of South Africa. In botanical taxonomy previous strategic work focussed on setting priorities and criteria for decision-making on where research should be concentrated, but there have been no similar activities for other taxa.

Purpose of the strategy

The purpose of the Strategy is to provide clear guidelines to taxonomic researchers as to where to direct research effort and resources to maximise the benefits of research to society. The Strategy also clarifies the co-ordinating role with which SANBI is mandated.

Scope of the strategy

Taxonomic coverage: The Strategy deals with the taxonomy of living organisms. Three domains of life are recognised: the Bacteria, Archaea and Eukarya. Whereas Bacteria and Archaea each comprise a Kingdom of their own, Eukarya is divided into four kingdoms: animals, plants, fungi and protists. Viruses and subviral agents (e.g. prions) are not classified in a Kingdom as they are not considered to be living organisms, and for this reason they are excluded from the Strategy. A South African Strategy for the Palaeosciences has recently been developed and gazetted, therefore this strategy is confined to organisms currently in existence.

Since the diversity (how many?), richness (how much?), extent of previous attention received, and the existing and available capacity differ across different groups of organisms (even within Kingdoms), the approach for the strategy has been to deal with each major group separately.

Geographic coverage: Organisms occurring naturally and as introduced aliens in South Africa, including all its terrestrial, fresh-water and marine habitats, were considered in developing the Strategy. Living organisms do not observe political boundaries, and many taxa that occur in the country extend beyond its borders.

Timeframe: The main temporal focus of the Strategy is the next five years (2013–2018). The Strategy will be reviewed and revised after this 5-year period.

Developing and implementing the strategy

For SANBI the availability of a national Strategy for taxonomy is a step towards promoting and co-ordinating this type of research in South Africa and also fulfils at least some requirements of the GTI. Deliberate implementation of the Strategy is more challenging as the taxonomic community is spread across many different types of autonomous institutions including museums (at all three tiers of government, namely local, provincial and national), universities, national facilities and science councils, over which SANBI does not have authority. Monetary allocation to research in South Africa is a primary responsibility of the Department of Science & Technology, therefore the Strategy is intended to inform taxonomic research funding at a national level. Allocation of funding can therefore be influenced by giving preference to required outputs of the Strategy.

Challenges to biosystematics research presented by current trends

The main challenges relate to a disjunction between what is needed from taxonomists to address the taxonomic impediment and what research is done by taxonomists, lack of access to taxonomic information in a format and medium that serves a broad community of users of such information, lack of appropriate capacity, especially at natural history museums, and a lack of co-ordination of taxonomic activities and outputs in South Africa.

In most needs assessments done globally and by individual countries, the following are regarded as the main requirements of the users of taxonomic data:

1. Reliable identification of material/specimens (either as a service, or enabling this through the provision of user-friendly identification keys/resources)—*What is it?*
2. Accurate species occurrence and abundance data sets—*Where does it occur? / How many are there?* and *How is this changing / has this changed over time?*

3. Co-ordinated information about species, including classification, nomenclature and information such as functional role, threat status and importance to humans—*What is it called and what does it do?*

Answers to these questions are needed to enable countries, regions and organisations to manage and conserve biodiversity, which in turn will enable people to have sustainable livelihoods and so must be seen as priorities. Appropriate human capacity, access to collecting permits, and the maintenance of collections are supporting activities essential to the delivery of these three main needs, as well as for future research and the selective expansion of collections of preserved organisms.

Chapter 2
ALGAE

Prof. John Bolton (Department of Botany, University of Cape Town) & Janine Victor (Biosystematics Research and Biodiversity Collections Division, SANBI)

'Algae' is not a taxon, and what are considered algae by those studying them (phycologists) are evolutionarily, and hence taxonomically, enormously diverse. While algae are traditionally defined as non-vascular, photosynthetic organisms with simple vegetative and reproductive structure (Bold & Wynne 1985), there are exceptions; for example many of the dinoflagellates are non-photosynthetic. Algae are represented across the breadth of the eukaryotic domain, including representatives that are deeply rooted in branches that give rise to the land plants and to the animals.

Review of current status of algal systematics in South Africa

Bolton & Stegenga (2002) estimated there to be around 800 species of marine macro-algae recorded for South Africa; around 9.5% of the global total estimate. Therefore, in the unlikely circumstance that seaweeds can represent a guide to algal diversity in general, a very rough estimate of algal diversity in South Africa would be around 6 900 species. No attempt has ever been made to list or add up the numbers of algal species recorded in South Africa.

The only group of algae that can be considered to have been reasonably well studied in recent years are the marine macro-algae (seaweeds). A comprehensive document exists with descriptions and illustrations of seaweeds of the west coast (Stegenga *et al.* 1997), and a less comprehensive guide has been produced for seaweeds of the east coast (De Clerck *et al.* 2005). A website is under construction (R.J. Anderson, Department of Agriculture, Forestry and Fisheries (DAFF)) that will have descriptions and illustrations of seaweeds of the intervening south coast. An annotated checklist of seaweeds recorded for South Africa is therefore urgently needed.

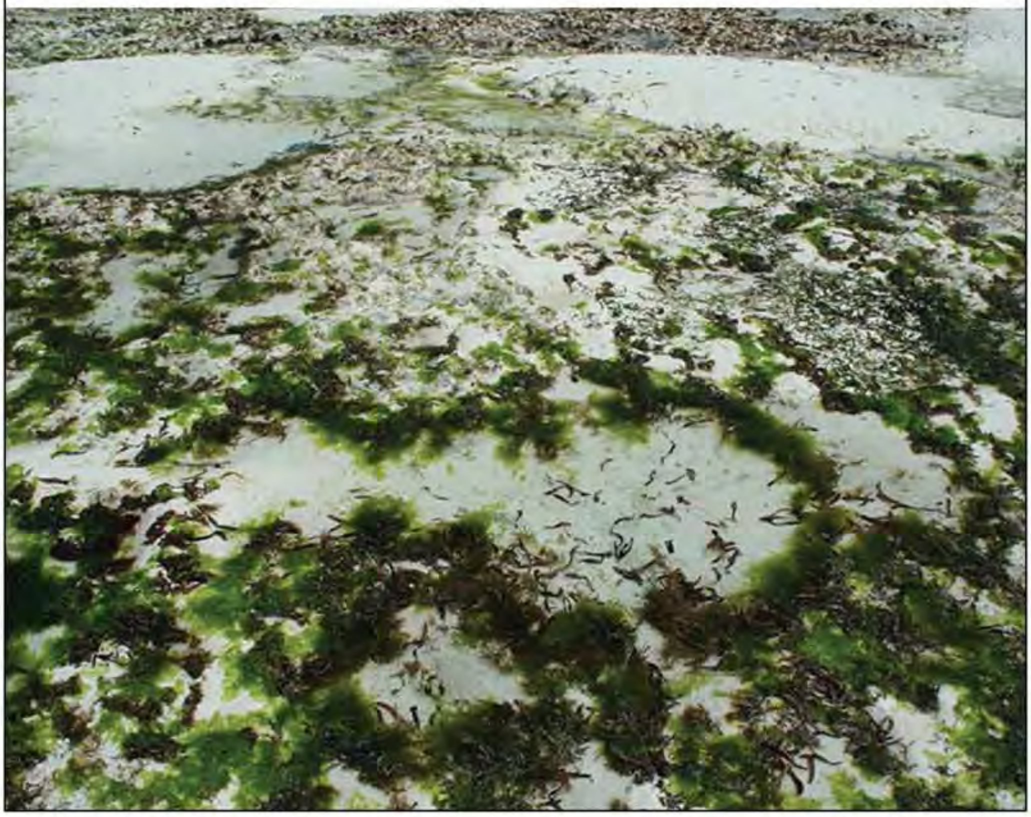
The diatoms were well studied in the past, but there is no checklist available for species that have been recorded in South Africa. Work has also been undertaken on inshore marine phytoflagellates. Most taxonomic investigations are as a result of serendipitous encounters with novel taxa or dealings with problem algae rather than due to in depth surveys, and nearly all have been limited to inshore waters.

Many records were made in the literature of freshwater algae many years ago (particularly in the 1930s and 1940s), but no attempt has ever been made to compile records of South African freshwater algae.

In South Africa, taxonomic work on algae is only carried out by a few academics and their students at universities, where all major algal collections are held. The majority work with marine macro-algae (seaweeds) and none of them is a full time algal taxonomist. There are growing collaborations with authors overseas who work on specific groups of algae.

Vision for the algae systematics research strategy

To document all existing literature records and specimens in collections of South African algae and to enhance and support taxonomic research on South African algae into the future.



Strategic objectives of the algae systematics research strategy

SO 1: Develop an inventory of all species recorded in the literature, with an online checklist as the ultimate goal.

SO 2: Develop a widely accessible online algal identification guide with descriptive information and keys.

SO 3: Develop capacity in taxonomic research on algae.

Activities to achieve objectives

SO 1: To collate and database taxonomic literature, develop a checklist, and liaise with SANBI to provide this as an online resource. A good starting point is a major literature-based algal website (www.Algaebase.org), managed by Prof. Michael Guiry (University College Galway, Ireland).

SO 2: To achieve an online Flora, the database (see SO 1) would need to be additionally populated with descriptions of all species, and these made accessible online.

SO 3: Initiate a research programme for postgraduate students addressing taxonomic problems, prioritising taxa of most relevance to society (i.e. economically and ecologically important taxa). Projects to develop electronic identification tools would need to be encouraged; and interns, postdoctoral fellows or students engaged to capture existing information into databases, including descriptions and images.

Chapter 3
ANIMALS

Prof. Michelle Hamer (Biosystematics Research & Biodiversity Collections Division, SANBI)

Review of the current status of animal taxonomy in South Africa

Animal diversity: South Africa has over 65 000 described species of animals, but it is recognised that as many as 80 000 remain to be discovered and described. Most animals are invertebrates, with the greatest species richness being represented by insects (>43 000 species). New animal species continue to be described at an increasing rate, with 3 668 new species described in the past decade.

Research capacity: Ninety-two researchers/academics contribute to animal taxonomy/systematics research in South Africa, and an additional 14 retired researchers continue to publish in the field. There is a marked skew in terms of taxonomic focus, with more taxonomists working on the <4 000 vertebrates species than on the >43 000 insect species. This translates to a ratio of taxonomists : known species number for vertebrates of 1:28, and for a major insect group, the Lepidoptera (butterflies and moths), of 1:7 000. The number of taxonomists based at museums has declined to 23, down from 62 in 1991. Age distribution of taxonomists indicates that there will be at least 15 vacancies from retirements in the next five years. A major concern is that there will potentially be only a single entomologist at a university to train postgraduates in insect taxonomy within the next five years.

Research collections: South Africa has vast research collections comprising over 15 million animal specimens in 23 institutions and 75 collections. Major challenges for collections relate to: (i) the governance of the collections, with most of the large institutions falling under national and provincial departments of arts and culture, which have no mandate for the curation of biological collections, and, (ii) the use and accessibility of the collections. The collections are viewed as being of value only to a small group of specialists, and the use of data and specimens for a range of decision-making and research activities is inadequately promoted.

Databases: The data associated with more than 6 million specimens in the research collections remain to be captured on databases, and a relatively small amount of data (approximately 600 000 records) from the collections has been provided to the South African Biodiversity Information Facility (SABIF) for dissemination and application in land use planning.

DNA barcoding is a technique that helps taxonomists with hard-to-identify specimens or parts of specimens, and is an innovative way for non-experts to identify biological material. While there has been some criticism of barcoding and it does not work for all taxa, it has been adopted by many countries and researchers, and its use has been proven in a range of applications. Barcode sequences are lodged and made accessible through the Barcode of Life Database (BOLD). By July 2012, 8 499 records of animals from South Africa were publically accessible in the BOLD database, but only 834 of these were identified to species level, which somewhat limits the current usefulness of the system.

Research publications: An analysis of research publications by animal taxonomists nationally over the past just-more-than-three decades, shows they have described less than a third of the new species discovered in South Africa during this time frame. Each taxonomist has described less than one species per year

on average. There has been a solid output in terms of publishing high quality molecular phylogenetic studies and this area could be considered a current strength. The bulk of this type of research, however, does not directly address the taxonomic impediment.

Given the diversity of animals in South Africa, and the financial and capacity constraints, it is impossible to deliver on the three needs for all animal species, and prioritisation, based on feasibility (including expertise available and the current state of knowledge relative to the diversity) and the rationale for taxonomic study (i.e. is the taxon of major importance in ecosystem functioning or a keystone taxon or of economic value?), is critical.

Vision for animal taxonomy in South Africa

Consolidation, co-ordination and dissemination of comprehensive taxonomic information for use by a wide range of stakeholders, and the generation of new knowledge in line with national priorities.

Strategic objectives for achieving the Vision

Four strategic objectives that relate directly to the core work of taxonomists are:

SO 1: To develop and make accessible accurate and comprehensive primary data sets for specimens of selected taxa for use in land-use planning, species threat assessments, biodiversity monitoring and research relating to global change impacts on biodiversity.

SO 2: To carry out taxonomic research that is aligned with the needs of major initiatives and that is integrated into broader research programmes to ensure that taxonomy delivers useful and used knowledge.

SO 3: To develop identification tools for taxa of major concern for conservation, sustainable use and the management of invasive and pest species, and disease vectors. This includes the development of a DNA barcode reference library for the priority species.

SO 4: To develop capacity to enable taxonomists to contribute to the broad dissemination of their outputs and to develop new capacity in line with identified priorities.

Four additional objectives deal with outputs that may not be considered as being the primary work of taxonomists, but their contributions to and participation in the activities are essential.

SO5: To provide a complete and regularly updated checklist of animals in South Africa, including classification, synonyms and local names that are publically accessible through the internet.

SO6: To co-ordinate and disseminate existing foundational information for priority species.

SO 7: To initiate discussions on the recommendations made in the National Research Foundation (NRF) report on the status of research collections of preserved animals in South Africa.

SO 8: To explore mechanisms for enabling access to collecting permits so that this is not a major impediment to the exploration of animal diversity in South Africa.

Priority activities required to achieve the strategic objectives [and responsible organisations or communities]

SO 1: Primary datasets

- Ongoing expansion and updating of taxonomy for existing comprehensive datasets that have been compiled (reptiles, butterflies, amphibians, spiders) or that are currently underway (mammals, line fish, dung beetles) [SABIF in collaboration with data owners, taxonomists].
- Development of additional comprehensive datasets for taxa including arachnid orders, dragonflies, bees, and freshwater and marine invertebrates [SABIF, taxonomists, data owners]. Compile and disseminate a list of datasets and information about these (i.e. metadata) in order to co-ordinate activities [SABIF].

SO 2: Taxonomic research

- Develop and implement projects that are of direct relevance or that are integrated into broader projects in the fields of global change, ecosystem functioning and the bio-economy, which are currently receiving both national and international attention [funding agencies, taxonomists].

- Use these projects as models and for the promotion of taxonomy to funders and decision-makers to illustrate the value of taxonomy [SANBI, taxonomists].

SO 3: Tools for identifying species

- Determine existing projects and resources for the identification of priority taxa and categories of animals; identify gaps and develop a plan for addressing these and for providing access to those that are already developed [SANBI, taxonomists].
- Provide an open access internet platform for the submission of identification keys for the animals of South Africa, and ensure that these are arranged and accessible in a logical and user-friendly way [SANBI].
- Provide a list of all species and localities for which material has been barcoded, and a list of those species that are a priority for getting material barcoded [SANBI, taxonomists].

- Initiate project(s) for sampling and submitting specimens from priority taxa and categories for barcoding to expand the barcode reference library [SANBI, taxonomists].
- Explore innovative mechanisms for the documentation, description and identification of species [SANBI, taxonomists, funding agencies].

SO 4: Capacity development

- Develop skills of taxonomists to enable them to submit material for barcoding, to use the BOLD database, and to use other new technologies or approaches associated with the generation, co-ordination and dissemination of taxonomic data [SANBI, taxonomists, funding agencies].
- Develop capacity for priority taxa through the training of M.Sc. and Ph.D. students. Where appropriate expertise is not available in South Africa, it may be necessary to send students overseas to work with experts on South Africa's fauna, or to bring internationally-based experts to South Africa where they could then also contribute more broadly to projects [taxonomists].
- Consider the involvement of 'citizen scientists' in exploring and documenting South Africa's biodiversity [SANBI, taxonomists, citizen scientists and relevant societies].
- Establish links with international taxonomists who can contribute to documenting South Africa's biodiversity and to capacity development where expertise does not exist locally [SANBI, taxonomists].

SO 5: A checklist of South Africa's animal species

- Establish and populate a website for dissemination of existing checklists [SANBI].
- Compile checklists for taxa where these do not yet exist using the literature and input from taxonomists nationally and globally [SANBI, taxonomists].
- Regularly update and maintain existing lists [SANBI, taxonomists].

SO 6: Compilation and co-ordination of species information

- Identify an appropriate mechanism for the co-ordination and dissemination of species pages, either through a South African website, or through the Encyclopedia of Life [SANBI].
- Provide access to species page templates and lists of species for which pages are required as a priority [SANBI].
- Initiate the compilation of pages, and disseminate these through a website as soon as they have been compiled [SANBI, taxonomists].

- Develop a process for submission of additional information, and for review and comments to continually improve the quality of information disseminated [SANBI].

SO 7: Research collections

- Hold multilateral discussions between relevant government departments to initiate a solution to the existing governance challenge [SANBI, NRF].
- Explore an open access policy for providing data to users. Mechanisms for monitoring the use of data should also be explored: showing use is critical in motivating for the investment in these resources [SANBI, SABIF, collection institutions].
- Ensure that the loss of collections is minimised. Develop strong plans that prioritise activities that are essential to securing the collections [collection institutions].

SO 8: Collecting permits for taxonomic research

- Establish a list of *bona fide* researchers that is accessible on the internet and promote this amongst conservation authorities to assist with decision-making regarding the issuing of permits [SANBI, taxonomists].
- Explore other mechanisms to streamline the permitting process to enable the exploration of South Africa's biodiversity [SANBI, permit issuing authorities].

Chapter 4
BACTERIA AND ARCHAEA

Prof. Fanus Venter (Department of Microbiology and Plant Pathology, University of Pretoria) & Janine Victor (Biosystematics Research and Biodiversity Collections, SANBI)

Grouped together, the bacteria and archaea (from here on referred to collectively as "bacteria") are the most abundant organisms on Earth, forming the largest component of the earth's biomass and genetic diversity. Bacteria play a crucial role in ecosystems, such as in nutrient cycling, primary production oxygenic photosynthesis, soil health and biodegradation. Bacteria play an essential role in animals (including humans) for digestion of food, protection against pathogens, vitamin production and disease resistance. In plants, bacteria contribute to growth promotion, nitrogen fixation, bioactive compounds and bio-control. They are also widely used in industry for food preservation and during the production of therapeutic proteins.

Only a small fraction of bacteria are pathogenic to humans, plants or animals. Of the more than 1 900 described bacterial genera (Euzeby 2013), only about 80 are known to contain human pathogenic species (Versalovic 2011). Despite the limited number of pathogenic bacterial species, they have significant economic impacts and the bulk of the available research funding is directed towards studying the systematics and epidemiology of these pathogens. Studies focusing on other environments where most of the world's bacterial diversity resides remain underfunded.

Bacteria are referred to obliquely in NEMBA, in that SANBI "may establish, maintain, protect and preserve collections of animals and micro-organisms in appropriate enclosures". This is in no way a unique situation and only indirect references to bacteria can be found in the biodiversity strategies of other countries. For example, in the Australian Biodiversity Conservation Strategy, one of the best documented and advanced strategies, the decision was taken not to focus on organisms *per se* but to rather deal with them in the context of ecosystems (Natural Resource Management Ministerial Council 2010).

Opposite: a natural hot water spring, approximately 75 × 91 m in size. Deep blue water in the centre is surrounded by mats of brilliant orange algae and bacteria. The colours vary according to the ratio of chlorophyll to carotenoid molecules produced by the organisms. During summer the organisms produce less chlorophyll, which causes the mats to appear yellow, orange and red. In winter, when sunlight is weaker and microbes produce more chlorophyll, the mats appear dark green. Source: http://en.wikipedia.org/wiki/File:Grand_prismatic_spring.jpg.

Review of current status of bacteria and archaea taxonomy

Currently there are about 12 900 formally described species of bacteria globally (Euzeby 2013), but it is estimated that there could be between 1 and 10 million species (Curtis *et al.* 2006). The prevailing hypothesis is that some bacterial species are cosmopolitan while other species or groups may be restricted to specific environments (Ramette & Tiedje 2007).

The focus of many initiatives for funding to support taxonomy has mainly been on eukaryotic organisms with little or no attention to the domains of bacteria and archaea (Woese *et al.* 1990). This has been a major criticism (Griffith 2012) as these domains represent the 'unseen majority' of life on Earth (Handelsman 2004).

One of the reasons why bacteria have often been overlooked in biodiversity programmes with a conservation focus, is the flawed perception that all bacteria are omnipresent, highly redundant and unlikely to be at risk to become extinct (Fierer 2008). This perception is strongly driven by Baas Becking's paradigm "everything is

everywhere but the environment selects" (Baas Becking 1934). However, it has been found that there is a clear sign of regional endemism for some groups of bacteria and they should be included in conservation strategies (Griffith 2012).

Implementation challenges

Nationally there is no current governmental capacity or legal framework to deal specifically with bacteria. There are currently only a small number of active South African bacteriologists (≤ 15 academics at seven universities) that have recently published studies on the taxonomy or diversity of bacteria. Bacterial systematics is not the sole focus area of any of these academics and several of them are already over 50 years of age.

Proposed biosystematics research strategy for bacteria and archaea

The proposed strategy for bacteria and archaea taxonomy aims to assess the existing capacity and resources in South Africa, propose infrastructure to collate taxonomic and associated information, identify gaps and priority areas for research, and to propose a means to achieve this.

SO 1: To document new species of bacteria that may represent a unique genetic resource for the country

As the national strategy has a strong focus on the unique biodiversity of South Africa, three niches/environments known to potentially harbour 'endemic' bacteria will form the initial focus of the programme. These niches were selected based on the potential benefit these endemic bacteria could have to society. They are:

- *Indigenous plants harbouring beneficial bacteria*: The nitrogen fixing *Burkholderia* species associated with legumes in the Cape Floristic Region have great potential as robust inoculants in acidic soils and would be able to outperform the current commercial inoculants as they would be able to cope better with the increasing temperatures as a result of climate change.
- *Indigenous invertebrates harbouring symbiotic bacteria*: Many of the symbiotic actinomycetes associated with invertebrates such as termites and mites have been shown to produce unique antibiotics that could be used to treat both bacterial and fungal infection.

- *Unique ecosystems e.g. hot springs, deserts, deep mines and traditional fermented foods*: Several unique enzymes and metabolites are excellent examples of the commercial and scientific benefit that could be obtained from the unique bacteria present in these environments.

SO 2: To provide checklists and maintain databases or links to information on bacteria of economic importance for South Africa

Human, animal and plant diseases have a large impact on the economy in South Africa and the primary focus of this objective is to create checklists of pathogenic and other economically important bacteria previously reported for South Africa. It is envisaged that these checklists will be used by the various government departments such as Department of Health and Department of Agriculture, Fisheries and Forestry for dealing with import permits and quarantine measures. It will also be of benefit to plant pathologists, pathologists in general, veterinarians and farmers.

A book capturing this information for bacterial plant diseases in South Africa already exists (Coutinho *et al.* 2009). There is a need to convert this information to a searchable and regularly updated database. Students/interns can be employed to convert this to an online database.

Various researchers in South Africa work on bacteria that produce novel secondary metabolites and/or enzymes. It would be of benefit to these researchers as well as the industries involved to have a database of South African strains able to produce beneficial compounds such as secondary metabolites, unique enzymes, pigments, antioxidants and biosurfactants.

SO 3: To create a database of relevant information and links to information that could guide identification

Many microbiologists without an interest in bacterial systematics need to identify bacteria on a regular basis. To assist these end-users of the taxonomic data, a database will be created that will provide standard operating procedures, links to important websites (e.g. RDP, All Species Living Tree project, LPSN) as well as a list of the latest references works that can be consulted (e.g. *Prokaryotes*; *Bergey's Manual*) The database will also provide information on where bacterial cultures originating from South Africa can be obtained from recognised national and international culture collections.

SO 4: To promote research investigating the impact of bacteria on biodiversity, conservation and the functioning of ecosystems

The primary aim of this programme will be to ensure that studies dealing with biodiversity and ecosystem health include a bacterial component. This will be achieved by providing information on funding opportunities, as well as the initiation of new joint research projects addressing issues such as the role of bacteria in the radiation of plant diversity or the impact of bacteria on ecosystem services and diversity.

SO 5: To establish the South African Bacterial Systematics Network: a network of researchers interested in bacterial systematics and diversity

The proposed strategy will not succeed unless the research community take responsibility for the promotion and implementation of this strategy. The proposed network will provide a forum for interaction, discussion and exchange of information. It can also assist with the co-ordination of effort to secure funding for research and the development of capacity. This forum should be linked to the existing societies such as the South African Society for Microbiology and the Southern African Society for Systematic Biology.

Paenibacillus dendritiformis colony. Image: Prof. Eshel Ben-Jacob, Tel-Aviv University, Israel. Source: Wiki Commons.

Chapter 5
FUNGI

Compiled by the South African Fungal Diversity Network[1]

Fungi comprise a unique group of organisms that occur in all habitats including soil, air, freshwater, marine sediments and on or inside the tissues of plants and animals and even other fungi. They include organisms commonly known as mushrooms, truffles, yeasts, rusts, smuts and moulds. Fungi are generally defined as being eukaryotic, heterotrophic, absorptive organisms that develop diffused, branched, tubular bodies and reproduce by means of spores (Shenoy *et al.* 2007). In addition to those organisms that clearly fit this description are others that have fungus-like properties, but that are not typical fungi.

In terms of this strategy, in addition to the organisms included in the Kingdom Fungi, the following groups that are not included in the Fungi, but which are traditionally studied by mycologists are also considered:

- *Lichens*, which are organisms representing an obligate symbiotic relationship between a fungus and a photosynthetic partner, which is usually a green algae or a cyanobacteria. Lichens occur in many habitats and have potential as indicators of air pollution, ozone depletion and toxic contamination.
- *Slime moulds*, a group comprising three major groups, plasmodial slime moulds, cellular slime moulds and protostelids (amoebae producing spores). Slime moulds usually exist as single-celled organisms (amoebae-like), but the cells can congregate and function as a single body to produce spores. They contribute to the decomposition of dead vegetation, and feed on bacteria, yeasts, and fungi.
- *Stramenophiles* are eukaryotes that comprise two major groups, the algae and colourless, fungus-like taxa. The algae are dealt with separately in another section of this strategy, but the other colourless, more fungus-like groups include taxa of economic and conservation importance, such as the late blight organism (*Phytophthora infestans*) responsible for the Irish famine and still causing major crop losses internationally, the related jarah dieback organism (*Phytophthora cinnamomi*) responsible for serious epidemics of both natural vegetation and

[1] This strategy was developed based on input from a workshop held at SANBI, Pretoria on 31 January 2013. Participants: Prof. K. Jacobs (Stellenbosch University), Prof. J. Dames (Rhodes University), Prof. E. Steenkamp, Dr W. de Beer, Dr S. Marincowitz (FABI, University of Pretoria), Dr M. Gryzenhout, Prof. G. Marais (University of Free State), Prof. J. Coetzee (Cape Peninsula University of Technology), Dr I. Rong, Dr A. Jacobs (ARC, PPRI), Ms J. Victor, and Prof. M. Hamer (SANBI). Additional input has been received from Dr A. Wood (ARC, PPRI) and Dr H. Vismer (MRC, Promec Unit).

tree crops internationally, and several groups that are parasitic on a range of animals and plants.

Fungi are critically important; most are terrestrial organisms that are symbionts of most plants, recyclers of nutrients and minerals, pathogens of plants and animals, bio-control agents, food sources for humans and other animals, and some are a source of valuable chemical products used in industries such as pharmaceuticals, biofuels, and food and beverage processing (Global Biodiversity Sub-Committee (GBSC) 2007).

Despite their importance, fungi are usually overlooked in biodiversity and taxonomy initiatives and activities, and they are not well known amongst scientists in general and, apart from those groups that are commonly used as food, by the general public. The main reason for this is that many fungi are microscopic and/or occur in habitats where they are not easily seen, such as in the tissues of other organisms or in the soil.

Based on the commonly-cited estimate of 1,5 million fungal species, only 100 000 are described and at the current rate of species description, it should take another 1 170 years to complete the global fungal inventory (Hibbet *et al.* 2011). With the declining capacity to document and describe the world's fungi, achievement of this aim is even less feasible.

When fungi are active in the environment, they consist of a mass of filaments (mycelium) of such extremely simple forms that it is impossible to identify to which species it belongs using what can be seen with the naked eye. The reproductive structures observed on the host material or on synthetic media have formed the basis of fungal classification, but these provide only a limited number of characters. Currently the integrated approach for fungal classification incorporates these morphological characters as well as phylogenetic relatedness amongst species based on gene sequences.

Review of current status of fungal systematics in South Africa

The South African indigenous fungi have generally been neglected by taxonomists. Better studied fungi include phytopathogens, especially on commercial crops, medically important fungi, mycotoxin-producing fungi and food-associated fungi. Poorly studied fungi include those associated with indigenous plants, soil fungi, especially mycorrhizal fungi (those associated with the roots of vascular plants), airborne fungi that may be important in human health, insect-associated fungi, freshwater and marine fungi and fungi in extreme environments.

Crous *et al.* (2006) stated that very few habitats and ecological niches in South Africa have been explored in terms of fungi. They estimated, based on the general trend in ratio of plant to fungi species of 1:7, that the number of fungi species nationally could be at least 171 000 species, a number which excludes the species associated with insects and many other ecological niches. Given the conservative predicted number of species, it is staggering that only 780 new species of fungi have been described from South Africa (Crous *et al*. 2006). This is probably a result of the indigenous fungal diversity not being considered as a research priority and virtually all resources, especially over the last 50 years, having been directed towards economically important species in South Africa. The origin of many of these species is unknown.

The number of researchers in South Africa who are actively working on fungal taxonomy, which includes documenting and describing species, is very small and comprises about 20 individuals. Not all of these researchers devote all their time to this type of taxonomy, and most of them are also involved in other aspects of research on fungal biology or evolution. There is only one researcher based at an institution overseas who makes a major contribution to documenting fungal diversity in South Africa.

Most of the researchers are based at universities, with two active research groups outside such institutions (at the National Collections of Fungi at the Plant Protection Research Institute (PPRI) of the Agricultural Research Council (ARC) and the PROMEC Unit of the Medical Research Council). A major constraint in terms of increasing capacity for fungal taxonomy is the lack of job opportunities, which means that it is difficult to encourage even those interested in the discipline to focus studies in this area. During 2012, about eight postgraduates who were studying fungi were including aspects of taxonomy in their projects.

There are a number of global databases that co-ordinate taxonomic information, particularly classification, nomenclatural changes and description of new taxa for fungi. Two gaps in the existing data have been identified: (i) the need to update host plant names, and (ii) co-ordinated biological information for species. There is currently no online taxonomic resource for South African fungi.

Given the enormous gaps in knowledge about South African fungi, and the very limited available resources in terms of capacity and funding to research these organisms, the objectives of this strategy focus on what can be achieved and which activities are most critical. Prioritising specific taxa for study is not necessary as groups of economic relevance are already prioritised by employers and research funders.

The main challenges for fungal taxonomy are as follows:

- Lack of job opportunities for postgraduates trained in fungal taxonomy.
- Fragmentation and lack of collaboration between researchers in South Africa.
- Lack of awareness and appreciation of fungal diversity and the importance of fungi in ecosystems and the economy amongst the public, funding agencies, and scientific institutions.
- Lack of opportunities (time, funding, projects) to explore, document and describe indigenous fungi.

While having appropriate capacity for both taxonomic research and collections management is critical, the lack of available posts for specialists in these fields means that it would not be strategic to attempt to increase current efforts to develop capacity. An adequate number of postgraduate students are currently being trained relative to opportunities for employment and so no specific objective is required at this stage. The situation will need to be reviewed in the future.

Vision for the fungal taxonomy strategy

To facilitate, co-ordinate and promote (i) the exploration and documentation of fungal diversity, (ii) collections, and (iii) awareness of fungal diversity and relevance in South Africa

Strategic objectives

SO 1: Increase communication and interaction between fungal taxonomists to promote collaboration, especially in terms of exploring South African fungi, and to ensure that fungal diversity and taxonomy are represented in relevant biodiversity forums and decision-making processes and are part of broader biodiversity initiatives.

SO 2: Increase the profile of fungal taxonomy by including fungi in a national checklist of South African biodiversity, provision of relevant priority species information for open dissemination, and in the International Barcode of Life project.

SO 3: Increase representation across taxa in collections and ensure long-term security of material and data and provide access to this.

Activities to achieve strategic objectives:

SO 1: Networking and communication

- Establish a South African Fungal Diversity Network.
- Develop a list server that enables members of the network to provide information on research being done, field trips, material for sharing, funding and collaboration opportunities, and new findings.
- Organise regular meetings to promote interactions and identify key activities and opportunities.
- Represent the fungal taxonomy community on relevant committees or at forums dealing with biodiversity/taxonomy/collections.

SO 3: National collections

- Circulate a statement that promotes the National Collections as the recognised national facility for both preserved and culture fungal collections to ensure that unused material, student material and collections at risk are deposited and secured.
- Develop a set of standards and requirements for material to be deposited and vouchered in the National Collections and promote this amongst researchers.
- Formalise the arrangements for establishing a mycorrhizal collection at Rhodes University that will eventually be deposited in the National Collections.

- Track South African material vouchered in overseas institutions and link these to publications.

A long-term objective should be to expand the National Collections of Fungi under the custodianship of the ARC to establish a centre for fungal diversity exploration. This type of facility is essential to developing a better understanding of fungi in South Africa within a reasonable timeframe, but it would require considerable resources that would be difficult to access at this stage. Over the next five years, the strategy should be to explore possible mechanisms for developing such a centre.

Chapter 6
PLANTS

Janine Victor (Biosystematics Research and Biodiversity Collections, SANBI)

Most plant taxonomic research aims towards revisions of taxonomic groups, or other similar compilations (such as conspectuses, Floras, synopses and monographs). These products provide answers to the questions as to what a plant is, what it looks like, and where it grows. Another primary objective of taxonomy is to develop a natural and predictive classification system that reflects evolutionary relationships among plants. To achieve this, results from molecular studies are integrated with other sources such as anatomical, cytological, cytogenetic, and palynological studies.

Bringing together the needs of end-users and current trends in plant taxonomic research, in conjunction with gaps in taxonomic knowledge, informs the priority areas for taxonomic research in South Africa. These focal points form the strategic objectives that are required and determine which research programmes should be established. In addition, the way in which research is conducted can be enhanced so as to add value to the outputs, ensuring that they are not only relevant to scientific end-users but also have impact on and benefit to society.

Review of current status of plant taxonomy in South Africa

Botanical exploration of South Africa started early in the 17th century and there is an extensive amount of literature available, including many Floras and revisions published in a diverse array of journals and books. There are *ca.* 20 000 indigenous and naturalised plant species in South Africa. Major plant collections (i.e. more than 100 000 specimens) are housed in eight herbaria throughout the country, the largest of which is SANBI's National Herbarium with approximately 1 200 000 specimens. There are an additional 24 smaller local herbaria in the country (Smith *et al.* 1999). SANBI is therefore the major employer of plant taxonomists at its three herbaria in the country, with a staff component of approximately 35 technical staff and scientists curating the collections and some doing research. There are also about 20 plant taxonomists at universities around the country, who teach taxonomy and supervise the few postgraduate students that specialise in taxonomic research. SANBI also has a comprehensive database, which is able to provide information such as the national checklist, checklists of any region or families, or of historical collections from particular areas. Some of this information is available online (www.sanbi.org.za) and other information is available on request from SANBI.

Vision for the plant research strategy

To document and provide predictive classifications for South African plant species, enabling users to identify and access knowledge about them, so that all can understand, conserve and benefit from biodiversity.

SANBI's specimen database with collection information for over 1.1 million plant specimens was interrogated using 'indicators' to reveal problematic plant groups and

thus possible gaps in taxonomic knowledge. These were used to inform where priority research activities should be aimed.

Strategic objectives and programmes of the strategy

The strategic objectives for the Biosystematics Research Strategy for plants are to:

SO 1: Produce an online electronic flora (e-Flora) of South African plants by 2020.

SO 2: Revise genera that are in need of revision.

SO 3: Resolve isolated taxonomic problems in species of conservation importance.

Activities required to achieve the strategic objectives

SO 1: e-Flora of South Africa

Produce family treatises for those families that have not yet been completed

Family treatments (such as Floras) of certain groups that are difficult to identify are of particular importance and should be prioritised, as well as those with taxonomic problems (Victor & Smith 2011) (Figure 1) and those that have not been treated.

Complete all regional floras for South Africa by 2018.

Completion of the regional floras by SANBI staff by March 2018, which would cover the entire country, is a high priority.

Produce an e-Flora for South African plants by 2020

It is proposed that an online Flora of South African plants can be achieved using existing species descriptions, in particular those that are available in recently published and forthcoming floras (family treatises or regional floras). Descriptions that are not published in family-level treatments or generic revisions can be extracted from regional Floras published by SANBI which will have covered the entire country by 2018. The e-Flora will be linked to the national plant checklist, and should have species descriptions and images for every species, as well as keys.

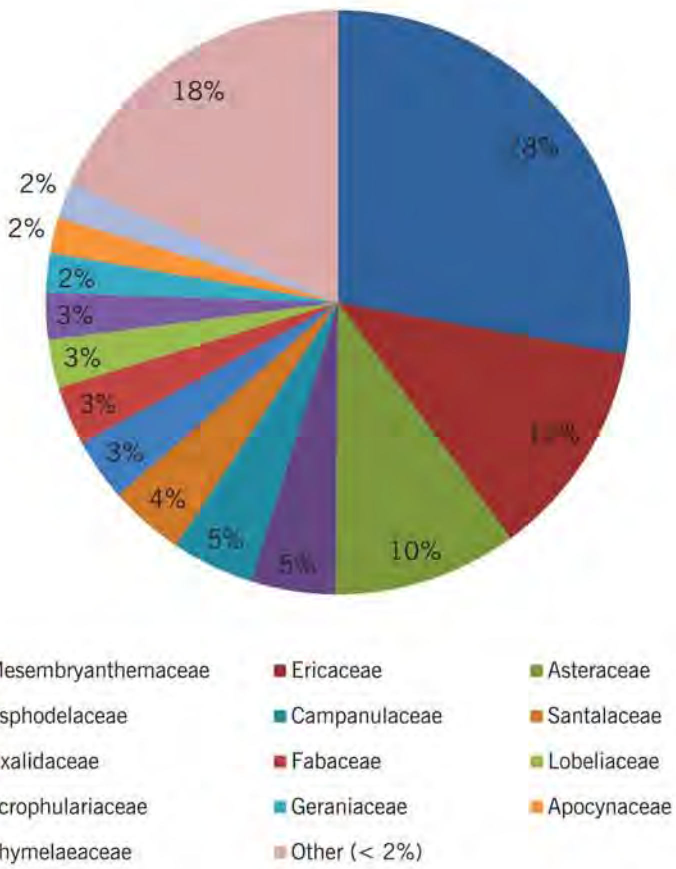


Figure 1.—Proportion of species per family that are Data Deficient for taxonomic reasons.

SO 2: Revisions of plant genera

There are approximately 931 currently recognised genera of indigenous plant species in South Africa. Compilation of the Red List was heavily reliant on taxonomic information such as from revisions (Raimondo *et al.* 2009), and in many cases lack of recent revisions was an obstacle to assessing the extinction risk faced by these taxa. Researching plant genera that are in need of revision, especially those that are of conservation or economic importance, will have a positive impact on conservation and the economy. This research includes discovering (inventorying and documenting) our flora.

Five criteria were considered to be indicators of plant genera in need of revision:

1. Date of last revision of the genus.
2. Proportion of plant species in each genus that are categorised as Data Deficient.
3. Proportion of unidentified specimens in each genus.
4. Economic importance of the family to which the genus belongs.
5. Proportion of species in genus occurring in South Africa.
6. From this analysis, a list of plant genera categorised according to their priority for revision was developed for angiosperms, gymnosperms and pteridophytes. Sufficient data are lacking to do a similar analysis for bryophytes. However, certain bryophyte families are treated as priorities in Programme 1.

SO 3: Data Deficient Plant Programme

The process of assessing the Red List status of plant species is often hindered because of uncertainties in taxonomic status of the taxon. There are over 1 000 of the plant taxa that are possibly threatened with extinction that have taxonomic problems.

These species are listed as Data Deficient for taxonomic reasons (DDT) and are regarded as priorities for taxonomic research efforts (Victor & Smith 2011) to assist conservation authorities to channel limited financial resources on efforts to protect such species.

The aim of this programme is to solve isolated problems targeting single species of conservation importance in genera that are otherwise not in need of revision and where the species are potentially threatened. Taxonomic problems impede the determination of conservation status of these species, and the species can therefore not receive conservation attention.

There are 272 taxonomically problematic taxa that are not covered by revisions, which constitute the priority list for this programme. Allowance is made for the possibility that resolving taxonomically problematic species listed under this programme may necessitate revising the genus to which it belongs.

Chapter 7
CONCLUSIONS

Priority objectives and actions across taxa

1. An online and updated taxonomic checklist of South Africa's biodiversity [algae, animals, bacteria and archaea and fungi].
2. An online platform for species information linked to literature and specimen data [all taxa].
3. An online resource for the identification of priority species [algae, animals and bacteria]
4. The establishment of networks of experts to promote (i) information sharing, (ii) collaboration and (iii) the importance of taxonomic research and data [bacteria and fungi].


Cultivation of seaweed for harvesting.

Constraints and considerations relating to the implementation of the Biosystematics Research Strategy

While SANBI is mandated with the "co-ordination and promotion of taxonomy in South Africa", its resources remain under pressure and further budget expansion would be required to adequately address the needs of the taxonomy of all biota. In addition, SANBI does not provide funding nationally for taxonomic research which remains a constraint. The new Department of Science & Technology programme for Foundational Biodiversity Information is a potential source of funds, but the objectives and focus of this programme may exclude some priorities included in this document. The broader National Biodiversity Research Strategy includes an objective on taxonomy, but funding for this strategy's implementation requires clarity.

In summary, points raised by the different individuals and groups who worked or commented on components of the Biosystematics Research Strategy highlighted the following considerations:

- SANBI's focus is on plants, but there is a need for a co-ordinating body for other taxa.
- Funding to support the implementation of many of the objectives.
- Shortage of capacity to carry out many of the activities identified, with many experts also having other research interests and responsibilities.
- The need for all taxonomists to buy into the objectives and use the strategy to guide the actions, approaches and research work.

Chapter 8
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APPENDIX 7: Strategy for biosystematics research in South Africa: overview of the plant systematics component

Strategy for biosystematics research in South Africa: overview of the plant systematics component

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ABSTRACT

A strategy has been developed by the South African National Biodiversity Institute (SANBI) to provide guidance to institutions and individual researchers that are involved in biosystematics research on the South African flora.

Users of taxonomic information require the names, descriptions of species and identification tools such as keys, along with information on distributions and habitats, various plant properties and evolutionary relationships. The basis of this information is provided via taxonomic research mainly at species level, which has battled to attract sufficient funding in the last few decades.

A prioritisation process was used as guideline for establishing taxonomic research priorities. Such a process is an effective way to clearly justify the use of resources (either derived from funding agencies or taxpayers) to carry out biosystematics research.

INTRODUCTION

Biosystematics research, which for our purposes includes the science of taxonomy and classification, underpins all biodiversity studies and involves discovering, naming, describing and classifying biological organisms. The importance of taxonomy as a vital discipline for all other fields of biological science is undisputed (Ebach et al. 2011).

Taxonomic research in South Africa has historically been driven by curiosity in the rich and diverse flora that develops through the course of exploration and curatorial work and by personal motivation to investigate groups of interest, in which problems are uncovered and investigated. The disadvantage of this approach is that the value of the results can be underestimated or remain unrecognised, and sometimes urgent taxonomic problems in neglected groups remain unresolved. Biosystematics research would benefit from having a coordinated strategy to address the needs of end users of plant names in a strategic manner, to improve the relevance and impact of research products that are delivered.

The three major resources required by users of plant names are an inventory of the flora of a geographical region or political area; a means to identify the taxa, i.e. descriptions of species and keys; and an inventory of specimen records in the area, from which information about the plants can be collated. These three requirements drive the prioritisation process for the research that is required to improve, complete and disseminate these products.

METHODS

The Biosystematics Research Strategy of the South African National Biodiversity Institute (SANBI) was developed around the three main outputs that taxonomists are responsible for:

1. the inventories (checklist) of the flora for the country,
2. descriptions of taxa and a means to identify them (e.g. keys),
3. and for each taxon, a compilation of associated data e.g. spatial distribution information, herbarium specimen data, and possibly data from fields such as morphology, anatomy, cytology, genetics, cytogenetics, chemistry and molecular biology.

These outputs require taxonomic information derived from research mainly at three different levels: family, genus and species/subspecies/variety level. Gaps in information at these levels provide guidance as to where research should be directed.

1. Family level

Victor & Smith (2011) prioritised which plant groups should receive focused taxonomic research attention by identifying families with a high incidence of taxonomic problems. In addition to this, those with outdated treatments should be prioritised. Treatments of large families that are understudied, particularly those with taxa that present challenges to identify in a herbarium, are of particular importance and should be prioritised.

The South African plant checklist, compiled by generations of SANBI's plant taxonomists and lodged on the SANBI website (http://www.sanbi.org/information), will constitute the backbone of an online electronic Flora of South Africa (e-Flora). Prioritisation of the families requiring treatments will contribute towards filling gaps in information required to populate the e-Flora.

2. Genus level

The following criteria were used to prioritise plant genera requiring taxonomic research: date on which genus was last revised; quality of revision (relying on specialist input to refine the genus-rank inventory); proportion of unidentified specimens in each genus in herbaria collections; proportion of plant species in each genus that is categorised as Data Deficient (IUCN 2001) for taxonomic reasons (DDT according to Victor 2006); economic importance of the family to which the genus belongs; and proportion of species in the genus occurring in South Africa.

More details on the procedure followed, as well as the algorithm employed to do the ranking of genera, are available on request from the first author.

3. Species level

Prioritising research on families and genera can overlook single species of conservation or economic importance in genera that are otherwise not in need of revision. Taxonomic uncertainties impede the determination of the conservation status of these species, and the species can therefore escape conservation attention. Species that are categorised as DDT but are not covered by the prioritisation process for families and genera are prioritised here.

The gaps in taxonomic knowledge on families, genera and species were used to inform where the priority research activities should be directed in the next five years.

RESULTS

In summary, the strategic objectives for the Biosystematics Research Strategy for plants are to:

1. produce an online Flora of South African plants by 2020;
2. revise priority plant genera that are in need of revision; and
3. resolve isolated taxonomic problems to improve the inventory.

These strategic objectives are the basis of three proposed research programmes.

Programme 1: e-Flora

Programme 1 addresses the first strategic objective, namely, to produce an e-Flora for South Africa by 2020. This will contribute to the World Flora Online, the first target of the Global Strategy for Plant Conservation (GSPC), following the approach published by Victor et al. (2013b).

The key tasks of Programme 1 are to:

1. maintain or develop research capacity in priority families;
2. produce family treatises for those families and geographical areas of South Africa that have not yet been completed; and
3. provide content for an online Flora for South African plants by 2020.

Programme 2: Revisions of plant genera

The strategic objective addressed by programme 2 is to revise plant genera that are most in need of revision, which will contribute to filling gaps in the knowledge of South Africa's flora.

From analyses of literature and SANBI herbarium specimen database information, a list of plant genera categorised according to their priority for revision was developed and circulated widely amongst biosystematics researchers in the country. The list of priority genera can be accessed on the SANBI website (http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies). This list will be updated regularly, and used to track progress to reflect the value of having a strategy in place.

Programme 3: Data Deficient Plant Programme

The aim of this programme is to solve isolated problems targeting taxonomically problematic species that are not targeted by Programmes 1 and 2, especially those of conservation or economic importance. This list of species identified to be taxonomically problematic will be made available on the SANBI website (www.sanbi.org.za). It is also recognised that resolving taxonomically problematic species listed under this programme may necessitate revising the genus to which it belongs.

CONCLUSIONS

An analysis of gaps in taxonomic knowledge has enabled the establishment of three strategic objectives, and three research programmes that will address these objectives. Within SANBI, existing capacity will be utilised towards addressing the priorities of the Biosystematics Research Strategy for its plant systematics component. It needs to be acknowledged that a considerable amount of biodiversity research on the South African flora is conducted outside SANBI, and outside South Africa, notably at institutions such as universities and museums, as well as by amateur/private taxonomists and naturalists. Higher education institutions such as universities are also responsible for the training of future taxonomists. Hence the strategy will be made available on the internet to be consulted by all potential stakeholders, and circulated to funding agencies so that funding towards these research priorities can be stimulated.

The benefits of a strategy for plant systematics are that it leads biosystematics research in South Africa by providing guidelines for research priorities; communicates the value of taxonomic research to the public, academic institutions and funding agencies; makes the most strategic use of limited time and resources; guides future decisions on capacity development, staff recruitment and training; stimulates dissemination of priority taxonomic information to end users; and provides a shared vision to guide research. This strategy will be updated regularly and act as a resource to stimulate interest in the research strategy, in this way coordinating biosystematics research on South African Flora.

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APPENDIX 8: Strategy for plant taxonomic research in South Africa 2015–2020*

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Strategy for plant taxonomic research in South Africa 2015–2020

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Abstract

The National Environmental Management: Biodiversity Act (NEMBA) No. 10 of 2004: Section 11 gives SANBI the mandate for leadership in South African biosystematics through coordination and promotion of taxonomy. This strategy for the plant taxonomic component of biosystematics research in the country will therefore provide guidance to South African institutions that are involved in this field of scientific endeavour. A coordinated strategy for plant taxonomic research that addresses the needs of end users will improve the relevance and impact of research products.

The end users of the products of taxonomic research comprise all users of plant names in scientific, commercial, policy-making, educational, and civil society spheres. Their requirements include the names and descriptions of species, along with information on diagnostic characters, distributions and habitats, properties (including use by wildlife and humans) and evolutionary relationships. The basis of this information is provided via alpha-taxonomic research, which has battled to attract funding in the last few decades. Global trends towards electronic publication of taxonomic data and databases and the use of innovative technologies for identifying species facilitates the dissemination of taxonomic information to end users.

Capacity and resources (financial and otherwise) available for conducting taxonomic research in South Africa are discussed and suggestions made. Three research programmes are

proposed to focus on the main gaps in taxonomic knowledge, namely, the e-Flora programme, the revisions of plant genera programme, and the Data Deficient plant programme; and a plant collecting programme is suggested to improve coverage of taxa and geographical areas in South Africa in terms of herbarium collections. These programmes cover the strategic objectives identified, addressing priority areas of research and aiming to produce the most useful products for end users. The importance of good data quality for end users is emphasised.

Introduction

The *Strategy for plant taxonomic research in South Africa 2015–2020* (hereinafter referred to as the Strategy) forms part of the *Biosystematics research strategy for South Africa* (Victor et al. 2013). Biosystematics research, which includes the science of taxonomy and classification, underpins biodiversity studies and involves discovering, naming, describing and classifying biological organisms. In this document, the term taxonomy is used in a broad sense and therefore includes systematics, which is the organisation and classification including investigation of the causes and processes of evolution and the study of phylogeny (Stuessy et al. 2014).

The mandate of the South African National Biodiversity Institute (SANBI), which comes from the National Environmental Management: Biodiversity Act No. 10 of 2004: Section 11, includes responsibilities to:

d) coordinate and promote the taxonomy of South Africa's biodiversity;

e) collect, generate, process, coordinate and disseminate information about biodiversity; and

f) undertake and promote research on indigenous biodiversity.

This document partly fulfils SANBI's mandate by providing a coordinated framework for plant taxonomic research that will be implemented within SANBI and promoted among other institutions and funding agencies. By coordinating and promoting plant taxonomic research throughout South Africa, this Strategy provides leadership in this regard.

Purpose of the Strategy

The Flora of southern Africa (FSA) region (South Africa, Namibia, Botswana, Lesotho and Swaziland) has the richest temperate flora in the world with approximately 22 000 species described to date, harbouring about 10 percent of the world's vascular plant flora in conjunction with extremely high levels of endemism, and three of Conservation International's global biodiversity Hotspots (Mittermeier et al. 2004). The bulk of this diversity (> 20 000 species) is found within South Africa, an estimated 57% of which is endemic to the country (Germishuizen et al. 2006). Taxonomic research has historically been driven by curiosity in the rich and diverse flora that develops through the normal course of exploration and curatorial work, and by personal motivation to investigate groups of interest, in which problems are uncovered and investigated. The disadvantage of this approach is that the real value of the results can be underestimated or remain unrecognised, and sometimes urgent problems remain unresolved. Taxonomic research would benefit from having a coordinated strategy to address the needs of end users in a strategic manner, to improve the relevance and impact of research products that are delivered.

As a government institution, SANBI is funded predominantly by the taxpayers of South Africa, thus its policies and strategies should ultimately stand in the service of society. The development of a strategy to promote and channel plant taxonomic research extends much more widely than the institution itself. It needs to be acknowledged that a considerable amount of biodiversity research on the South African biota is conducted outside SANBI, notably at institutions such as universities and museums, as well as by amateur/private taxonomists and naturalists. Tertiary institutions such as universities are also responsible for the training of the human capital eventually employed by SANBI. On the other hand SANBI, with its regional network of herbaria, botanical gardens and most comprehensive plant collections for southern Africa globally, is an indispensable resource to be consulted by anybody studying the botanical diversity of the region. Hence this Strategy will be circulated and available to taxonomic researchers at universities, as well as be made accessible on the internet to be consulted by all potential stakeholders. In so doing it is also deliberately aimed at stimulating the involvement by people from outside SANBI, and to encourage them to focus on the same priorities. In addition, a list of taxonomic expertise and projects has been made available online at http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies, with the intention of facilitating the coordination of taxonomic research in South Africa. The Strategy will also be circulated to funding agencies so that funding towards the identified priority research programmes can be stimulated. SANBI also encourages taxonomic researchers from outside the organisation to make use of its extensive herbarium and living plant collections, as well as excellent library resources.

The benefits of a strategy for plant taxonomic research are that it provides guidelines for research priorities; communicates the value of taxonomic research to the public, academic institutions and funding agencies; makes the most strategic use of limited time and resources; guides future decisions on capacity development, staff recruitment and training; stimulates the dissemination of priority taxonomic information to end users; and provides a shared vision to guide research. The vision of the Strategy is to document and provide predictive classifications for South African plant species, enabling users to identify and access knowledge about them, so that all can understand, conserve and benefit from biodiversity. This document addresses primarily the plant taxonomic research in South Africa, but includes discussions on herbarium collections and associated data, capacity for conducting research, and implementation of the Strategy. These topics are addressed in more detail in Victor (2015). During the development of this Strategy, the authors consulted taxonomists from most universities of South Africa, as well as abroad (Royal Botanic Gardens Kew, Missouri Botanical Garden, and University of Zurich), to share, and where appropriate, incorporate views beneficial to Strategy development and implementation in South Africa.

Development of the Strategy

Botanical exploration of South Africa started early in the 17th century (Gunn & Codd 1981). Based on extensive collections of Cape plants, the *Flora capensis* was established in 1860 by Harvey and Sonder, and the final volume was published in 1933. Active taxonomic research, including the production of Floras, has continued since then. Despite an extensive body of literature on the South African flora, gaps still exist. The first step for prioritising taxonomic research was therefore to evaluate what has been done and what is most urgently required.

Until 2013, the National Herbarium, Pretoria (PRE) Computerised Information System (PRECIS) documented the primary collection data of most plant specimens housed in the three SANBI herbaria (National Herbarium, Compton Herbarium and KwaZulu-Natal Herbarium), with collection information for more than 1.2 million plant specimens. This database was interrogated using ‘indicators’ (Victor et al. 2015) to reveal problematic plant groups and thus possible gaps in taxonomic knowledge. These gaps were used to inform where the priority research activities should be aimed until 2020, taking into consideration the current trends in taxonomic research within South Africa and internationally. The Strategy will be reassessed every five years.

Needs analysis

An extensive list of end users of taxonomic research products and the type of information they could require was compiled by Morin et al. (1988). A notable omission from this list is botanical researchers, comprising all disciplines that require plant material for their research.

Current end users of SANBI herbaria were investigated to add to identifying the end users of taxonomic research and their needs. Virtually all herbaria throughout South Africa are resources for the public requiring identification of plants, and many herbaria offer such a service for a broad spectrum of users. Analysis of the records of specimens submitted for identification to the three SANBI herbaria shows that the most frequent users of this service are (in no particular order):

- university researchers and students;
- other, non-SANBI herbaria;
- environmental consultants;
- members of the public;
- Agricultural Research Council (especially veterinary institutes) of the Department of Agriculture of the South African government;
- Council for Scientific and Industrial Research of the Department of Science and Technology of the South African government;
- natural history museums (national and international);
- local interest groups e.g. the Botanical Society of South Africa;
- commercial plant nurseries and garden centres;
- conservation agencies e.g. South African National Parks, South African provincial nature conservation bodies; and

- non-biosystematics SANBI staff e.g. Millennium Seed Bank project; Invasive Aliens Early Detection and Rapid Response Programme; Threatened Species Programme; and horticulturalists.

Requests for data addressed to SANBI herbaria include information such as species lists for geographical areas, and distributions of species. In order of frequency these clients are: taxonomists from SANBI herbaria; researchers at universities; scientists from other SANBI divisions; environmental decision makers (e.g. consultants); environmental policy makers; conservationists; veterinarians and agronomists (P. Winter, pers. comm.). These end users all require accurate taxonomic information and data derived from herbarium specimens and their associated labels to enable correct recommendations on, for example, proposed land use, and informed decisions that take occurrence of threatened taxa into account.

Identification of stakeholder needs was necessary to establish important directions for research activities. Accurate and reliable scientific information about plant and animal species is becoming increasingly important in South Africa as economic development puts pressure on sustainable use of natural resources. The basis for that information is taxonomy (West 1996). Standard information provided by taxonomists includes names, descriptions, distribution and habitat information and evolutionary relationships; but additional information such as unique properties, ecology, pollination syndrome and conservation information is often gathered.

In 2002, a national workshop for stakeholders and end users of botanical information and herbaria was held at the National Herbarium of SANBI (Steenkamp & Smith 2002). One of the objectives of the workshop was to determine the kind of botanical information needed by user groups, along with setting priorities associated with providing this information. The workshop was attended by 34 stakeholders and end users from agricultural institutions, botanical societies, conservation agencies, environmental consultants, ethnobotanists, universities, and others. The five most important requirements determined as a result of this workshop, in descending order of priority, were:

- updated, accurate checklists for all South African plant species;
- species lists for specified geographical areas enriched with additional information such as Red List status or residential status (e.g. aliens);

- a centralised information database system with all associated information on the plants that is factually accurate and freely accessible to all;
- fully representative herbarium collections; and
- an efficient and affordable plant identification system.

A review of enquiries, data requests, visitors and services requested from SANBI's herbaria from 2010 to 2014 shows that there is still continuous pressure on herbarium staff for these activities to be prioritised, and the results of the workshop conducted in 2002 remain current. These requirements largely depend on accurate specimen identifications, which in turn rely on precise species demarcations and comprehensive information that are generated through taxonomic research. Taxonomic researchers are well placed to provide this information to enable the work in virtually all other fields of biological endeavour, such as to assist conservationists to assess the extinction risk of the species, and to determine how to manage them.

South Africa's exceptionally rich and diverse flora faces challenges in terms of management and conservation. Careful planning, sufficient human capacity and resources, and efficient use of capacity and resources are required to ensure that the demands of these tasks are appropriately and comprehensively met. The capacity as at December 2014 for conducting taxonomic research in South Africa was assessed to determine whether there are sufficient resources in terms of: (1) human capacity, (2) research material and (3) financial and other resources, to implement and monitor a strategy for plant taxonomic research in South Africa in the future. This enabled identification of shortages of capacity or resources that might prove to be an obstacle in implementing the Strategy.

Human capacity for plant taxonomic research in South Africa

There are approximately 35 professional plant taxonomists employed in academic posts as lecturers and/or researchers in South Africa, of which 19 are at SANBI and 16 at universities. In addition to taxonomic researchers, there are many trained taxonomists employed as herbarium curators or technical support staff, both at SANBI and at universities; at least five of these staff members conduct research as well. At least nine people who are not employed as plant taxonomists, conduct plant taxonomic research; in addition at least 13 retired professionals actively contributed to taxonomic research in the past five years.

Few plant taxonomists employed in South Africa will retire from formal employment within the next five years, and more than half of the plant taxonomists in the workforce are under the age of 50. The main obstacle to maintaining or increasing capacity at SANBI and other government-funded institutions such as universities and museums, is the Employment Equity Act, number 55 of 1998 which discourages recruitment of researchers from the white population group. In the past five years, six plant taxonomist scientist posts have been advertised at SANBI's three herbaria, and it was possible to fill only two of these with candidates meeting the Employment Equity targets.

Current state of taxonomic research

The main sources of information for plants are family treatises, geographical Floras and taxonomic revisions of genera. For species level information, various internet web pages provide information on species, particularly if they are of horticultural or economic value. At genus level research is usually published in the form of revisions of genera. A compilation of all taxonomic revisions for South African plant genera for this study reveals that there are 50 genera that were last revised prior to 1900, and of these, 16 genera (mostly of the Aizoaceae/Mesembryanthemaceae) have never been revised. Family-scale treatments have often been done by production of a conspectus or Flora-style fascicle. The Flora of southern Africa project was initiated in 1955 aiming to produce family treatises for the 180 angiosperm families in South Africa, Botswana, Lesotho, Swaziland and Namibia. Progress with the FSA project was not as rapid as expected, and after 40 years only about 18% of the taxa had been treated. A decision to de-emphasise the FSA in favour of publishing manuscripts in SANBIs in-house journal, *Bothalia*, under the banner of 'FSA contributions' was taken in 1995. Although the FSA project does not currently exist as a formal project, volumes may still be published in future in *Strelitzia*, an in-house journal of SANBI. Additional major sources of taxonomic information for southern Africa have been published in *Strelitzia*. A series of regional Floras have been published or are still in progress, with the eventual aim of providing coverage of the whole country. Floras for the northern provinces (comprising Gauteng, Limpopo, Mpumalanga and North-West and covering over 5 700 species), Western Cape and parts of the Northern and Eastern Cape ('Core Cape Subregion' covering approximately 9 200 species and 'Extra Cape Subregion' covering about 3 700 species) have recently been completed (Retief & Herman, 1997; Manning & Goldblatt 2013; Snijman 2013); and those for Free State (almost 3 000 species) and Eastern Cape (over 7 300 species) have been completed and submitted for publication. A volume on the remaining parts of the Northern Cape is in preparation, covering an estimated 3 200 species, and will be submitted for publication in 2016. Once the Flora of KwaZulu-Natal is completed, these regional treatises will cover the flora of the entire country.

Trends in plant taxonomic research

According to Von Staden et al. (2013) there has been a decline in revisionary output by taxonomists. An assessment was conducted to determine whether this corresponds with lowered productivity of taxonomists, using number of new taxa of South African plants described per year as an indicator (Victor 2015). Results showed that the number of new taxa described over the past 34 years by South African and international botanists fluctuates overall but has not declined; however the number of new taxa described as part of a revision has declined with a corresponding increase in number published in stand-alone papers or as part of a revision of a small group of species (Victor 2015). From these data we can infer that the number of revisions being published has declined, which is supported by the survey by Von Staden et al. (2013).

The decline in revisionary output corresponds with an increase in the number of species described in stand-alone publications as well as an increase in numbers of papers in molecular phylogeny being published. Fragmentation of publications into units describing new taxa or revising small sections of a genus enables the information to be available for use in checklists and by end users much faster than working for years to consolidate everything and publish it when the revision is complete. An electronic means of dissemination, such as a single-portal online Flora, would solve the problem of fragmentation and enable all published literature to be available in a consolidated source immediately.

Research programmes should not place too much emphasis on the production of Floras, as revising plant genera or sections thereof may be a more effective and more rapid way of solving taxonomic problems and identifying potential new species. Flora-style contributions of plant families are useful for consolidating what is known but may not be an immediate priority. As is often the case globally, consolidation of information into Flora-style products can be done concurrently or after the primary research is conducted and published.

Although the conclusions reached by Von Staden et al. (2013) that taxonomic output in terms of 'revisions' has declined is supported, this cannot be extrapolated to taxonomic research output as a whole but rather to changes in emphasis of research topic. An analysis of the output by taxonomic researchers in terms of numbers of papers published in ISI-rated journals (Victor 2015) shows that there is potential capacity to conduct and publish taxonomic research, although much of the research output effort is not spent on taxonomic research.

The needs of most end users are for information of a microtaxonomic nature, but molecular phylogenetic work supplies information of a macrotaxonomic nature. Using modern analytical techniques to create phylogenies is useful, and indeed often necessary to resolve difficult taxonomic groupings, such as clarifying delimitation of genera. In the past, certain authors claimed that advances in molecular biology and phylogenetic reconstruction were driving systematic research to the detriment of traditional taxonomy (Wortley et al. 2002). It is therefore important not to overemphasise phylogenetic studies at the expense of alpha-taxonomy, but rather support comprehensive taxonomic revisions making use of datasets from a diverse range of sources (including molecular) where necessary. It should, however, be noted that classifications produced by the phylogenetic school of classification are, in contrast to those of the evolutionary school, often less informative to end users of plant names (e.g. Van Wyk 2007; Brummitt 2014).

There appears to be a split between taxonomists doing molecular phylogenetic work (mainly at universities) and those doing more traditional alpha-taxonomy (mainly at SANBI), and perhaps not enough collaboration exists to unite those two ends of the spectrum. Fostering collaboration to ensure that phylogenetic work is not the end product but rather, incorporated into revisions, would be of great benefit to taxonomic research products, because although end users do not directly require the results of macrotaxonomic studies, it is still a vital component of research.

Peer-reviewed publications remain an important yardstick for measuring productivity of taxonomists. However, some of the most important products to end users often include those that are published in other forms. Among the more important local products is the checklist of South African plants, which has been published in hard copy e.g. Germishuizen et al. (2006) and is available online under the title Plants of Southern Africa (POSA) on the SANBI website (http://posa.sanbi.org/searchspp.php). In addition, certain products generated predominantly by SANBI taxonomists, some with valuable contributions from university-based taxonomists, have been very popular, e.g. *Seedplants of southern Africa: families and genera* (Leistner 2000); *Herbarium essentials* (Victor et al. 2004); and *Guide to the plant* *families of southern Africa* (Koekemoer et al. 2015). University taxonomists produce books to a lesser extent, but notable are publications such as *Medicinal plants of South Africa* (Van Wyk et al. 2009), *Field guide to trees of southern Africa* (Van Wyk & Van Wyk 2013), *Field guide to the wild flowers of the Highveld* (Van Wyk & Malan 1997) and *Orchids of South Africa — a field guide* (Johnson & Bytebier 2015).

A discussion forum was held by SANBI staff members (D. Raimondo in collaboration with L. Von Staden, M. Hamer and J.E. Victor) at the Southern African Society for Systematic Biology conference in Arniston, July 2012, to determine ways to stimulate the production of taxonomic revisions. The participants were, inter alia, asked what obstacles prevented them from carrying out taxonomic revisions, and reasons given were low impact factor of taxonomic journals; time consuming nature of revisionary work leading to lower publication output; and a lack of information about research priorities. It was suggested that [DST] funding should be directed towards projects that would contribute towards specific priority research targets.

Recommendations for addressing capacity shortages

A review of capacity for plant taxonomic research in South Africa (Victor 2015) concludes that there is a severe shortage of capacity available to manage the country's diverse flora in terms of taxonomy and provision of foundational information. Taxonomists in South Africa are productive and are not limited by financial and infrastructural resources. However, there are still vast areas of the country that remain under-collected, and many taxa under-represented in herbarium collections, which indicate that taxonomists are partially limited by lack of plant material for research purposes as well as from which specimen data records can be databased for end users. Intense study of a smaller group of taxa can generate a large amount of information, as opposed to often, but not always, less intensive studies such as a Flora contribution. With approximately 20 000 plant species in South Africa and around 40 researching taxonomists (including technicians appointed in non-academic posts), the ratio of number of species to taxonomist is about 500 species to one. The large number of taxa (about 3800) represented by fewer than five specimens in SANBI herbaria illustrates how little is known for a large portion of the South African flora. It can therefore be concluded that more human capacity for taxonomic research in South Africa is urgently required. For now, to maximise the effectiveness of existing human capacity, prioritised activities need to be identified and efforts redirected towards these (Victor et al. 2015).

A future potential problem is addressing employment equity targets. There is an unequal distribution of taxonomic researchers at universities, with fewer traditionally black universities offering post-graduate training in taxonomy. The lack of capacity for postgraduate students to study taxonomy at the traditionally black universities is a severe impediment to successful transformation of the workforce in South Africa. More universities could undertake postgraduate training of students in taxonomy with external assistance in the form of a taxonomist co-supervisor from SANBI or another university. SANBI has at least 12 senior plant taxonomic researchers who have the ability to co-supervise research projects, but only four are currently involved in this activity. Bursaries offered to students at universities that currently do not have capacity to supervise postgraduate studies in taxonomy could stimulate the interest in plant systematics amongst previously disadvantaged population groups. A solution to this would be for SANBI to more actively promote collaboration with these universities to offer skills for co-supervising or mentoring postgraduate students, and facilitate (or offer) bursaries for this purpose, especially targeting universities currently without taxonomists. This could stimulate the interest in plant systematics amongst previously disadvantaged population groups. However with only about 40 positions for plant taxonomic researchers in the country, there is limited opportunity for employment and therefore the number of bursaries offered should be calculated carefully to ensure a steady supply for the availability of posts. To provide a choice of quality taxonomists the pool of candidates needs to be competitive, therefore it is essential to train more taxonomists than posts becoming available. The specialist nature of taxonomy limits career opportunities, therefore taxonomists need to have skills in other fields so that they can find careers in for example environmental consulting or conservation, two fields in which trained taxonomists have successfully found employment in South Africa.

An alternative solution to providing future capacity for taxonomic research is for scientists to mentor interested and talented support staff employed in technical positions in herbaria, provided such candidates have an interest in, and aptitude for, taxonomic research. At least 11 senior SANBI plant taxonomists are actively mentoring junior scientists, graduates conducting internships or technicians, or have done so in the past five years.

Traditionally black universities urgently need to create taxonomy posts so that equity can be redressed. This is one of the only long term solutions to the problem. In the meantime it would be beneficial for SANBI to produce more text-book type resources (for example Victor et al. 2004; Koekemoer et al. 2015), where the need exists, so that universities that do not employ taxonomists can still offer the course in a suitably stimulating manner so as to captivate potentially interested taxonomists.

The need for more taxonomists can clearly be justified but may not be prioritised in a country that already has such shortages of capacity in pre-primary, primary, secondary and tertiary education and social services, such as an effective police force, for example. Therefore aside from lobbying for more jobs to be created, there is an urgent need to utilise existing resources (human and other) effectively, and develop a strategy to ensure that priority activities are conducted.

Material available for taxonomic research

Herbarium specimen collections

Herbaria are indispensable resources for taxonomic research. South Africa has at least 72 herbaria, housing more than 3.2 million plant specimens. The collection of plant specimens and associated data in herbaria underpins plant taxonomic and broader scientific work. Although there are a large number of specimens in herbaria around South Africa, the representation of specimens geographically is unequally distributed. In the three SANBI herbaria, there are parts of the interior of the country that are represented by fewer than 10 specimens per quarter degree grid square (representing roughly 25×25km, or 625 km^2), and vast areas represented by fewer than 50 specimens per quarter degree grid square. For more than 10 quarter degree grid squares, SANBI herbaria do not have any specimens at all. In many cases this can be attributed partly to lower levels of diversity but even if this is the case, the number of specimens should be higher than 50 per quarter degree grid to be representative of the flora for the area.

Another indicator of representation of South African flora in herbaria is the number of specimens per species. Species with very low numbers of specimens in herbaria are characteristically rare taxa and often distributed in inaccessible or hard to access localities. It is important to establish a dedicated and comprehensive programme to collect specimens that are representative of all taxa. Ideally, the full geographical distribution range and morphological variation of taxa should be represented in collections. This improves the knowledge base of plant diversity and is a prerequisite for conducting taxonomic research of a high standard, and ultimately, providing comprehensive information to end users.

Databased information

The database of plant specimen information is a critically important product provided by SANBI, with information disseminated online. PRECIS was developed in the 1970s, with non-expert typists transcribing information from herbarium specimen labels into the database. PRECIS subsequently became the largest botanical database in South Africa and the southern hemisphere, progressively capturing and documenting the information from over 1.2 million preserved plant specimen labels. The information in this database was transferred to a Botanical Research And Herbarium Management System (BRAHMS) database in 2013. In spite of quality control procedures that are in place at the three SANBI herbaria, errors in the database abound, exposing SANBI to severe criticism. All herbaria need to have quality control procedures in place to ensure that the information provided is of sufficient standard to be used by end users.

Strategic objectives

SANBI is committed to contributing to the targets set by the Global Strategy for Plant Conservation (GSPC), including target 1, which aims to complete an electronic World Flora Online (see http://www.plants2020.net/world_flora/). Therefore, the first strategic objective for plant taxonomic research in South Africa is to produce an online Flora for the country by 2020. Families for which recent Floras or other treatises exist, or recent taxonomic revisions of plant genera are available, will relatively easily be incorporated into an electronic database that can be put online to serve this purpose, but groups that have not been treated, or treated only in part, will need to be prioritised in order to achieve GSPC target 1.

Researching plant genera that are in need of revision, especially those of conservation or economic importance, are examples of groups that should be treated as a priority. Gaps in taxonomic information at genus level can be identified and priorities determined accordingly. Therefore the second strategic objective is to revise priority plant genera for which existing treatments are inadequate.

The need to distinguish taxa that were Data Deficient (DD) according to the IUCN criteria for assessing conservation status (IUCN 2001) for taxonomic reasons from those that were DD for other reasons resulted in the use of the letter ‘T’ being adopted to flag those taxa (Victor 2006). Taxa listed as ‘DDT’ are regarded as priorities for taxonomic research efforts (Victor & Smith 2011), because conservation authorities should not expend limited financial resources on efforts to protect taxa that might be inseparable from common taxa. Meanwhile DDT species can cause significant fiscal implications for developers when the Environmental Impact Assessment (EIA) process is delayed by the occurrence of a potentially threatened species that is unclear because of taxonomic problems. If the taxonomic status is in doubt, this can lead to unnecessary wastage of financial resources, or potential neglect of a cryptic species in danger of going extinct; it can also impact on the ability to sustainably utilise a taxon of economic importance. The third strategic objective is to address this gap by resolving isolated taxonomic problems in species of conservation or economic importance.

A plant collecting programme for SANBI's herbaria will improve the value of collections and their associated data. Strategic prioritisation for expanding the collections through a systematic and efficient approach will expand the knowledge base of plant diversity. Collecting from specifically targeted geographical areas and focussing on plant taxa that are under-represented in SANBI's herbaria would provide vital foundational information not only for taxonomic purposes, but also for providing information for end users, e.g. conservationists. The fourth strategic objective is therefore to improve the provision of foundational biodiversity information from herbaria and specimen label databases by prioritising collecting activities towards both geographical areas and plant taxa that are under-represented in SANBI herbarium collections. This is followed by recommendations to address concerns with data quality (see next section). Focussing on and inevitably addressing these recommendations will fulfil the objective of improving the quality of the data provided by herbarium collections as a resource for taxonomic and other research.

In summary, the strategic objectives for the *Strategy for plant taxonomic research in South Africa 2015–2020* are to:

4. produce an open access, online checklist and Flora of South African plants by 2020;
5. revise priority plant genera that are in need of revision;
6. resolve taxonomic problems in single taxa or small taxon groups to improve the South African plant checklist; and
7. improve the herbarium collections as a research resource.

These strategic objectives are developed into three research programmes and a proposed plant collecting programme.

Programmes of activity for taxonomic research

Research programme 1: e-Flora

Programme 1 addresses the first strategic objective, namely, to produce an open access, online Flora for South Africa (e-Flora) by 2020. This entails ensuring research capacity is available in prioritised plant families, and addressing gaps in taxonomic information that will contribute to the updating of the checklist of South African plants. The e-Flora will contribute to the World Flora Online, the first target of the GSPC, following the approach published by Victor et al. (2013).

The key tasks of Programme 1 are to:

1. maintain or develop research capacity in priority families;
2. produce treatises for geographical areas of South Africa that have not yet been completed;
3. ensure that an accurate, updated checklist of South African plants is available online; and
4. produce an open access, online Flora for South African plants by 2020.

One way to prioritise which plant families should receive focused taxonomic research attention is to target those families with a high level of taxonomic problems. This analysis was conducted by Victor & Smith (2011), and the results showed that the families that should be prioritised for focussed taxonomic attention and in which capacity must be maintained or developed, are Aizoaceae (in a broad sense including Mesembryanthemaceae), Apocynaceae (in a broad sense including Asclepiadaceae and Periplocaceae), Asphodelaceae, Asteraceae, Campanulaceae, Ericaceae, Fabaceae (Leguminosae), Geraniaceae, Lobeliaceae, Oxalidaceae, Santalaceae, Scrophulariaceae and Thymelaeaceae. Capacity for research and curation of all of these families currently exists at SANBI and universities.

Family-scale treatments have often been done by production of a conspectus or Flora-style fascicle. Any family that has not been treated in the FSA series published by SANBI, or after 1960, is regarded as a priority. Treatments of large families (i.e. those containing more than 100 species) that are understudied (with more than 50% of taxa revised prior to 1960), particularly those with taxa that present challenges to identify, are of particular importance and should be prioritised. These include the Cyperaceae, Hyacinthaceae, Malvaceae, Rhamnaceae and Rutaceae. Of the South African members of these families, the only one for which a family treatment is currently being undertaken is the Cyperaceae. Active research is being conducted in Hyacinthaceae and Rutaceae. There is little capacity for the remaining families at research institutions, herbaria and universities. New staff members at SANBI will be required to develop expertise in these priority families.

Of the cryptograms, one hornwort (Anthocerophyta), 13 moss (Bryophyta) and 31 liverwort (Marchantiophyta) families and have not been covered in FSA or other family treatise publications. Because of the inadequate taxonomy of some groups and insufficient records and distribution data, especially in the central and western parts of southern Africa (Van Rooy & Van Wyk 2010), the remaining bryophyte families are regarded as priorities for research. Taxonomic research on these families is currently being undertaken by taxonomists at SANBI, in collaboration with scientists at universities and research institutions in the United States of America, Brazil, Finland and South Africa.

Victor et al. (2013) proposed that an online Flora of South African plants can be achieved using existing species descriptions. As such, SANBI has employed an e-Flora coordinator and an assistant who are dedicated to completing this task. The e-Flora coordinator is tasked with collaborating with taxonomists from around the country, including professionals and amateurs, to contribute to providing descriptions and information for the e-Flora. Descriptions will be obtained from the most recent revisions available, and those that are outstanding and unobtainable by 2018 will be extracted from the regional Floras published by SANBI which will have covered the flora of the entire country by 2018. Floras for the northern provinces (comprising Gauteng, Limpopo, Mpumalanga and North West), Western Cape, and parts of Northern Cape have recently been completed (Retief & Herman, 1997; Manning & Goldblatt 2013; Snijman 2013); and those for the Free State and Eastern Cape have been completed and submitted for publication. A Flora for the remaining parts of the Northern Cape province not covered in the ‘Plants of the greater cape floristic region’ treated by Manning & Goldblatt (2013) and Snijman (2013) is in preparation and will be submitted for publication in 2016. If work towards a treatise on the KwaZulu-Natal Flora can be concluded by 2019, completion of these regional Floras by SANBI staff will cover the flora of the entire country, and will contribute towards filling gaps in the online Flora of South African Plants (Victor et al. 2013).

A South African National Plant Checklist (currently known as the Plants of South Africa, or POSA) has been created by SANBI and lodged on the SANBI website (http://posa.sanbi.org/searchspp.php). The checklist will be expanded and improved and should have links to descriptions and images for every taxon, as well as keys, which will constitute the e-Flora. SANBI has one dedicated scientist and an assistant to develop and maintain the checklist, to ensure that the e-Flora is completed by 2020.

Research programme 2: revisions of plant genera

The strategic objective addressed by programme 2 is to revise plant genera that are in need of revision, which will contribute to filling in gaps in knowledge of South Africa's flora. Research includes discovering (categorising and documenting) South Africa's flora. Analyses were conducted on angiosperms, gymnosperms and pteridophytes according to the methodology described in Victor et al. (2015). Sufficient data are lacking to do a similar analysis for bryophytes, however bryophyte priorities are addressed at family level in Programme 1.

To provide an objective list of genera requiring revision, indicators are used as criteria for prioritisation in the current analysis as described by Victor et al. (2015). The indicators used in this analysis were as follows:

a) The date of the publication of the last revision

If the last treatment of a genus is that published in *Flora capensis* or up to the date when the final volume of *Flora capensis* was published (1933), it is of highest importance. Before the end of World War II, university trained botanists were rare in South Africa (Rourke 1999), and use of advanced technology and multiple sources of data for revisions was minimal. Therefore genera covered by treatments published before 1945 are likely to be less comprehensive than those published thereafter. The 1970s coincided with the advent of electronic databases, as well as increased incorporation of more modern techniques in systematics following trends abroad. With few exceptions, any treatment published more recently than 1970 is considered to be not necessary to revise as the treatment should be modern and adequate (see below). However it should be noted that providing a revision of a group can trigger opportunistic research and further refinement of the group, as clarification of demarcation between taxa and provision of new keys can elucidate cryptic taxa that were not formerly apparent.

Taxonomic treatments in old revisions may well be adequate in terms of species concept and nomenclature, in which case it might not be necessary to revise the group. Conversely, some groups having been relatively recently revised may be inadequate or out of date. Quality of a revision is an important additional consideration, because even if a group has been revised very recently, if the rigor and scope of the work is not up to standard, it would necessitate further work. If this becomes apparent to specialists then the group can be included on the priority list for revision if motivation is provided. Thus although the date of last revision was used as an indication of whether a new revision is required, the list was further refined by circulating it to specialists and considering expert advice.

b) Proportion of unidentified specimens of genera in SANBI herbaria

A high proportion of unidentified herbarium specimens within a genus can be an indicator of potential taxonomic problems resulting from inadequate revisions. A revision (whether old or new) may be inadequate due to any of the following factors: a lack of clear descriptions of species, lack of clarity of generic delimitations, keys that are difficult to use, and/or the presence of undescribed species. The number of unidentified specimens in the PRECIS database was used to detect potential problematic genera that require prioritising for taxonomic research, and this forms another criterion for selecting priority genera.

c) Proportion of taxa classified as DDT

Species that are classified as DDT on the South African Red List are lacking in information often as a result of inadequate or incomplete information provided in taxonomic literature (especially distribution information). The proportion of species listed as DDT in each genus therefore provides a useful indication of potential need for revision of a genus, and was used to determine priority groups for taxonomic research.

d) Economic importance

The fourth criterion used to determine priority genera for revision was economic importance of the plant group. The top seven economically important families were determined by conducting a survey of the literature as well as expert advice. Economically important plant families are considered to be those that have a higher proportion of taxa of importance in South Africa with respect to their status such as crop plants, food plants, medicinal value, horticultural value, timber, or invasive or naturalised alien species. A literature survey and opinion survey amongst South African taxonomists revealed that the top seven economically important plant families in South Africa are Poaceae (frequently acknowledged as the most economically important plant family in the world); Fabaceae (considered to be the most important dicotyledonous plant family in the world according to Harborne 1994); Geraniaceae, Rutaceae, Apiaceae, Asphodelaceae and Asteraceae.

e) Proportion of taxa occurring in South Africa

The final criterion used to prioritise genera for taxonomic revision was the proportion of taxa in each genus occurring in South Africa. When the majority of the genus does not occur in South Africa, the cost of doing a revision escalates when fieldwork is necessary to collect material for examination, or to conduct field-based natural history observations. For example *Buchnera* and *Bassia* were both excluded from priority lists because more than 75% of the species do not occur in South Africa. It is preferable to do a comprehensive study, such as a monograph, of a complete group, rather than a partial investigation, therefore for the next five years the priority will be to strategically focus on genera that are endemic or near-endemic to South Africa.

From these analyses, a list of plant genera categorised according to their priority for revision (http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies) was developed and circulated widely amongst biosystematics researchers in South Africa and abroad. Because these objective analyses could inadvertently ignore important plant genera that did not qualify using the indicators, specialists were asked to contribute suggestions for genera to be prioritised for revision based on their expert knowledge, giving a sound justification as to why the genus should be considered. Additional justifications for inclusion of a genus as a priority for revision included:

- whether or not the revision is satisfactory in terms of including an effective key for plant identifications, clear descriptions that adequately delimit taxon boundaries, and sufficient clarity on taxonomic status of each taxon; and
- whether or not a large number of undescribed taxa that cannot be adequately placed within the genus without revising the whole genus are known to exist.

The preliminary results of the analyses were thus used in conjunction with expert input to develop the list of priority genera.

Research programme 3: Data Deficient plants

The aim of this programme is to solve problems targeting single species or small groups of related taxa of conservation or economic importance in large genera that are otherwise not in need of revision. Taxonomic problems impede the determination of conservation status of threatened taxa, or the potential sustainable use of economically important taxa; and these taxa can therefore escape conservation attention.

The process of assessing the Red List status of plant species is often hindered because of uncertainties in taxonomic status of the taxon. For over 1 000 of the plant taxa that are possibly threatened with extinction, taxonomic problems exist and therefore insufficient data are available to accurately assess their conservation status. At the time of writing of this report (June 2015), there are 246 taxonomically problematic taxa that are not covered by revisions (http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies). These taxa constitute the priority list of this programme. Additional taxa of economic importance that are taxonomically problematic were listed in cases where the genus as a whole does not require revision. Projects dealing with a single species and its nearest relatives have the advantage of being of a manageable size suitable for students enrolled in Honours courses. The programme will be promoted at universities to stimulate interest in, and the involvement of, students in small taxonomic research projects that could result in publications, intellectual growth, and by implication, in capacity of taxonomy.

Allowance is made for the possibility that resolving taxonomically problematic species listed under this programme may necessitate revising the genus to which it belongs.

Cross-cutting considerations for research

Conducting taxonomic research in such a way that insight is provided into other fields, especially focusing on determining evolutionary relationships and specialisations, remains of paramount importance. Studies on function/process (as opposed to structure/pattern) will both inform taxonomic work, and provide high-profile research outputs for attracting funding. For example, Desmet et al. (2002) recommend that in addition to describing infraspecific variation, taxonomists should formulate hypotheses as to how this variation is distributed in the landscape, and how it came about, so that spatial components of evolutionary processes can be identified for purposes of conservation of evolutionary processes. Another example is determining phylogenetic diversity, a conservation tool that measures quantitatively the genealogical history of a group of species, which is then used to prioritise species for conservation (Hartmann & André 2013).

Programme of activity to improve the herbarium collections as a research resource

Plant collecting programme

This programme gives a generalised outline of proposed actions to improve the coverage of the country and the flora by herbarium collections. It is recommended that herbarium curators of all institutions develop more detailed plans to prioritise gaps in their own collections that are relevant to the activities, areas and taxa covered by their herbaria.

The following priorities are identified for targeted collecting trips to improve the taxonomic and geographic representation of plant specimens in herbaria:

a) Taxa that are under-represented in the herbarium collection

The ideal number of plant specimens representing each taxon will differ between herbaria, and between taxa. As a general guideline for SANBI herbaria, if fewer than five specimens exist for one taxon, then it is considered to be under-represented and should be prioritised for collecting. Targeting under-represented species should ideally be conducted by taxonomists who specialise in the family of which the taxon is a member, and with experience in the field, to prevent unnecessary wastage of resources. The list of under-collected taxa should be used in conjunction with the list of plant taxa classified as DDT in the Red List and genera prioritised for taxonomic research in programme 2, because most taxa prioritised as DDT are also under-collected or are members of genera requiring taxonomic revision.

b) Geographically under-represented areas

The SANBI herbaria house collections from throughout South Africa, although this particularly applies to the National Herbarium. Therefore the BRAHMS database can be interrogated to derive areas which are under-represented in terms of herbarium specimens. In the case of SANBI herbaria, any quarter degree grid that has fewer than 50 specimens in herbaria is considered to be under-represented. Because of the large areas that are under-collected, it is recommended that all quarter degree grid squares with fewer than 10 specimens (especially those with none) are targeted as first priority. Once there is more complete coverage of these areas, the next priority will be to target areas with fewer than 50 specimens per quarter degree grid square.

Because this is a vast area of the country, further strategic identification of important areas to target for expanding herbarium specimen holdings are necessary. It is recommended that collecting plans are developed on an annual basis to target for example areas earmarked for development within under-represented areas, and areas that have high diversity but are under-represented due to being in remote and inaccessible locations. Areas known to have low diversity should arguably be excluded from a targeted collecting programme, but care should be taken not to omit pockets of high diversity in landscapes that are otherwise reasonably homogenous.

As an incentive to improving collections and to reduce costs of this programme, herbaria, especially those of SANBI, should offer a free identification service to plant collectors who specifically target under-collected areas or under-collected taxa prioritised for collection, in return for donation of high quality specimens that adhere to quality standards (e.g. fertile specimens fully representative of the plant, along with good field notes).

Maps of under-collected areas should be generated annually to monitor and illustrate progress with improving representation of specimen coverage. As there are over 100 quarter degree grid references with fewer than 10 specimens in SANBI herbaria, an initial aim could be to reduce this by five quarter degree grids every year (targeting areas earmarked for development). Progress with collection of under-represented plant taxa can similarly be monitored by generating lists of taxa with five or fewer specimens annually and tracking progress, and should be available on the website.

Collection of samples for DNA barcoding is encouraged as a routine part of fieldwork for taxonomic research. It is vital that samples are linked to correctly identified voucher specimens. Although it is not currently prioritised as an independent exercise in the Strategy, once a sufficiently comprehensive library of DNA barcodes has been accumulated on the flora of South Africa, DNA barcoding will be able to play an important role in identification of specimens and be a prioritised activity. This is likely to become a prioritised activity in future updates of the Strategy once revisions of the most taxonomically problematic groups have been achieved.

Recommendations for addressing data quality

It is critical that the quality of data derived from herbarium specimen labels and disseminated to end users is accurate, and data validation and detailed checking is therefore not a separate programme but rather a key activity of all taxonomists and support staff at SANBI. All herbaria that capture, house, maintain, and disseminate electronic data of herbarium label information should adhere to the following recommendations:

- Quality standards for populating plant specimen databases need to be set to minimise errors, and persons responsible for populating the database must take care in transcribing information and adhere to quality standards, ensuring that the label information is accurately mirrored in the database.
- Two main sources of errors exist in most databases that hold plant specimen label information. Data need to be screened for errors in: (1) names (identification) and (2) localities (georeferenced as well as lower resolution such as quarter degree grid) on a regular basis. This can be done by, for example, generating taxon distribution maps and identifying points that appear to be out of place.
- Errors should be corrected by scientists or technical support officers who are experienced at identifying the taxa concerned, and have knowledge of the geography of the area concerned. Identifications and locality, georeferenced and quarter degree grids must all be corrected on databases to ensure that the data accurately mirrors data given on the specimens.
- Georeferencing of specimen locality information should be done by experienced people.
- When herbaria send specimens to other institutions on loan, it should be made a requirement that following completion of the study, the loan recipient should assist in updating the corresponding information in the database, or be available to assist the responsible staff member in updating the database to accurately reflect the latest information.

Within the three SANBI herbaria, all scientists and support staff are tasked with data cleaning, and quality control of new information added to the database is in place. Monitoring of progress is an essential component of improving data quality in SANBI herbaria as they are providing a service to the public. In the BRAHMS database it is possible to develop a tool to show progress with verification and changes resulting in improvement of quality over time.

Changes and updates that have been made to the database should be summarised and displayed on a SANBI website page at quarterly intervals to illustrate to end users how progress is being made to clean up data.

Discussion and conclusions

An analysis of gaps in taxonomic knowledge has enabled the establishment of four strategic objectives, and three research programmes and a collecting programme that will address the strategic objectives. Within SANBI, existing capacity in biosystematics research will be utilised towards addressing the priorities of the Strategy. The Strategy will be further promoted amongst university researchers to stimulate their involvement, and in particular to stimulate interest of potential taxonomists in projects from, especially, programme 3. Such projects have the additional advantage of being cross-cutting between taxonomy, population biology, ecology and conservation, and are therefore ideal for students who have not yet specialised in a particular field of research.

A primary objective of taxonomy is to develop a natural and predictive classification system with high information content and that reflects evolutionary relationships among plants. To achieve this, results from molecular studies are integrated with other sources such as morphological, anatomical, cytological, physiological and palynological studies. Modern revisions also include a phylogeny to circumscribe the group of interest, identify nearest relatives, and identify patterns of character evolution. Understanding evolutionary relationships can assist in understanding more complex characteristics of an organism, such as the causal factors for its rarity as an example, leading to enhanced ability for priority setting by conservationists and development of management plans. The value of taxonomic information produced should be enhanced by research methodologies and dissemination channels that add value to the products of the research.

Enhancing the availability of taxonomic information to the public through popular publications is one of the most important requirements of end users. There is a great demand for popular publications such as field guides with images to aid identification. In order to achieve dissemination to the broader public and other stakeholders, and thus for taxonomic research to have a positive impact on society, it would be of great benefit to develop online identification tools (including apps for mobile devices) and information portals in line with the first strategic objective of this Strategy. Electronic keys of the largest genera and families, with images of species and key characters, would be particularly useful to end users. An area for development of disseminating taxonomic information to the public is in applications for mobile cellular phones and iPads. An example that could be followed is the free iPhone app, Plant-O-Matic (see: http://go.nature.com/9pg7vQ) which gives access to the records of all plants in the Americas, over 88 000 species, with links to images of herbarium specimens from the Missouri Botanical Garden's Tropicos database (Nature Plants Editorial, 2015).

The SANBI website hosts a list of taxonomic priorities for research and expertise of botanists, both professional and amateur, from herbaria and universities countrywide, as well as priority genera for research. This list will be updated regularly and act as a resource to stimulate interest in the Strategy, in this way coordinating biosystematics research on South African Flora.

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APPENDIX 9: The taxonomic and conservation status of *Agrostis eriantha* var. *planifolia*

main building, high up on slope amongst big boulders, (–CB), 7 Feb. 2009, *Struwig 41* (PUC, WIND). **2114** (Uis): Numas Gorge, high up in kloof, underneath *Acacia montis-usti* behind big boulders, (–BA), 6 Feb. 2009, *Struwig 39* (PUC, WIND); Brandberg Mountain, on top, Baswald Rinne Area, (–BC): 19 May 1977, *Craven 490* (PUC, WIND). **2115** (Karibib): Klein Spitzkoppe, against mountain slope amongst rocks, (–CC), 5 Feb. 2009, *Struwig 36* (PUC, WIND). **2214** (Swakopmund): Swakopmund district, 63 miles SE of Walvis Bay in Namib area, (–DA), 2 Mar. 1965, *Barnard 85* (PRE, WIND). **2215** (Trekkopje): Tsaobis Leopard Farm, S of Karibib, (–DD), 21 Feb. 1990, *Hardy 7017* (PRE, WIND). **2416** (Maltahöhe): Naukluft Mountains at Büllspoort, (–AA), 16 Dec. 1947, *Rodin 2833 & Strey 2132* (BOL); C14, Naukluft Mountains, mountain slope behind the river, (–AA), 13 Feb. 2009, 7 Apr. 2010, 8 Apr. 2010, *Struwig 59*, *160*, *163* (PUC, PRE, WIND); Farm Tsais-Maltahöhe, (–AB), 16 May 1978, *Müller & Tilson 894* (PRE, WIND); C19. Tsaris Mountains, (–AB), 8 Apr. 2010, *Struwig 164* (PUC, WIND); Maltahöhe, Farm Mooirivier MAL 160, on S-facing slopes, (–CA), 11 Apr. 1980, *Müller 1362* (PRE, WIND). **2616** (Aus): Kuibis, (–DD), 1 Mar. 1912, *Range 1283* (BOL).

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POACEAE

THE TAXONOMIC AND CONSERVATION STATUS OF *AGROSTIS ERIANTHA* VAR. *PLANIFOLIA*

INTRODUCTION

Agrostis eriantha Hack. (1904) is a tufted, rhizomatous perennial that grows in wetlands of Swaziland, Lesotho, Limpopo, Mpumalanga, Gauteng, Free State, KwaZulu-Natal, and Eastern Cape. This relatively rare grass appears to be sensitive to disturbance and is mainly found in pristine habitats. In 1945, Goossen & Paperndorf described a form of the species collected by Pole-Evans on the farm Doornkloof, Irene, as *A. eriantha* Hack.var. *planifolia* Gooss. & Paperndorf. The main diagnostic character used to distinguish the two varieties was the length of the callus hairs as shown in Figures 1 and 2. In *Agrostis eriantha* var. *eriantha*, the callus hairs are up to one third the lemma length while in var. *planifolia*, the callus hairs are up to half the lemma length. Another suggested difference was in the leaf blades, which are said to be folded in var. *eriantha* and flat in var. *planifolia*. Other possible differences are discussed in the results section.

The only known collections of *A. eriantha* var. *planifolia* are the type specimen and another Pole-Evans collection from Irene, collected two days after the type specimen. However, examination of Pole-Evans' register shows that he made mistakes with localities and was also not consistent with dates, casting doubt on whether the second specimen was really another collection rather than a duplicate of the type. Unfortunately, as with the Type specimen, there is very little information. Since this plant was first discovered, forms with callus hair length equal to that of the type specimen have never been found again, despite repeated searches at the type locality and nearby habitat.

Various unanswered questions concerning *A. eriantha* var. *planifolia* have made it difficult for an assessment of the conservation status of this plant to be made. Since it has only been collected once, it remained uncertain whether it is extremely limited in distribution and still awaiting re-discovery, or alternatively, extinct. However,

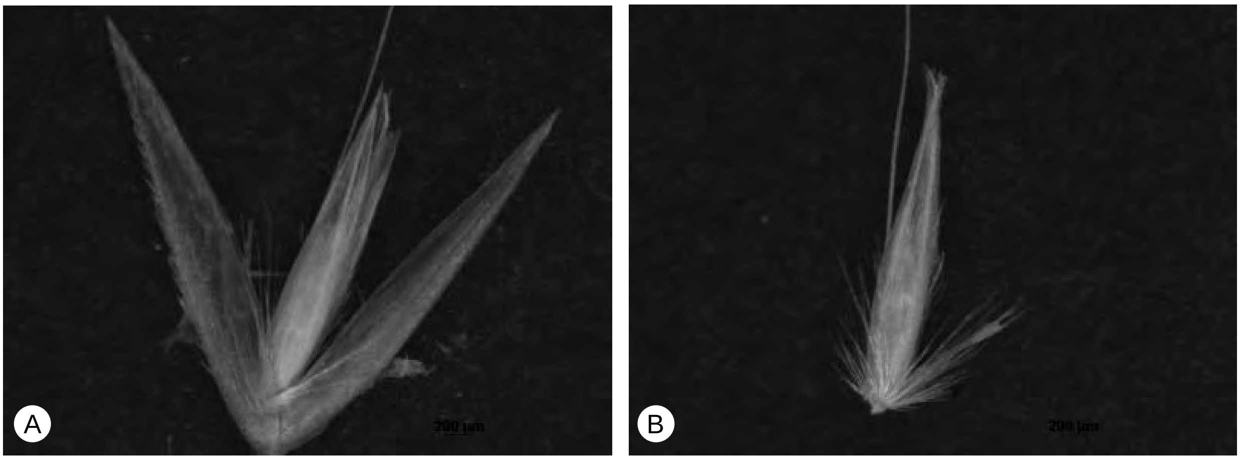

FIGURE 1.—*Agrostis eriantha* subsp. *planifolia*, Pole-Evans 666 (PRE). A, spikelet; B, lemma. Scale bar: A, B, 200 µm. Photographer: Caroline Mashau.

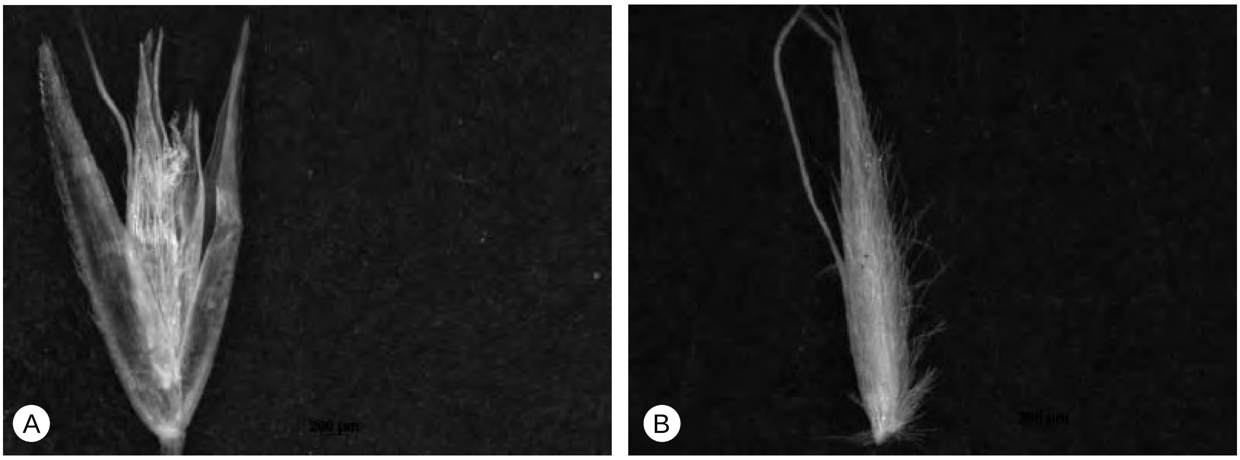

FIGURE 2.—*Agrostis eriantha* subsp. *eriantha*, Smook 5026 (PRE).A, spikelet; B, lemma. Scale bar: A, B, 200 µm. Photographer: Caroline Mashau.

it is also possible that this taxon is merely an aberrant form of *A. eriantha*. In recent years, development proposals in the vicinity of this taxon have been complicated by its potential (but unconfirmed) presence, a situation which has financial implications for developers. Thus it is of great importance to clarify the taxonomic and conservation status of this taxon.

The current conservation status of this variety (Raimondo *et al.* 2009) is Data Deficient (DD). Additionally it is flagged 'T', indicating taxonomic uncertainty (Victor 2006).

METHODS

Fieldwork was conducted at the type locality and surrounding areas in Gauteng. The type locality has been transformed and no *Agrostis eriantha* remains there. The two closest wetlands to the type locality that are in a relatively reasonable condition are Rietvlei Nature Reserve and the Grootfontein Agricultural Holdings. Specimens of *A. eriantha* were collected from both of these sites. Callus hairs of the specimens were compared with those of *A. eriantha* var. *planifolia*. In addition, the callus hairs of 94 specimens of *Agrostis eriantha* var. *eriantha* housed in the National Herbarium (PRE) were investigated to determine variation in callus hair length within this taxon.

As a comparison, callus hair variation in *Agrostis lachnantha* Nees, a closely related and sympatric species, was investigated to determine the consistency of this character. Samples from 11 specimens were investigated.

RESULTS

The comparison shows that the morphological characteristics of specimens collected near the type locality match the type and description of *A. eriantha* var. *eriantha*. No specimen of *A. eriantha* var. *eriantha* has callus hairs quite as long as *A. eriantha* var. *planifolia*, but some variation in length was found (Table 1).

Variability of callus hair length between different specimens of *Agrostis lachnantha* was investigated to assess the reliability of callus hair length as a character. This investigation revealed that callus hair length varied up to one third the lemma length not only between specimens but also within the same specimen.

TABLE 1.—Differences between *Agrostis eriantha* var. *eriantha* and *A. eriantha* var. *planifolia*

Character	*A. eriantha* var. *eriantha*	*A. eriantha* var. *planifolia*	Character reliability
Leaf blade	Folded.	Flat.	Could be artefact of pressing.
Glumes (apices)	Acute to acuminate.	Acute.	Overlapping character insufficient to distinguish between two taxa.
Lemma	Hairy.	Glabrous, margins hairy.	Variability of hairiness cannot be assessed on just two specimens.
Palea	± Equal to slightly shorter than lemma.	Shorter than lemma.	Overlapping character, not sufficient to distinguish varieties.
Callus	Hairs up to $^1/_3$ the lemma length, but variable.	Hairs up to $^1/_2$ the lemma length, variability uncertain due to small sample size.	Character variable throughout genus, and too variable to constitute a reliable difference between these varieties.

DISCUSSION AND CONCLUSION

Agrostis lachnantha was divided into two varieties, *A. lachnantha* var. *lachnantha* and *A. lachnantha* var. *glabra* on the basis of hairiness of the lemma by Goossen & Papendorf (1945). However it was later found, and confirmed in this investigation, that hairs on the lemma are variable in length and cannot reliably be used to distinguish varieties. The variety was therefore reduced to synonymy under *A. lachnantha* (Gibbs Russell *et al.* 1990).

The results of our investigations suggest that variation in callus hair length is not a reliable character to use to distinguish between taxa in *Agrostis eriantha*. Given that *A. eriantha* var. *planifolia* has never been recollected (with the exception of one other specimen from the type locality), it is probable that it is an aberrant form. *Agrostis eriantha* var. *planifolia* is therefore reduced to synonymy under *A. eriantha*. This species is a widespread grass and the conservation status is confirmed to be Least Concern.

Agrostis eriantha *Hack*. in Vierteljahresschrift der Naturforschenden Gesellschaft in Zürich 49: 172 (1904). Syntypes: South Africa, [Gauteng], 'in humidis prope Pretoria', Jan. 1894, *Schlechter 4144* (PRE, syn.!); [Eastern Cape], 'in collibus prope Middleburg', Dec. 1893, *Schlechter 4052* (PRE, syn.!).

Agrostis eriantha Hack. var. *planifolia* Goossens & Papendorf:181 (1945), syn. nov. Type: South Africa, [Gauteng], Irene, Doornkloof, *Pole-Evans 666* (PRE, holo.!).

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RUBIACEAE

TAXONOMIC NOTES ON *SERICANTHE ANDONGENSIS* AND A NEW COMBINATION AND STATUS IN *SERICANTHE* FROM LIMPOPO, SOUTH AFRICA

Rubiaceae Juss. is one of the five largest families of flowering plants with over 13 000 species (Bremer 2009) and belongs in the order Gentianales Juss. ex Bercht. & J.Presl (APG III 2009; Reveal 2012b). Members of Rubiaceae can be recognized in the vegetative state by their opposite, sometimes whorled, entire leaves and interpetiolar stipules with axillary colleters. The flowers are usually bisexual or sometimes unisexual or functionally unisexual and polysymmetric, often with a narrow corolla tube and spreading lobes; the ovary is inferior in most species, with a nectary or disc on top, except in members of tribe Gaertnereae in subfamily Rubioideae, which have a secondarily superior ovary (Jansen *et al.* 1996), and the fruit is baccate, drupaceous, or capsular (Stevens 2001–[accessed December 2011]). There is strong molecular support for three subfamilies:

APPENDIX 10: The taxonomic and conservation status of *Sebaea fourcadei*

GENTIANACEAE

THE TAXONOMIC AND CONSERVATION STATUS OF *SEBAEA FOURCADEI*

INTRODUCTION

Sebaea Sol. ex R.Br. (Gentianaceae tribe Exaceae) likely consists of about 65 species, mainly in South Africa, with a few in Tropical Africa, Asia, Australia and New Zealand (Kissling *et al.* 2009a, b). The southern African species were revised by Marais (1961) and Marais & Verdoorn (1963), but no recent worldwide taxonomic treatment exists for *Sebaea*, and species estimates range from a conservative ± 60 species up to ± 150–159 species (Kissling *et al.* 2009a). *Sebaea fourcadei* was described by Marais (1961) from only two specimens collected near Humansdorp and Knysna in the Eastern Cape in South Africa. Since then only one additional specimen has been identified, collected from Hofman's Bosch near Humansdorp by L. Britten in 1919. It remained unidentified in the Selmar Schonland herbarium (GRA) until 2012. Fourcade was thought to have been the first person to discover the species, but his collection dates from 1932 and Britten was therefore the first to find it.

Sebaea fourcadei is closely allied to *Sebaea ramosissima* (Marais & Verdoorn 1963), which has a much wider and slightly more easterly distribution. The two species are both slender herbs with flowers superficially similar, but differ in that the former has capitate stigmas and smaller anthers, whereas stigmas of *S. ramosissima* are clavate. The ranges of the two species are parapatric since *S. fourcadei* has been found only east of Port Elizabeth, between Knysna and Humansdorp, whereas *S. ramosissima* occurs between Port Elizabeth and East London in the Eastern Cape and as far north as Middelburg. However, considering the morphological similarities, the possibility remained that the two might be conspecific if it was found that anther length and stigma shape were variable characters within the two species. *Sebaea fourcadei* was accordingly classified as DDT (Data Deficient with taxonomic problems) in the Red List of South African Plants (Raimondo *et al*. 2009). The flag, 'T' indicates that there is insufficient information to adequately assess its conservation status, mainly because of taxonomic uncertainty (Victor 2006).

We aimed to clarify the distinction between the two species, and to try to rediscover it in its original habitat, allowing for a better assessment of its conservation and taxonomic status.

MATERIAL AND METHODS

All herbarium specimens of *Sebaea ramosissima* Gilg. in PRE and one of *S. fourcadei* Marais housed in GRA were studied. Special attention was given to the diagnostic characters, i.e. the length of the anthers and the shape of the stigma. Type specimens were viewed on the ALUKA website (http://plants.jstor.org). Acronyms for herbaria are listed in Holmgren *et al*. (1990) and Smith & Willis (1999).

RESULTS

Morphology

Both *Sebaea fourcadei* and *S. ramosissima* are slender annual herbs, simple or branched, growing up to 25 cm high. Examination of the herbarium specimens confirmed the similarities and differences between specimens as follows. Leaf size and shape are similar, as well as inflorescence. The yellow corolla is slightly smaller in *S. fourcadei*, with the tube measuring 3–4 mm long and lobes 2.7–3.5 mm long, whereas in *S. ramosissima* the flowers are larger with the tube 3.5–6.0 mm long and lobes 5.5–8.0 mm long. The most distinctive characters separating the two species are the capitate stigma in *S. fourcadei*, whereas in *S. ramosissima* the stigma is clavate; in addition, the anthers of *S. fourcadei* are much smaller, up to 1.25 mm long, whereas those of *S. ramosissima* are 2–3 mm long. These differences are consistent across specimens examined, and we therefore confirm that the two species are distinct.

FIGURE 1.—Belvedere, the settlement in Humansdorp where *Sebaea fourcadei* used to occur. Photographer: J.E. Victor.

Ecology

Field trips were undertaken in September 2011 and December 2012 to search the Knysna and Humansdorp sites to rediscover the species. Unfortunately, the known localities at Belvedere, near Knysna (Figure 1) and the farm Geelhoutboom, near Humansdorp, are now transformed by residential development and agricultural practices. It is therefore unlikely that *S. fourcadei* still exists there. We also searched possible habitats nearby, e.g. Goukamma Nature Reserve but were unable to relocate the species.

Specimens examined

Sebaea fourcadei

EASTERN CAPE.—**3424** (Humansdorp): Geelhoutboom, Lower Tsitsikimma, 500' [132 m], (–BB), Nov. 1932, *H.G. Fourcade 4880*, (Bolus, iso.—ALUKA image!); Hofman's Bosch, Jan. 1919, *Britten 1110* (GRA!); **3423** (Knysna): Belvedere, (–AA), Oct. 1931, *V.A. Duthie* 1175, (K, —scanned image!).

Sebaea ramosissima

EASTERN CAPE.—**3326** (Bathurst): (–DB) *Burchell 3784* (K—ALUKA image!, PRE!, syn.); **3227** (King William's Town): (–CD) *Tyson 3129*, (SAM.—ALUKA image!, syn.); Cape, *Ecklon 661* (M.—ALUKA image!). **3124** (Graaff Reinet): Old Wapadsberg Pass road, (–DD), 26 Nov. 1977, *Hilliard 10688* (PRE). **3124** (Middelburg): Compassberg farm, (–AD), 1 Mar. 1962, *Acocks 22090* (PRE). **3226** (Mpofu Game Reserve): Intloni area Section 9. Upper Blinkwater River area, (–DA), 2 Feb. 2006, Von Staden. **3226** (Mpofu Game Reserve): Public road to post Retief Conservancy, (–DA), 28 Feb. 2006, *Bredenkamp 3329* (PRE). **3227** (King William's Town): Hatcheries, Pirie forest, (–CC), 9 Nov. 1901, *Galpin 5933* (PRE). **3326** (Partly: Southwell): Lower Albany, (—BA), Nov. 1893, *Schonland 780* (PRE). **3327** (Peddie District): Bell, (–AA), Dec. 1906, *Galpin 7708* (PRE).

CONCLUSION

The two localities in which *Sebaea fourcadei* was formerly found are both transformed, and the species is unlikely to still occur there. It may still exist in suitable pristine habitats between Knysna and Humansdorp, but intensive surveys need to be conducted to rediscover this species. At present, we consider that the species may be extinct, having been unable to relocate it at the known localities due to transformation brought about by agriculture around Humansdorp and housing developments at Belvedere (Figure 1).

It is recommended that the IUCN conservation status of *Sebaea fourcadei* be changed to CR: PE (Critically Endangered, possibly extinct).

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APPENDIX 11: Taxonomic status of *Pelargonium reniforme* Curt.

Taxonomic status of *Pelargonium reniforme* Curt.

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Background: *Pelargonium reniforme* Curt. is a morphologically variable species that many authors have attempted to split or combine. Confusion relating to the differences between the two subspecies currently included under *P. reniforme* has impeded attempts to assess their conservation status. *Pelargonium reniforme* is closely related to *Pelargonium sidoides*; the two species are indistinguishable when not flowering and their distributions overlap in some areas.

Objectives: With this study, we aimed to clarify the taxonomic status of the two subspecies of *P. reniforme*, which has relevance in terms of their conservation status.

Method: Leaf shape, petiole length, internode length and flower colour were assessed by studying herbarium specimens of the two subspecies of *P. reniforme* and specimens of *P. sidoides*. Living specimens of the two subspecies were also examined in their natural habitat.

Results: The current investigation showed that the morphological characters used to distinguish the two subspecies of *P. reniforme* are too variable to separate them. Variation in some morphological characters may be related to environmental conditions.

Conclusion: The recognition of the two subspecies of *P. reniforme* as distinct taxa is no longer justified.

Introduction

There are over 200 species of *Pelargonium* L'Hér. ex Aiton in South Africa and comparatively few species elsewhere in the world (Vorster 2000). The genus *Pelargonium* is characterised by a zygomorphic flower with a nectariferous spur fused to the pedicel, five petals (rarely four or two), with the posterior petals larger than the anterior petals and 10 stamens, of which only two to seven are fertile (Van der Walt 1985).

There are 16 sections recognised in the genus (Bakker *et al.* 2004). *Pelargonium reniforme* Curt. is a member of section *Reniformia* (R.Knuth) Dreyer ex J.P.Roux (Roux 2013) and is distributed from Middelburg in Mpumalanga southwards to Riversdale in Western Cape and as far west as Mthatha in Eastern Cape. This species is a small shrublet with tuberous roots and pink to deep magenta flowers. Variation in *P. reniforme* in internode length, leaf shape and petiole length has led to several taxonomic opinions. Ecklon and Zeyher (1835) split *P. reniforme* into three distinct species of the genus *Cortusina* (DC.) Eckl. & Zeyh., namely *Cortusina velutina* Eckl. & Zeyh., *Cortusina rubro-purpurea* Eckl. & Zeyh. and *Cortusina reniformis* (Curt.) Eckl. & Zeyh., but these were reduced by Harvey (1860) to varieties as var. *velutinum* (Eckl. & Zeyh.) Harv., var. *sidaefolium* (Thunb.) Harv. and var. *reniforme*. Knuth (1912) later regarded var. *velutinum* as a synonym of *P. reniforme* and raised var. *sidaefolium* to species status as *P. sidaefolium* (Thunb.) Knuth, which is currently known as *P. sidoides* DC. In 1995, Dreyer, Marais and Van der Walt re-established the recognition of infraspecific taxa of *P. reniforme* by recognising *P. reniforme* subsp. *velutinum* (Eckl. & Zeyh.) Dreyer.

Pelargonium reniforme subsp. *reniforme* was applied by Dreyer, Marais and Van der Walt (1995) to plants with elongated internodes (5 mm – 12 mm), reniform leaves and petioles 5 mm – 50 mm long. This form, although sympatric with *P. reniforme* subsp. *velutinum*, is more abundant in the Port Elizabeth area, Eastern Cape, where it is restricted to drier coastal plains below 300 m.a.s.l. The form designated as *P. reniforme* subsp. *velutinum* has internodes of 1 mm – 7 mm in length and cordate or reniform leaves with petioles of 25 mm – 130 mm in length. Plants with characteristics corresponding to *P. reniforme* subsp. *velutinum* are, according to Dreyer *et al.* (1995), more abundant between Grahamstown and Queenstown, Eastern Cape. In all other respects the two subspecies are identical and their distinction is difficult.

The closely allied *Pelargonium sidoides* differs from *P. reniforme* in having black or very dark purple flowers. It is usually indistinguishable from *P. reniforme* when not flowering, in having an identical habit and leaves that are similar in shape and size, usually cordate and velvety. The distribution of *P. sidoides* overlaps with that of *P. reniforme* but is wider, the species occurring throughout Eastern Cape, Lesotho, Free State and southern Gauteng (Van der Walt & Vorster 1988).

Medicinal use and conservation status

Some *Pelargonium* species are valued by traditional healers for their medicinal uses. The roots or extracts of roots of both *P. sidoides* and *P. reniforme* are used to treat diarrhoea, bronchitis, stomach ailments and respiratory tract infections (Watt & Breyer-Brandwijk 1962). Both species play an important role in traditional medicine and are therefore subject to occasional harvesting for local use, but *P. sidoides* is harvested at a much larger scale for export to Europe for use in the manufacture of a number of medicinal products (Brendler & Van Wyk 2008).

The conservation statuses of the two subspecies of *P. reniforme* are listed as 'Not Evaluated' (South African National Biodiversity Institute [SANBI] 2013a, 2013b), as the difficulty in distinguishing between them hinders data collection for conservation assessments. There is concern about the conservation status of *P. reniforme* as it can be harvested along with *P. sidoides* where the two occur sympatrically because of their morphological similarity. The conservation status of *P. reniforme* is thus currently listed as 'Near Threatened' as a result of suspected widespread overharvesting (Raimondo *et al.* 2012). The conservation status of *P. sidoides* is 'Least Concern' because, although it is heavily harvested, it is a very widespread and common species (De Castro *et al.* 2012). The clarification of morphological differences between the two subspecies of *P. reniforme* is regarded as a high priority by the Threatened Species Programme (D. Raimondo pers. comm., 29 May 2012) so that the conservation status can be properly assessed. We therefore investigated the species in an attempt to resolve the taxonomic problem. Morphological comparisons were made between the two subspecies, as well as with the nearest relative, *P. sidoides*, to clarify taxonomic uncertainty and subsequently contribute to the conservation of this species. The possibility that variation in some morphological characters is related to environmental conditions was also investigated by observing specimens of both subspecies of *P. reniforme* in their natural habitat.

Research method and design

Specimens (101 in total) of both subspecies of *P. reniforme* from the National Herbarium in Pretoria (PRE), all wild-collected and covering the entire geographical range of the subspecies, were studied to assess morphological variation between the two subspecies. A total of 15 specimens were previously identified as *P. reniforme* subsp. *reniforme* and 86 as *P. reniforme* subsp. *velutinum*. In addition, 140 specimens of *P. sidoides* from PRE were investigated in order to determine whether similar variation occurred in this species. The diagnostic characters distinguishing the two subspecies – that is, the lengths of the petioles and the internodes, as well as the leaf-shapes – were recorded for each specimen. A digital image of the holotype of *P. reniforme subsp. velutinum* from the Herbarium at the Swedish Museum of Natural History, Stockholm (S) was also examined. Observations of both subspecies were made in the area between Humansdorp, East London and Queenstown.

Taxonomic treatment

Pelargonium reniforme Curt. in Curtis's Botanical Magazine 14: 493 (1800); Pers.: 229 (1806); Desf.: 457 (1809); Willd.: 703 (1809); Ait.: 171 (1812); Haw.: 307 (1812); Sweet: t. 48 (1820); DC.: 666 (1824); Hoffmg.: 95 (1824); Loudon: 574(1829); Don: 737 (1831); Steud.: 289 (1841); Harv.: 300 (1860); Knuth: 447 (1912); Pole-Evans: 672 (1937); Watt and Breyer-Brandwijk: 454 (1962); Batten and Bokelman: 89 (1966); Smith: 381 (1966); Clifford: 237 (1970); J.J.A. van der Walt: 40, Figure (1977); Webb: 69 (1894); Dreyer, Marais and Van der Walt: 325 (1995). *Cortusina reniforme* (Curt.) Eckl. & Zeyh.: 77 (1835). *Geranium reniforme* (Curt.) Andr.: 108 (18000; Poir.: 751 (1812); Steud.: 679 (1840). *Geraniospermum reniforme* (Curt.) Kuntze: 95 (1891). Iconotype: Curt.: t. 493 (1800).

Cortusina velutina Eckl. & Zeyh.: 77 (1935). *Pelargonium reniforme* var. *velutinum* (Eckl. & Zeyh.) Harv.: 300 (1860). *Pelargonium reniforme* subsp. *velutinum* (Eckl. & Zeyh.) Dreyer, in Dreyer, Marais and Van der Walt: 328 (1995). Type: SOUTH AFRICA. **Eastern Cape**: 'campestriis ad fluvium "Zwartkopsrivier" et collibus in "Adow" [Addo] (Uitenhage)', *Ecklon & Zeyher 598* (S, holo. – digital image!).

Description

Comparison of diagnostic characters of the two subspecies

Based on field observations as well as morphological comparison of herbarium specimens, *P. reniforme* subsp. *velutinum* was found to have internodes that were variable in length and a range of petiole lengths overlapping with those of subsp. *reniforme* (Table 1). This finding contradicts the descriptions given by Dreyer *et al.* (1995) to distinguish the two subspecies.

TABLE 1: Summary of diagnostic characteristics of *Pelargonium* species recorded from herbarium specimens.

Character	*Pelargonium reniforme* subsp. *reniforme*	*Pelargonium reniforme* subsp. *velutinum*	*Pelargonium sidoides*
Leaf shape	Reniform	Cordate or reniform	Cordate or reniform
Petiole length measurements from herbarium specimens (mm)	10–115	6–138	12–200
Petiole length according to Dreyer *et al.* (1995) (mm)	5–508	25–130	Not given
Internode length (mm)	1–15	1–10	1–3
Internode length according to Dreyer *et al.* (1995) (mm)	5–12	1–7	Not given

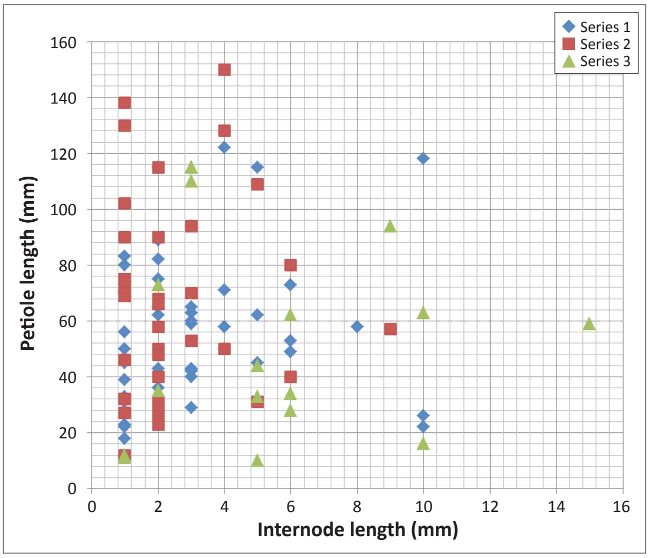
Source: Comparative data where stated from Dreyer, L.L., Marais, E.M. & Van der Walt, J.J.A., 1995, 'A subspecific division of *Pelargonium reniforme* Curt. (Geraniaceae)', *South African Journal of Botany* 61(6), 325–330

Character variation was plotted on a scatter plot chart (Figure 1), which shows that all variation overlaps in both subspecies. This implies that these characters cannot be used to distinguish the two subspecies. The petiole length of subspecies *velutinum* overlaps completely with that of subspecies *reniforme* and this characteristic is therefore also not useful to distinguish the two subspecies. Most of the specimens with characteristics that correspond with subspecies *velutinum* have cordate leaves; although, there are a few that are reniform. All specimens corresponding to subspecies *reniforme* have reniform leaves. Figure 1 shows that variation in the leaf shape is not correlated with petiole length or internode length and therefore this character is too variable to reliably be used to distinguish subspecies.

Pelargonium sidoides is vegetatively similar to the descriptions given in Dreyer *et al.* (1995) for subspecies of *P. reniforme*; however, one consistent characteristic of *P. sidoides* is the short internodes (usually 1 mm but never longer than 3 mm in length), whereas the internode length in *P. reniforme* varies between specimens. The other consistent difference between the two taxa is the flower colour, as described above.

Influence of habitat on morphology

Although specimens with the form *P. reniforme* subsp. *reniforme* are concentrated around Port Elizabeth, observations of plant characteristics in this area revealed that a possible cause for variation is the microhabitat in which the plant was growing. Plants growing in the shade of dense grass in the Port Elizabeth area tended to have both longer internodes (as in subsp. *reniforme*), as well as longer petioles (as in subsp. *velutinum*). It is possible that availability of nutrients, water and sunlight affects internode and petiole lengths, which could explain much of the variability of these characteristics in *P. reniforme*.



Source: Authors' own creation

Series 1, *Pelargonium reniforme* subsp. *velutinum* with cordate leaves; Series 2, *Pelargonium reniforme* subsp. *velutinum* with reniform leaves; Series 3, *Pelargonium reniforme* subsp. *reniforme* with reniform leaves.

FIGURE 1: Scatter-plot chart of character variation within *Pelargonium reniforme* subsp. *reniforme* and *Pelargonium reniforme* subsp. *velutinum*.

Conclusion

The findings of this study show that it is not possible to reliably distinguish between *P. reniforme* subsp. *reniforme* and *P. reniforme* subsp. *velutinum* and we recognise a single variable species for all populations.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

M.A. (SANBI) examined herbarium specimens and took measurements under the training and guidance of J.E.V. (SANBI). M.A. contributed to writing of the manuscript and collated background information. J.E.V. undertook fieldwork, contributed to writing the manuscript and editing it and supervised the project.

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APPENDIX 12: Plan for the *Flora of southern Africa*

Exotic families are marked with an asterisk.

Published volumes and parts are shown in bold.

Cryptogram volumes

Cryptogam volumes (apart from Charophyta) are not numbered, but are known by the name of the group they cover.

Charophyta (as Vol. 9 in 1978)

Bryophyta: Part 1: Musci: **Fascicle 1: Sphagnaceae, Andreaeaceae, Fissidentaceae, Nanobryaceae, Archidiaceae, Ditrichaceae, Seligeriaceae, Dicranaceae, Calymperaceae, Encalyptaceae, Pottiaceae, Bryobartramiaceae, Grimmiaceae (1981)**

Fascicle 2: Gigaspermaceae, Ephemeraceae, Funariaceae, Splachnaceae, Bryaceae, Mniaceae, Eustichiaceae, Rhizogoniaceae, Aulacomniaceae, Bartramiaceae (1987)

Fascicle 3: Erpodiaceae, Rhachitheciaceae, Ptychomitriaceae, Orthotrichaceae, Rhabdoweisiaceae, Racopilaceae, Fontinalaceae, Wardiaceae, Hedwigiaceae, Cryphaeaceae, Leucodontaceae, Prionodontaceae, Trachypodaceae, Pterobryaceae, Meteoriaceae, Leptodontaceae, Neckeraceae, Thamnobryaceae, Hookeriaceae (1998)

Fascicle 4: Fabroniaceae, Leskeaceae, Thuidiaceae, Rigodiaceae, Amblystegiaceae, Brachytheciaceae, Entodontaceae, Plagiotheciaceae, Catagoniaceae, Sematophyllaceae, Hypnaceae, Hylocomiaceae, Polytrichaceae

Hepatophyta: Part 1: Marchantiopsida: **Fascicle 1: Targioniaceae, Lunulariaceae, Aytoniaceae, Cleveaceae, Exormothecaceae, Marchantiaceae, Oxymitraceae, Ricciaceae (1999)**

Anthocerotophyta

Pteridophyta (1986)

Flowering plants volumes

Vol. 1: Stangeriaceae, Zamiaceae, Podocarpaceae, Pinaceae*, Cupressaceae, Welwitschiaceae, Typhaceae, Zosteraceae, Potamogetonaceae, Ruppiaceae, Zannichelliaceae, Najadaceae, Aponogetonaceae, Juncaginaceae, Alismataceae, Hydrocharitaceae (1966)

Vol. 2: Poaceae

Vol. 3: Cyperaceae, Arecaceae, Araceae, Lemnaceae, Flagellariaceae

Vol. 4: Part 1: Restionaceae

Part 2: Xyridaceae, Eriocaulaceae, Commelinaceae, Pontederiaceae, Juncaceae (1985)

Vol. 5: Part 1: Fascicle 1: **Aloaceae (First part): *Aloe* (2000)**

Fascicle 2: **Asphodelaceae (First part): *Kniphofia* (2005)**

Colchicaceae, Eriospermaceae, Asphodelaceae **(*Chortolirion*, 1995 in *Bothalia* 25: 31–33; *Poellnitzia*, 1995 in *Bothalia* 25: 35, 36)**

Part 2: Alliaceae, Liliaceae*, Hyacinthaceae, **Agavaceae* (1996 in *Bothalia* 26: 31–35)**

Part 3: Dracaenaceae, Asparagaceae, Luzuriagaceae, Smilacaceae (1992)

Vol. 6: Haemodoraceae, Amaryllidaceae, Hypoxidaceae, Tecophilaeaceae, Velloziaceae, Dioscoreaceae

Vol. 7: Iridaceae: Part 1: Nivenioideae

Part 2: Ixioideae: Fascicle 1: **Ixieae (First part): Ixiinae, Tritoniinae (1999)**

Fascicle 2: *Syringodea*, *Romulea* (1983)

Vol. 8: Musaceae, Strelitziaceae, **Zingiberaceae (1998 in *Bothalia* 28: 35–39)**, Cannaceae*, Burmanniaceae, Orchidaceae **(*Holothrix*, 1996 in *Bothalia* 26: 125–140)**

Vol. 9: **Part: Urticaceae (2001)**

Casuarinaceae* **(2000 in *Bothalia* 30: 143–146), Piperaceae (2000 in *Bothalia* 30: 25–30)**, Salicaceae, Myricaceae, Fagaceae*, **Ulmaceae (1999 in *Bothalia* 29: 239–247)**, Moraceae, **Cannabaceae* (1999 in *Bothalia* 29: 249–252)**, Proteaceae

Vol. 10: Part 1: **Loranthaceae, Viscaceae (1979)**, Santalaceae, Grubbiaceae, Opiliaceae, Olacaceae, Balanophoraceae, Aristolochiaceae, Rafflesiaceae, Hydnoraceae, Polygonaceae, Chenopodiaceae, Amaranthaceae, Nyctaginaceae

Vol. 11: Phytolaccaceae, Aizoaceae, Mesembryanthemaceae

Vol. 12: Portulacaceae, Basellaceae, Caryophyllaceae, Illecebraceae, Cabombaceae, Nymphaeaceae, **Ceratophyllaceae (1997 in *Bothalia* 27: 125–128)**, Ranunculaceae, Menispermaceae, Annonaceae, Trimeniaceae, Lauraceae, Hernandiaceae, Papaveraceae, Fumariaceae

Vol. 13: Brassicaceae, Capparaceae, Resedaceae, Moringaceae, Droseraceae, Roridulaceae, Podostemaceae, Hydrostachyaceae (1970)

Vol. 14: Crassulaceae (1985)

Vol. 15: Vahliaceae, Montiniaceae, Escalloniaceae, Pittosporaceae, Cunoniaceae, Myrothamnaceae, Bruniaceae, Hamamelidaceae, Rosaceae, Connaraceae

Vol. 16: Fabaceae: **Part 1: Mimosoideae (1975)**

Part 2: Caesalpinioideae (1977)

Part 3: Papilionoideae: Fascicle 1: Swartzieae–Robinieae

Fascicle 2: Indigofereae

Fascicle 3: Desmodieae, Phaseoleae

Fascicle 4: Psoraleeae–Galegeae

Fascicle 5: Loteae–Liparieae

Fascicle 6: Crotalarieae (*Aspalathus*) (1988)

Fascicle 7: Crotalarieae (*Bolusia–Lebeckia*)

Fascicle 8: Crotalarieae (*Lotononis–Wiborgia*)

Fascicle 9: Crotalarieae (*Pearsonia–Argyrolobium*), Genisteae (*Cytisus–Ulex*)

Vol. 17: Geraniaceae, Oxalidaceae

Vol. 18: Part 1: Linaceae, Erythroxylaceae, Zygophyllaceae, Balanitaceae

Part 2: Rutaceae

Part 3: Simaroubaceae, Burseraceae, Ptaeroxylaceae, Meliaceae (Aitoniaceae), Malpighiaceae (1986)

Vol. 19: Part 1: Polygalaceae, Dichapetalaceae

Part 2: Euphorbiaceae, Callitrichaceae, **Buxaceae (1996 in *Bothalia* 26: 37–40)**

Part 3: Anacardiaceae: **Fascicle 1: *Rhus* (1993)**

Fascicle 2: remaining genera

Aquifoliaceae (1994 in *Bothalia* 24: 163–166)

Vol. 20: Celastraceae, Icacinaceae, Sapindaceae, Melianthaceae, Greyiaceae, Balsaminaceae, Rhamnaceae, Vitaceae

Vol. 21: **Part 1: Tiliaceae (1984)**

Malvaceae, Bombacaceae, Sterculiaceae

Vol. 22: Ochnaceae, Clusiaceae, Elatinaceae, Frankeniaceae, Tamaricaceae, Canellaceae, Violaceae, Flacourtiaceae, Turneraceae, Passifloraceae, Achariaceae, Loasaceae, Begoniaceae, Cactaceae (1976)

Vol. 23: Geissolomataceae, Penaeaceae, Oliniaceae, Thymelaeaceae, Lythraceae, Lecythidaceae

Vol. 24: Rhizophoraceae, Combretaceae, Myrtaceae, Melastomataceae, **Onagraceae (1997 in *Bothalia* 27: 149–165), Trapaceae (1998 in *Bothalia* 28: 11–14)**, Haloragaceae, Gunneraceae, Araliaceae, Apiaceae, Cornaceae

Vol. 25: Ericaceae

Vol. 26: Myrsinaceae, Primulaceae, Plumbaginaceae, Sapotaceae, Ebenaceae, Oleaceae, Salvadoraceae, Loganiaceae, Gentianaceae, Apocynaceae (1963)

Vol. 27: Part 1: Periplocaceae, Asclepiadaceae (Microloma–Xysmalobium)

Part 2: Asclepiadaceae (*Schizoglossum–Woodia*)

Part 3: Asclepiadaceae (*Asclepias–Anisotoma*)

Part 4: Asclepiadaceae (*Brachystelma, Ceropegia, Riocreuxia*) (1980)

Asclepiadaceae (remaining genera)

Vol. 28: Part 1: Convolvulaceae (2000)

Part 2: Hydrophyllaceae, Boraginaceae

Part 3: Stilbaceae, Verbenaceae **(*Vitex*, 1996 in *Bothalia* 26: 141–151)**

Part 4: Lamiaceae (1985)

Part 5: Solanaceae, Retziaceae

Vol. 29: Scrophulariaceae

Vol. 30: Part 1: Bignoniaceae, Pedaliaceae, Martyniaceae, Orobanchaceae

Part 2: Gesneriaceae, Lentibulariaceae

Part 3: Acanthaceae: Fascicle 1: Justiciinae (1995)

Acanthaceae (remaining genera), Myoporaceae

Vol. 31: Part 1: Fascicle 1: **Plantaginaceae (1998 in *Bothalia* 28: 151–157)**, Rubiaceae (Rubioideae—First part)

Fascicle 2: Rubiaceae (Rubioideae—Second part): Paederieae, Anthospermeae, Rubieae (1986)

Fascicle 3: Ixoroideae, Chinchonoideae

Part 2: Valerianaceae, Dipsacaceae, Cucurbitaceae

Vol. 32: Campanulaceae, **Sphenocleaceae (2000 in *Bothalia* 30: 31–33)**, Lobeliaceae, Goodeniaceae

Vol. 33: Asteraceae: Part 1: Lactuceae, Mutisieae, 'Tarchonantheae'

Part 2: Vernonieae, Cardueae

Part 3: Arctotideae

Part 4: Anthemideae: **Fascicle 1: *Eriocephalus, Lasiospermum* (2001)**

Part 5: Astereae

Part 6: Calenduleae

Part 7: Inuleae: Fascicle 1: Inulinae

Fascicle 2: **Gnaphaliinae (First part) (1983)**

Part 8: Heliantheae, Eupatorieae

Part 9: Senecioneae

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FSA contributions 1: Aquifoliaceae. S. Andrews. 1994. *Bothalia* 24: 163–166.

FSA contributions 2: Asphodelaceae/Aloaceae, 1029010 Chortolirion. G.F. Smith. 1995. *Bothalia* 25: 31–33.

FSA contributions 3: Asphodelaceae/Aloaceae, 1028010 Chortolirion. G.F. Smith. 1995. *Bothalia* 25: 35, 36.

FSA contributions 4: Agavaceae. G.F. Smith & M. Mössmer. 1996. *Bothalia* 26: 31–35.

FSA contributions 5: Buxaceae. H.F. Glen. 1996. *Bothalia* 26: 37–40.

FSA contributions 6: Orchidaceae: Holothrix. K.L. Immelman. 1996. *Bothalia* 26: 125–140.

FSA contributions 7: Verbenaceae: Vitex. C.L. Bredenkamp & D.J. Botha. 1996. *Bothalia* 26: 141–151.

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FSA contributions 15: Piperaceae. K.L. Immelman. 2000. *Bothalia* 30: 25–30.

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FSA contributions 17: Casuarinaceae. C.M. Wilmot-Dear. 2000. *Bothalia* 30: 143–146.

FSA contributions 18: Salicaceae s. str. M. Jordaan. 2005. *Bothalia* 35: 7–20.

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FSA contributions 21: Connaraceae. M. Jordaan. 2013. *Bothalia* 43: 99–108.
FSA Contribution 22: Asteraceae: Calenduleae: *Garuleum*. N. Swelankomo. 2013. *Bothalia* 43: 167–178.