Phytotaxa 269 (3): 193–208
http://www.mapress.com/j/pt/

Article

ISSN 1179-3155 (print edition)
PHYTOTAXA
ISSN 1179-3163 (online edition)

http://dx.doi.org/10.11646/phytotaxa.269.3.3

History and drivers of plant taxonomy in South Africa

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Abstract

The development of plant taxonomy in South Africa from about 1600 to 2015 is reviewed, with emphasis on the main driving factors that have influenced the research direction, techniques used, and choice of taxonomic research topic. In addition, key personalities and important historical events are highlighted. The early scientific interest in the flora of South Africa and, by implication, its taxonomy was initially driven by curiosity. Exploration of plants for economic purposes especially for medicinal use and later, agriculture, drove the scientific development of botany and formed the foundation of formal botany in the country. Establishment of botanical gardens and herbaria influenced botanical research, in particular the field of taxonomy. Technological advances lead to increased modernisation of taxonomy as new sources of information derived from other fields of botany were incorporated into taxonomic research. Funding priorities and availability of financial resources influence the taxonomic research that is conducted, and international initiatives that impact on priorities in biodiversity science have further impact on taxonomy. At present the predominant culture of taxonomy is directed towards electronic dissemination of taxonomic information, leading to increased accessibility and connectivity. Strategic planning of plant taxonomy in South Africa has become more formal as relevance and impact of research products increasingly need to be justified with respect to the financial costs of conducting taxonomic research.

Key words: barcoding, botanical gardens, botany, connectivity phase, development, flora, herbarium, SABONET, SANBI, research, systematics, taxonomists, training

Introduction

This review examines 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 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 drivers that influence taxonomy. For the purposes of this review, plant taxonomy is defined as the naming, description and classification of organisms, encompassing the investigation of causes and processes of evolution and the study of phylogeny (Stuessy *et al*. 2014), and is here regarded as synonymous with the word 'systematics'. Since the mandate to coordinate taxonomy in South Africa belongs to the South African National Biodiversity Institute (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. Timelines depicting key events in the development of plant taxonomy in South Africa from about 1600 to 2015 are supplied in Figs. 1–3.

In addition to those mentioned in this article, numerous amateur botanists and eminent scientists or plant collectors have contributed significantly to the development of South African taxonomy. Biographic notes on many of the amateur and professional 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),

Accepted by Piero Delprete: 20 Jul. 2016; published: 5 Aug. 2016

McCracken & McCracken (1988), Rourke (1999), and Huntley (2012). Many observations on recent developments were made through interpretation and personal communication by the authors, hence the lack of citation for recent historical events.

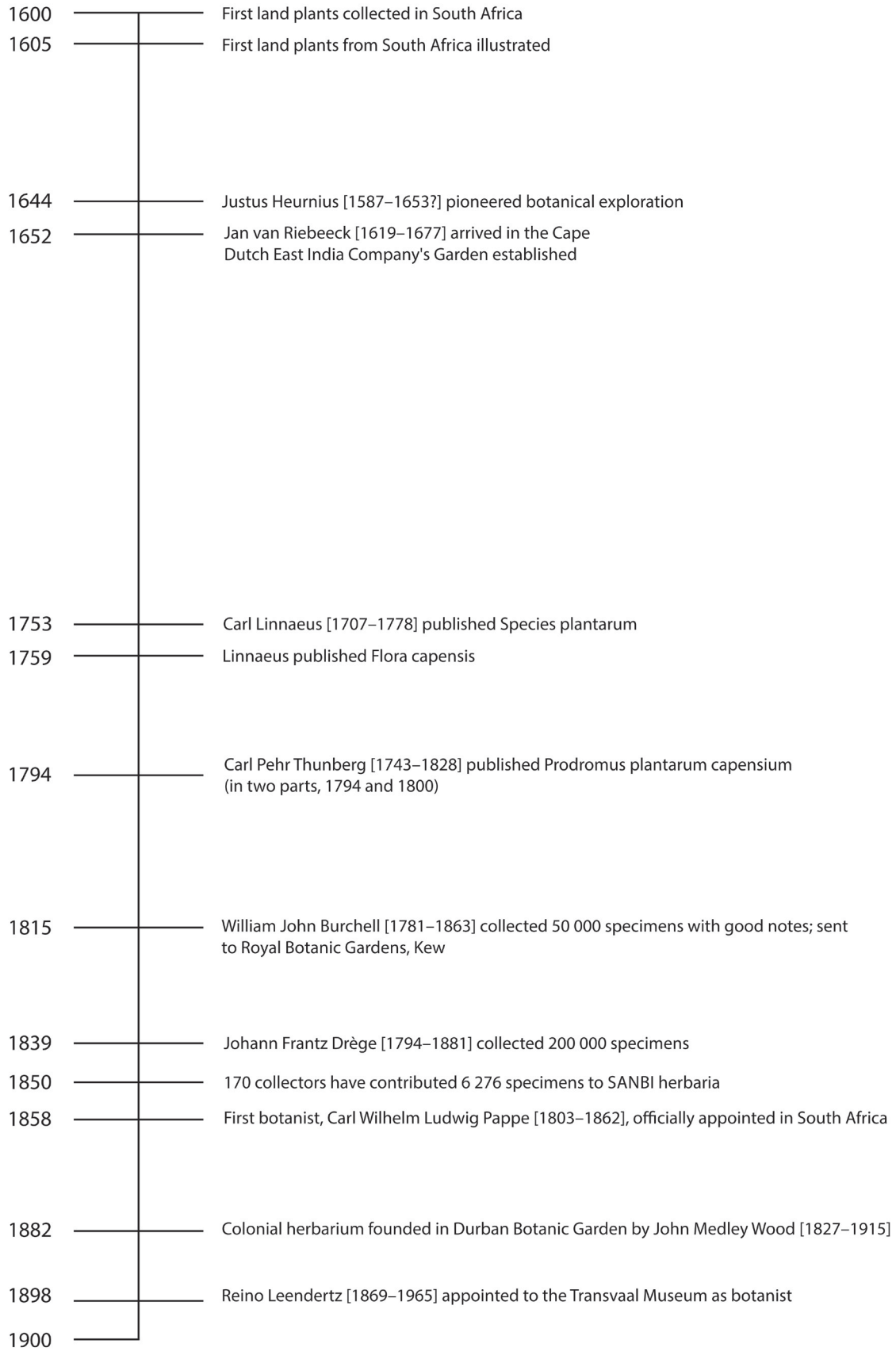

FIGURE 1. Timeline: 1600–1900. The exploration phase in South African botanical taxonomy, covering about 300 years.

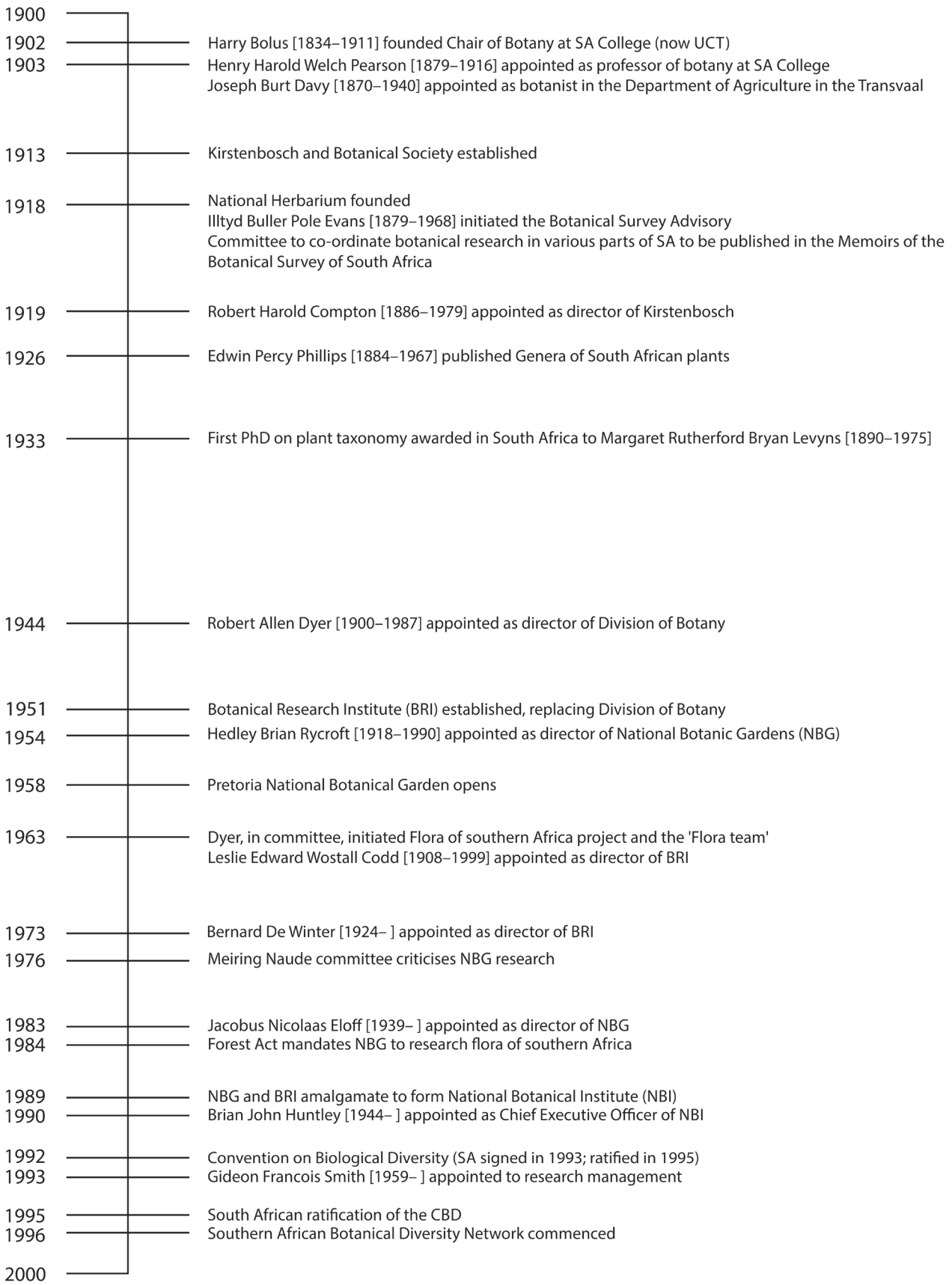

FIGURE 2. Timeline: 1900–2000. The synthetic and experimentation phase in South African botanical taxonomy. The synthetic phase covered about 70 years, and transitioned into the experimentation phase with the application of modern technology and computerisation in South Africa in the 1970s.

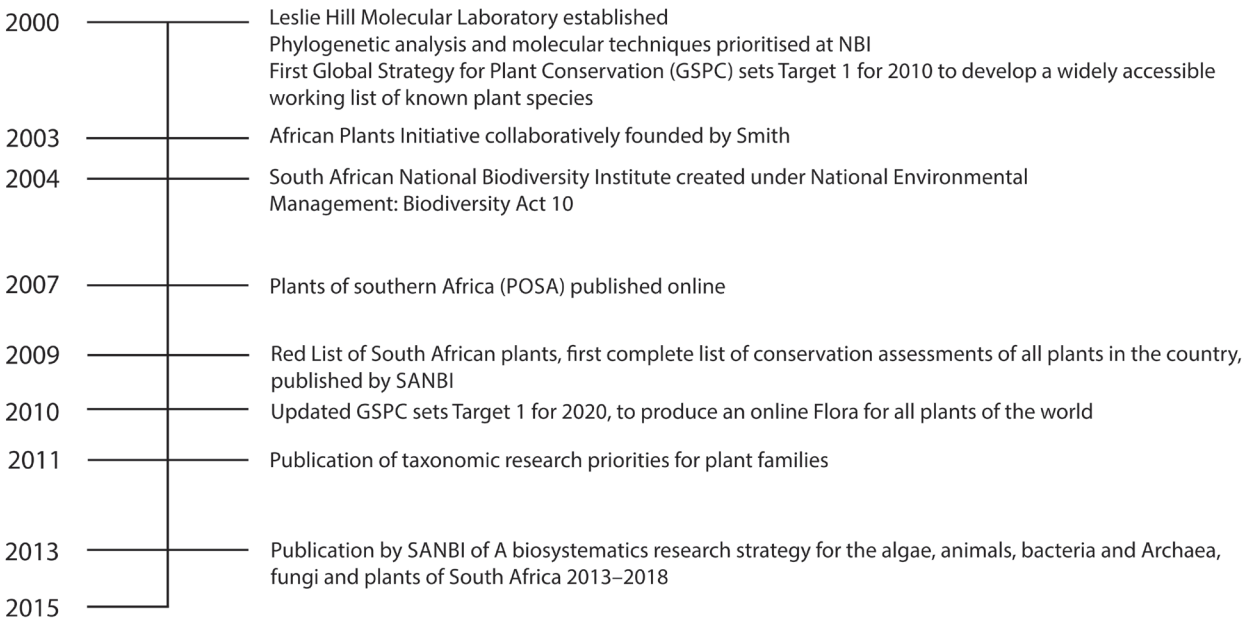

FIGURE 3. Timeline: 2000–2015. The phase of connectivity of South African taxonomy.

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 Bartholomew Diaz 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 species of *Haemanthus* Linnaeus (1753: 325) 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* Brown (1811: 81) 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 the 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 made little attempt to cast them into a classification system. This changed after 1753 when Carl Linnaeus published *Species plantarum*, in which the value of using binomial plant names became increasingly apparent in his proposed classification system based predominantly on reproductive organs. This so-called sexual classification system facilitated the identification of species but is now accepted as having been largely artificial as it failed to reflect natural groupings. This was about a century before the publication of Charles Darwin's *On the origin of species*, in which evolution became better understood, and was eventually provided for, in 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 precise locality notes and descriptions, with 'Cape of Good Hope', or 'Cabo Bona Spei', being examples of typical early localities recorded. 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 features and additional information collected in the field. Burchell advocated the establishment of a botanical garden in Cape Town, and collected over 40 000 plant specimens between 1811 and 1815. The large majority have not been preserved but of those that have, most are kept in the herbarium of the Royal Botanic Gardens, Kew. Johann F. Drège was another botanist who collected a sizeable number of plant 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.

Until about 1850 more than 170 people collected herbarium specimens of South African plant species (Glen & Germishuizen 2010), although only 6 276 of these are presently in SANBI herbaria (comprising the National Herbarium in Pretoria, Compton Herbarium in Cape Town and KwaZulu-Natal Herbarium in Durban) 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, the discovery of diamonds (Kimberley) and gold (Mpumalanga and the Witwatersrand), and hence 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 over the ensuing 120 years, peaking in 1976 according to specimen accession records of SANBI's herbaria (Fig. 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.

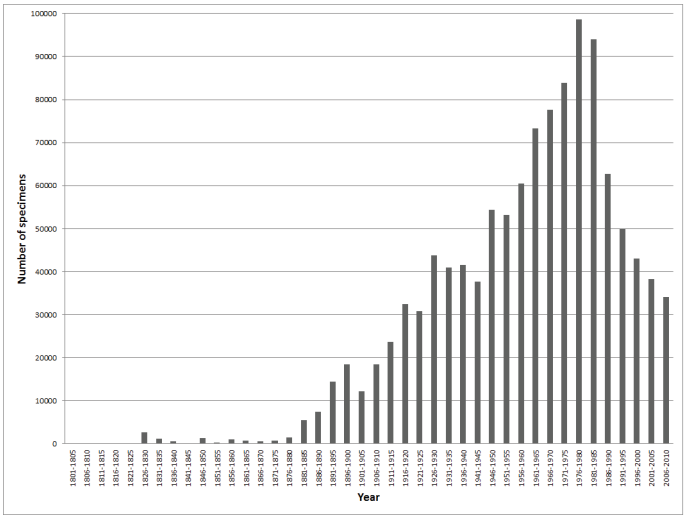

FIGURE 4. Number of herbarium specimens of South African plants collected per 5 year interval represented in SANBI herbaria.

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 records of notable botanists who 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 present-day 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 South Africa. 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 South Africa. 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.

Influence of establishment of formal botany in South Africa

In 1759 Carl Linnaeus published the first *Flora capensis* consisting of 502 names of plant species that he received from botanists doing fieldwork in 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 what is today the University College of Dublin, Ireland, and was approached by Joseph D. Hooker to assist in a series of Colonial Floras along with Otto 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 *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 was appointed. This was Carl W.L. Pappe, a medical practitioner not trained in botany, 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 the routine search for and description of new species, often conducted by amateur taxonomists. 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 plant taxonomy to students, a tradition that has been continued by his successors. Until 1960, although many universities had been founded in the country, very few plant 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. 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, now the KwaZulu-Natal Herbarium, was placed under the Division upon agreement with John Medley Wood, the curator of the herbarium, thus imparting a national character on the Division. The Natal Herbarium was

officially established as the Colonial Herbarium in 1882, but its history can be traced back to 1848 (Schrire 1983). 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 South Africa* (1920 to current), now *Flowering plants of Africa*, and *Bothalia* (1921–2013), now *Bothalia—African Biodiversity & Conservation*. At that time Inez Verdoorn was appointed 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 the 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 prescribed book 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.

The overarching influence on plant taxonomy for a few decades at the beginning of the 20th century remained the search for economically important plants. 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 first compilation of plant genera of South Africa, the *Genera of South African flowering plants* (Phillips 1926, 1951). He was succeeded by 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. 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. FSA covered the flora of the following countries in southern Africa: South Africa, Namibia, Lesotho and Swaziland; Botswana was added later. The first FSA volume was published in 1963 and the project continued beyond the conversion of BRI to the National Botanical Institute (NBI) in 1989, and the 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 until 1973. Codd was an inspiring and gifted plant taxonomist who was very supportive of young taxonomists, nurturing taxonomic capacity for the future.

Influence of the South African botanical gardens and their herbaria on taxonomic research

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 vital 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 various species of buchu (*Agathosma* Willdenow (1809: 259)). 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, 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, 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 in the 1800s in Grahamstown, in which Selmar Schönland of the newly established Rhodes University College would hold classes on the study of living plants; King William's Town, curated by Thomas R. Sim who proclaimed that until botany was taught in schools the importance of botanical gardens would not be understood and was then successful in getting the subject introduced into Dale College in 1893; Graaff-Reinet and Queenstown. The Durban Botanic Gardens was established in the 1850s (McCracken 1996). 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 (Schrire 1983). Medley Wood contributed extensively to the collections in the herbarium and discovered at least 62 new plant species. 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 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 was 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 NBG 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.

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 their beginnings in South Africa as providing sailors and settlers with agricultural supplies, botanical gardens evolved to play increasingly important roles 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.

Modernisation of taxonomy in South Africa

Bernard de Winter took over as director of the BRI in 1973 following Codd's retirement. De Winter (1970) recognised that modern approaches to taxonomy, using information obtained from as many fields of research as possible, would enhance traditional taxonomy based mainly on macromorphology. Modern approaches at the time, which were in vogue in Europe and North America, included using additional taxonomic evidence derived from sources such as anatomy, palynology, cytology, genetics, physiology, and chemistry to improve classifications. 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 of plant pollen and anatomy, first published in the 1970s, gained popularity in the 1980s and especially 1990s. For example, 10 papers in which SEM techniques were used were published in *South African Journal of Botany* in 1996. In addition, De Winter believed that taxonomy should serve as a source of all kinds of information concerning distribution, economic uses, and 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 *et al*. 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 plants 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 (Germishuizen & Meyer 2003; Germishuizen *et al*. 2006), 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 was transferred to 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*. 1999). 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 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 J. Huntley as institutional Director. The objectives of the NBI were contained in the Forest Amendment Act 1991 (Article 58). These objectives were as follows:

- 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;
- establish, develop and maintain collections of plants in national botanical gardens and in herbaria;
- undertake and promote research in connection with indigenous plants and related matters;
- study and cultivate specimens of endangered plant species;
- investigate and utilise the economic potential of indigenous plants; and
- 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 various 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 natural history information, such as abundance and population size, 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 phylogenetic analyses, later complemented by molecular techniques in plant taxonomy was prioritised, 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, and following the departure of Eloff, one of us (GFS) became the Director of Research, and collaboratively established large internationally funded initiatives. Thereafter the CSPs prioritised specific projects rather than giving broad guidelines for prioritisation.

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 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, among 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, 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 (later 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 categorising plant diversity (Smith & Smith 2006).

In 2003 the African Plants Initiative, which expanded into the Global Plants Initiative, was initiated (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 (Smith & Figueiredo 2013), 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, plant taxonomic research 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 biosystematics 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. Convention on Biological Diversity; CITES) 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.

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 one of us (GFS) 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 taxonomic studies underway at SANBI in 2005–2006, 12 were utilising molecular techniques, mostly to produce 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); and journals in which molecular papers could be published often have a much higher impact factor than those in which more 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 importance of the final uptake of the 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 for the Biosystematics and Biodiversity Collections division, where one of the activities listed 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 *et al*. 1998).

International initiatives that drive South African taxonomy

The first target of the original Global Strategy for Plant Conservation (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 (http://www.floraiberica.es/eng/).

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 posterity in herbaria. Progress in molecular techniques, and the development of phylogenetic analyses (e.g. Bayesian analysis), has enhanced the popularity of these fields of study (Stuessy *et al.* 2014). It is also now possible given the recent advances in high-throughput sequencing technologies that more complete genomic datasets (comprising both DNA and RNA data) will contribute significantly towards a better understanding of evolutionary relationships amongst species (RBG Kew 2016).

Current priorities for taxonomic research

A 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 (Victor *et al.* 2015a). Existing taxonomic data derived from databases were analysed, and the literature interrogated, using an objective methodology that was developed to determine taxonomic priorities, not only for plants, but also for most other groups of organisms (Victor *et al*. 2015b). The SANBI website hosts a list of taxonomic projects and expertise of botanists, both professional and amateur, from herbaria and universities countrywide, as well as priority genera for research (http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies). This list is kept up-to-date with the intention of providing a means of coordinating biosystematics research on the South African flora.

One of the primary objectives of taxonomy is to develop a natural and predictive classification system with high information content that reflects evolutionary relationships among plants. To achieve this, results from molecular studies (among the best data sources for phylogenetic reconstruction) are integrated with other sources of evidence such as comparative anatomical, ecological, embryological, cytological, physiological, and palynological studies. Although alpha-taxonomic work is prioritised, it is best enhanced with a variety of information from other sources to produce the best possible research products (Victor *et al*. 2015a).

Within SANBI, existing capacity in biosystematics research is and will continue to be utilised towards addressing the priorities identified in the Strategy. There is still a need for further exploration of South Africa's biodiversity, so that improved foundational biodiversity information can be provided to end users (Victor *et al*. 2015a). The e-Flora project (Victor *et al*. 2013b), once delivered online in 2020, will continue to be maintained by the Biosystematics Division of SANBI, and further developed and improved. 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, in particular the many end users of plant taxonomic information.

Conclusions and future prospects

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 molecular research. Modern taxonomic research employs

more complex methods of analysis including statistical/numerical techniques and phylogenetic analyses. 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 predominating 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, identifying specific families, genera and species complexes requiring taxonomic attention. South African researchers have increasingly needed to account for how government money is spent, and relevance and impact of research products on society need to be justified. This has required SANBI leaders to develop more stringent prioritisation exercises (Victor *et al*. 2013a; Victor *et al.* 2015a).

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 the 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 very 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 potentially facilitate the identification of plant specimens. However, if we are unable to closely match the sequence of an unknown specimen to that of an existing reference specimen, a barcode sequence cannot qualify the taxon as a new species or as an undetermined 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.

Certain persons have the 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. However, although at present there is emphasis on creation of technological identification tools and the e-Flora of South Africa, it is estimated that about 5% (or 1100 species) of the current known flora is yet undiscovered (Victor *et al*. 2015c). Therefore, taxonomic expertise will remain vital for the naming, description, classification, and evolutionary and phylogenetic interpretation of biodiversity based on the full spectrum of variation patterns displayed by plants comprising the rich and diverse flora of South Africa.

Acknowledgements

The authors are grateful for the generous assistance provided by Ms Shanelle Ribeiro, Ms Hannelie Snyman, Mr Katleho Molofo and Ms Sandra Turck. The University of Pretoria is thanked for financial support. We would also like to thank the anonymous referees for their valuable input.

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