Taxonomic research priorities for the conservation of the South African flora

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DATES:
Received: 16 Mar. 2012
Revised: 28 Aug. 2012
Accepted: 26 Sep. 2012

KEYWORDS:
threatened species; IUCN Red List; taxonomic revisions; taxonomic productivity; Global Strategy for Plant Conservation

HOW TO CITE:
Von Staden L, Raimondo D, Dayaram A. Taxonomic research priorities for the conservation of the South African flora. S Afr J Sci. 2013;109(3/4), Art. #1182, 10 pages. http://dx.doi.org/10.1590/sajs.2013/1182

Taxonomic revisions, monographs and floras are the most important, and often the only source of data for assessing the extinction risk of plants, with recent revisions contributing to more accurate assessments. The recently completed Red List of South African plants involved an overview of the taxonomic literature pertaining to the South African flora, providing an opportunity to identify critical gaps in taxonomic coverage. In this study we identified taxonomic research priorities for effective conservation of South African plants. Priorities were identified at genus level, according to time since last revision, level of endemism, collecting effort, proportion of taxa included in revisions, and specimen identification confidence. Although the results indicate that 62% of the flora has been recently revised, revisionary taxonomic output has declined drastically, particularly in the past 10 years. This decline is a result of a decrease in revisionary productivity per taxonomist and not a result of a decline in the number of working taxonomists. The family Aizoaceae is the top priority for taxonomic research with 55% of taxa in need of revision, followed by Hyacinthaceae with 34% of taxa not yet revised. Ericaceae, Euphorbiaceae, Rutaceae, Malvaceae, Asteraceae and Acanthaceae are also priorities with over 30% of taxa last revised before 1970. We recommend the reinstatement of the *Flora of Southern Africa* project in an online format in order to centralise South Africa's existing taxonomic information and reinvigorate revisionary taxonomic study. This project will allow South Africa to fulfil its commitments to the Convention on Biodiversity by achieving Target 1 of the Global Strategy for Plant Conservation.

Introduction

The first comprehensive Red List of the indigenous vascular plants of South Africa was published in 2009.[1] The Red List project involved the evaluation of more than 20 000 plant taxa (species, subspecies and varieties) against scientifically based, quantitative criteria for the determination of extinction risk.[2,3] These criteria demand data on population size, rates of population decline, range size, number and location of subpopulations, and knowledge of threats, ecology and biology of species. Such data are available for only a small number of well-studied species; however, the criteria are flexible enough to allow estimation and inference of criteria parameters in the absence of high-quality observation data.[2] For example range size may be estimated based on georeferenced herbarium specimens and population decline may be inferred if the extent of a species' habitat is known to be decreasing as a result of human impact.

There is, however, a core body of information without which risk of extinction cannot be assessed: knowledge of the distribution range, habitat requirements and the biology of the species. This basic information is obtained primarily from the taxonomic literature. Taxonomy as a science is the synthesis of data derived from collected specimens to define and circumscribe species and their distributions. While taxonomic study is not able to supply all the data required for Red List assessments, it allows for further study of biodiversity by providing a means to name and classify biological observations. Therefore, groups of species that are taxonomically well studied are also generally better known biologically, while those that are in need of taxonomic revision tend to remain poorly known species.

The comprehensive assessment of South African plants was significantly aided by recent, comprehensive taxonomic monographs, revisions, floras and, to a lesser extent, conspectuses. Recent treatments mean that the majority of taxa in a group are well defined, and their distributions and habitats are accurately circumscribed. In addition, groups with recent taxonomic treatments are most often better collected, which means that herbarium specimens are a more reliable indicator of the relative abundance of taxa, and there is higher confidence that specimen identifications are correct.[4]

On the other hand, taxa in genera and families with no or very outdated revisions were extremely difficult to evaluate, and many had to be assigned to the category 'Data Deficient' , indicating that they are suspected to be at risk of extinction, but sufficient data to apply the quantitative criteria is lacking. Confidence in the accuracy of the assessments for taxa in such groups is also very low,[5] and one study has shown that 75% of Red List assessments completed in the absence of revisions were incorrect categorisations, when compared to reassessments of the same taxa after the completion of revisions.[6]

In this study we used the bibliography of over 3000 taxonomic literature references that was compiled as part of the South African plant Red List project to evaluate the state of revisionary taxonomic coverage of the South African flora, identify knowledge gaps and set research priorities, as well as to analyse recent taxonomic output to assess the capacity of South African taxonomic researchers to meet research needs towards achieving Target 1 of the Global Strategy for Plant Conservation (GSPC).

History of plant taxonomy in South Africa

The first South African plants were described and illustrated in European herbals in the 17th century,[7] but the first attempt to catalogue, describe and classify all known plants of the Cape flora was completed by the Swedish botanist Carl Peter Thunberg between 1807 and 1820.[7] This achievement was followed by the *Flora Capensis*

series, which was published in seven volumes between 1859 and 1925 and contained treatments of more than 11 000 taxa.

As the knowledge of the richness and diversity of the South African flora was understandably still very limited in the late 19th century, the series became out of date very quickly, and in the 1960s the *Flora of Southern Africa* series was established by the state-funded Botanical Research Institute (now the South African National Biodiversity Institute), with the aim of completing a taxonomic treatment of the plants of South Africa, Namibia, Botswana, Swaziland and Lesotho by 2000.[8] Revisions were completed by staff of the institute, but contributions from other local and international researchers were also accepted. Progress has been slow,[9] however, and to date flora treatments of only 402 genera, representing 17% of the indigenous South African vascular plant taxa, have been completed (including 18 shorter 'FSA contributions' published in the journal *Bothalia*), and no new sections have been published since 2005.

In the meantime many local and internationally based researchers have completed revisions and monographs of South African plant families and genera independently of the *Flora of Southern Africa* project. These publications are valuable contributions to the knowledge of the South African flora, but unfortunately these independent revisions are scattered across many scientific journals and various other publications, making them difficult to access, particularly for users outside the academic system.

Taxonomy and conservation of the South African flora

The effective conservation of South Africa's indigenous plants is a significant challenge. South Africa has the world's richest temperate flora,[10] with ca. 20 700 indigenous vascular plant taxa in 1890 genera and 252 families. Eight families comprising 349 genera – 67% of plant taxa – are endemic to South Africa. In addition, South Africa is one of only two countries in the world whose borders contain three globally recognised hotspots of biodiversity,[11] comprising areas with exceptionally high levels of species diversity and endemism that are also under significant threat from human impact on the environment. With the limited resources allocated to conservation, it is essential that well-informed priorities are set to ensure effective channelling of conservation efforts. Red Lists are primarily used to guide priority setting in a wide range of conservation initiatives in South Africa, and because they are reliant on adequate taxonomic treatments, a sound taxonomic baseline is needed to avoid the misdirection of scarce resources resulting from a lack of knowledge of species, their distributions and habitat requirements.

Increased international focus on stemming the loss of biodiversity, starting with the Rio Earth Summit of 1992 where the United Nations Convention on Biological Diversity (CBD) was ratified, has led to a renewed recognition of the importance of the science of descriptive (alpha) taxonomy as the basis without which the effective conservation of biodiversity cannot be achieved.[5,6,12-15] As a result, numerous initiatives and projects aimed at increasing support for taxonomic research through funding and capacity building have been established,[16-20] and yet, at the same time, the decline of taxonomic research worldwide continues.[9,21-24]

The GSPC is a programme of the CBD aimed at providing a framework for a coordinated approach to plant conservation through 16 outcome-oriented targets. As a party to the CBD, South Africa has adopted the GSPC for implementation at national level. The importance of a strong taxonomic basis for plant conservation is recognised in GSPC Target 1, which in the second phase (2010–2020) of the implementation of the strategy has been revised from 'a working list of known plant species completed by 2010' to 'an online flora of all known plants available by 2020'. This change was made because the compilation of a global checklist of plant species was largely successfully achieved, and because checklists alone are not sufficient to support plant conservation: information on geographic distribution, identification tools, pictures and basic descriptions are also needed.[25]

This new target presents a challenge because South Africa lags behind many other regional flora projects of the world, which are either already complete or nearing completion.[9] Achieving this target for South Africa requires consolidating taxonomic information from scattered publications, updating outdated information and focusing on addressing gaps in the knowledge of our flora. As the Red List project relied so heavily on taxonomic literature, it necessitated a near-comprehensive overview of the taxonomic literature pertaining to the South African flora, and therefore provided a unique opportunity to identify critical gaps in taxonomic coverage of the flora.

Methods

Literature review

All vascular plant genera with three or more taxa indigenous to South Africa (923 genera in total), representing 94% of the flora, were included in the analysis. For each genus, all taxonomic revisions (including flora treatments) were recorded in a database, together with the date of publication, in order to determine the most recent date of taxonomic revision for each taxon. As taxonomic treatments can take many forms (e.g. monographs, revisions, synopses and conspectuses), and there is no strict definition of what must be included in each of these types of treatments, for the purposes of this study, any treatment that contained an identification key to species level, scientific names listed together with their protologue citations, type specimens, and synonyms, were included. Partial revisions, such as for subgenera and subcountry geographical regions, were also included, but short taxonomic notes, such as revisions of species complexes and descriptions of new taxa, were excluded. Although such shorter publications contribute to the bulk of taxonomic literature available on the South African flora, it has been noted that there is a trend to publish taxonomic notes instead of complete revisions or monographs, particularly when revisionary research is undertaken as part of postgraduate studies, with the full revision remaining unpublished in a dissertation. For this reason, whether a revision is published or unpublished was also recorded, in order to quantify what proportion of the flora is affected by this trend. New species descriptions are an important contribution to the documentation of biodiversity; however, if these descriptions are published independently of revisionary studies they do not contribute to a better understanding of taxonomic groups that may otherwise be in need of revision,[4] and hence were not included in the analysis.

For partial revisions, and those that were outdated, the taxa included in the revision were recorded. For recent, full revisions, the assumption was made that all indigenous South African taxa were treated. A cut-off date of 1970 was chosen to differentiate revisions considered recent enough to aid Red List assessments from those considered outdated. Taxonomic treatments published since the 1970s usually contain distribution and habitat information (including distribution maps), which is the most critical information needed for the evaluation of extinction risk, while earlier publications tend to be limited to morphological descriptions and cited specimens, which means that species' habitat requirements need to be inferred. It is recognised that some revisions completed prior to 1970 may still be taxonomically sound and sufficient for identifying specimens. Treatments predating 1970 are thus only considered outdated from a conservation assessment perspective.

Taxa were categorised as follows: (1) taxa that have never been included in any taxonomic revisions, (2) taxa that have not been revised since the *Flora Capensis* series, (3) taxa that were last revised before 1970 and (4) taxa with recent enough revisions to support confident Red List assessments. This last category was further divided into taxa for which the most recent revisions were published or unpublished.

Evaluation of taxonomic coverage of the flora

The proportion of the South African flora in need of taxonomic revision was then quantified by evaluating the number of taxa in each of the four categories as a proportion of the total number of taxa of the South African flora. These four categories were also used to indicate which of South Africa's 20 largest plant families, together representing 75% of the flora, are most in need of taxonomic study, by highlighting those plant families in which a large proportion of the taxa fall within Categories 1 to 3. For smaller families, priorities are best set at the genus level.

Setting priorities

Although broad areas in need of research focus were identified at the family level, taxonomic revisions are typically undertaken at the genus level. Data compiled for the first section of this study were therefore then used to prioritise genera most urgently in need of taxonomic revision. Priorities were set according to scores for a number of factors that indicate a need for taxonomic revision, in addition to data on when genera were last revised, as some older revisions may still be otherwise adequate in their delimitations and coverage of taxa. These factors were: endemism, data deficiency, collecting effort, proportion of genus revised and specimen identification confidence. The overall priority score was calculated by averaging the scores for each factor; all factors considered were given equal weight. Genera were then ranked according to their overall score, from highest to lowest priority.

Endemism

Endemic genera and families represent South Africa's unique contribution to the global flora, and should be a priority for local researchers.[26] Genera were prioritised according to the proportion of the global number of recognised taxa per genus that are endemic to South Africa, with highest priority given to endemic and near endemic genera.

Data deficiency

A high proportion of taxa classified as Data Deficient in the Red List of South African plants is an indication of a lack of sufficient knowledge of a genus, and need for further study. Genera were prioritised according to the proportion of taxa in each genus classified as Data Deficient, and highest priority assigned to genera with the highest proportion of data deficiency.

Collecting effort

In poorly collected genera, it is very difficult to discern whether a lack of herbarium specimens indicates genuine rarity (and therefore higher potential extinction risk), or a lack of collecting effort. It has been shown that at least 15 herbarium specimens are needed to reach 95% accuracy in distribution range size estimates for plant species, and with fewer than 5 specimens, less than 10% of conservation assessments are correct.[27] Collecting effort is closely linked to taxonomic study, as research stimulates increased collecting of a particular group under study. Taxonomically problematic genera are typically poorly collected.[28] Herbarium specimen data encoded in the South African National Biodiversity Institute (SANBI)'s National Herbarium, Pretoria Computerised Information System (PRECIS) database were analysed to identify genera with high proportions of taxa with five or fewer specimens, and these were allocated higher research priority.

Taxon coverage of revisions

New taxa are often described and published independently of revisions. Excessive independent publications decrease the value of existing revisions for circumscribing and identifying taxa, as newly recognised taxa are not incorporated into frameworks for identification such as dichotomous keys, which can only be produced as part of broadly comparative studies such as revisions,[4] or otherwise do not contribute to a better knowledge and understanding of genera that may be in need of revision.

In other instances, genera may have recent revisions, but the publications cover only a subset of the South African taxa. Such genera may be given low priority if only the date of most recent revision is considered. In order to highlight such genera, as well as those requiring synthesis, a revision taxon coverage score was calculated for each genus, with the number of South African taxa included in the revision(s) for the genus as a proportion of the currently recognised number of South African taxa. Higher priority was given to genera where a high proportion of recognised taxa are not treated within existing taxonomic revisions.

Specimen identification confidence

Even though some genera may have revisions, current treatments may be inadequate, resulting in a number of unidentifiable specimens.[26] In genera with outdated revisions, unidentified specimens may also indicate the existence of unrecognised taxa, and a need for taxonomic revision. PRECIS specimen data were used to identify genera with high proportions of unidentified specimens or specimens identified with low confidence, in order to give such genera higher research priority.

Date last revised

Genera were prioritised according to the date of their most recent revision. In instances where genera had been partially revised, or where taxonomic changes had resulted in the combining of a number of smaller genera that were independently revised previously (such as *Erica* and *Moraea*), an exact date of latest revision for the genus as a whole could not be pinpointed, and in such cases an average of the most recent date of revision for each taxon in the genus was calculated.

As values for the other factors were scaled such that higher numbers indicated higher priority, the number of years since the average of the most recent date of revision for each taxon was used to score each genus. No score was recorded for genera with no revisions, and total scores were then calculated as an average of the scores of the five other factors.

The factors analysed were selected specifically to highlight research needs in terms of the focus of this study: to increase the revisionary coverage of the South African flora in order to improve confidence in Red List assessments. There are many other factors, such as economic importance or traditional or cultural value, that could also be considered, and which would provide different priorities.

It is recognised that some of the priority genera highlighted through this process may already be under revision. It was not possible for this study to include a survey of current taxonomic studies, and it was considered more important to list all priorities as a means to encourage ongoing study. Furthermore, many studies of genera noted to be under revision in a previous analysis of the flora[29] were never published.

Taxonomic output

For all revisions analysed, all authors, as well as the institutional affiliation of the senior author, were recorded in one of the following categories: (1) SANBI – all researchers based at any one of the herbaria or botanical gardens associated with this state-funded research institute, which has existed under various names (Botanical Research Institute, National Botanical Gardens and National Botanical Institute) over the past 50 years; (2) South African Universities – academic staff as well as researchers associated with university-based herbaria such as Bolus Herbarium (University of Cape Town) and Bews Herbarium (University of KwaZulu-Natal); (3) researchers from international institutions, including herbaria, botanical gardens and universities and (4) independent researchers, i.e. part-time or amateur botanists or indigenous plant enthusiasts from a horticultural background.

These data, together with counts of the number of taxa revised in each publication and the date of publication, allowed the calculation of the contribution of different institutions to taxonomic revisionary output, as well as detection of changes in output over time. The contribution of individual researchers over time was also analysed to quantify changes in capacity and productivity.

Revisionary productivity was calculated as the number of taxa revised per researcher per decade. For multi-authored publications, each author was given credit in terms of number of taxa revised by dividing the total number of taxa revised in the publication by the number of authors.

Results

State of South African plant taxonomy

The analysis revealed that 62% of the South African flora has been revised recently enough to support conservation assessments (Figure 1), but that 8% of recent treatments (5% of the flora) remain unpublished. A total of 13% of the flora has no taxonomic revision and 6% of taxa has not been revised since the *Flora Capensis* series, meaning that 19% of the flora is urgently in need of taxonomic research.

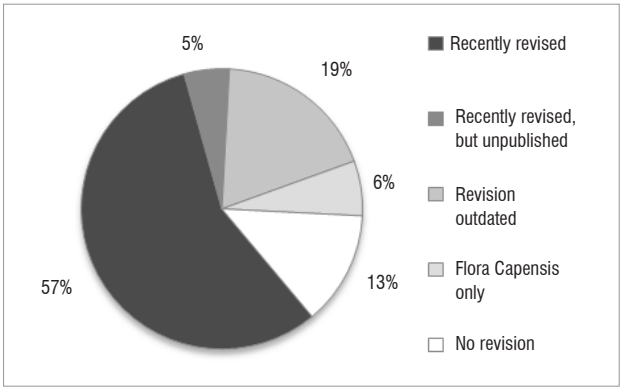

Figure 1: Overview of the taxonomic status of the South African flora, showing the proportion of taxa (species and subspecific ranks) that have been recently revised, those with outdated (older than 1970) revisions, those not treated since the *Flora Capensis* series and those with no revision.

Research priorities for conservation

The succulent family Aizoaceae, commonly known as 'vygies' or 'ice plants', is considered the top priority for taxonomic research (Table 1), with 52% of taxa in need of revision. Not only are 16 of the top 20 highest priority genera in the Aizoaceae, but 13 of the 16 South African plant genera without any revision are also in the Aizoaceae (Table 2).

Table 2: South African plant genera which to date have had no taxonomic revision, not even partial revisions, in order of priority from highest to lowest

Genus	Family	Number of taxa indigenous to South Africa	Endemism to South Africa
Delosperma	Aizoaceae	142	Near endemic
Arenifera	Aizoaceae	4	Endemic
Dicrocaulon	Aizoaceae	7	Endemic
Hereroa	Aizoaceae	27	Near endemic
Antimima	Aizoaceae	96	Near endemic
Rhinephyllum	Aizoaceae	10	Endemic
Corpuscularia	Aizoaceae	8	Endemic
Chasmatophyllum	Aizoaceae	8	Near endemic
Peersia	Aizoaceae	3	Endemic
Rabiea	Aizoaceae	6	Near endemic
Schwantesia	Aizoaceae	8	Near endemic
Nananthus	Aizoaceae	6	Near endemic
Braunsia	Aizoaceae	7	Endemic
Chamarea	Apiaceae	5	Near endemic
Bassia	Chenopodiaceae	3	Widespread
Ceraria	Portulacaceae	3	Near endemic

The Aizoaceae is South Africa's second most diverse plant family, and is divided into four subfamilies. Two of these subfamilies, Mesembryanthemoideae and Ruschioideae, are near endemic to

Table 1: South Africa's 20 largest plant families, in order of priority (highest to lowest) in terms of taxa in need of revision, with the top priority genus within each family

Family	Number of taxa indigenous to South Africa	Proportion of recognised taxa not treated in any revisions	Proportion of taxa last revised pre-1970	Highest priority genus within family
Aizoaceae	1758	52%	12%	*Lampranthus*
Hyacinthaceae	492	34%	11%	*Lachenalia*
Malvaceae	334	17%	34%	*Anisodontea*
Ericaceae	944	13%	75%	*Erica*
Euphorbiaceae	387	12%	65%	*Clutia*
Asteraceae	2259	11%	33%	*Marasmodes*
Cyperaceae	438	11%	28%	*Cyathocoma*
Fabaceae	1633	10%	15%	*Lessertia*
Asphodelaceae	568	9%	9%	*Astroloba*
Scrophulariaceae	802	8%	13%	*Microdon*
Geraniaceae	312	8%	5%	*Pelargonium*
Acanthaceae	275	7%	33%	*Acanthopsis*
Proteaceae	377	7%	19%	*Serruria*
Apocynaceae	675	7%	7%	*Emplectanthus*
Rutaceae	307	6%	49%	*Agathosma*
Iridaceae	1182	6%	5%	*Micranthus*
Crassulaceae	343	5%	0%	*Tylecodon*
Poaceae	726	4%	1%	*Prionanthium*
Orchidaceae	501	2%	0%	*Huttonaea*
Restionaceae	347	0%	0%	*Restio*

southern Africa and together represent more than 90% of the species diversity within Aizoaceae. Both these subfamilies have their centres of diversity and endemism within two of South Africa's biodiversity hotspots – the Fynbos and Succulent Karoo Biomes.[30]

Research priorities for the two subfamilies were set in the 1990s, when only 21% of taxa had been revised since 1940.[28] Progress has been made, largely within the Mesembryanthemoideae where 75% of taxa have been revised recently enough to aid confident Red List assessments. However, within the Ruschioideae, the largest subfamily within the Aizoaceae, only 36% of taxa have been recently revised and 58% have never been revised. Conservation assessments are further hampered by poor specimen representation in SANBI herbaria (74% of taxa are known from five or fewer specimens) and low confidence in specimen identifications (32% of specimens in PRECIS are not identified to species level or identified with uncertainty).

The Hyacinthaceae is another high priority, with 34% of taxa not yet revised, as a result of most of the family's largest genera such as *Lachenalia*, *Albuca*, and *Drimia* being only partly revised. In addition, several conflicting name changes, published as part of molecular phylogenetic studies,[31-36] have, in the absence of comprehensive revisions, led to great confusion over which taxa should be recognised, what their correct names are, and how they should be circumscribed.

The Ericaceae, Euphorbiaceae, Rutaceae, Malvaceae, Asteraceae and Acanthaceae have lower proportions of taxa that are not revised, but all have more than 30% of taxa last revised before 1970 (Table 1). The family Ericaceae contains a single genus – *Erica* – which is South Africa's largest plant genus with over 900 recognised taxa. This genus has its centre of endemism within the fynbos biodiversity hotspot and has a large number of highly range-restricted endemics. *Erica* was synoptically revised in 1964–1965,[37] but, with only an identification key and diagnostic characters provided for each taxon, this treatment is insufficient for supporting conservation assessments. Only 11% of *Erica* taxa have been recently revised in a number of partial revisions, and 124 taxa (13% of the recognised taxa) have been described independently of revisions, with the result that 88% of the genus is still in need of synthesis and revision.

Within the Asteraceae, the fynbos endemic genus *Marasmodes* is most urgently in need of revision. Only three taxa were recognised in *Flora Capensis*,[38] and a further two were described by 1946.[39,40] Plants within *Marasmodes* are cryptic, and flower outside the peak fynbos flowering season, with the result that *Marasmodes* is poorly collected. Recently, eight new species were described based on existing herbarium material.[41] These new species are very poorly known, and are apparently restricted to highly threatened lowland fynbos. A better understanding of the delimitation, distribution and abundance of all *Marasmodes* species is still needed, and would benefit greatly from field study, which is a matter of urgency as the last remaining fragments of lowland fynbos are rapidly disappearing.

South Africa's most studied large plant families are the Iridaceae, Restionaceae, Poaceae and Orchidaceae (Table 1), and genera within these families generally scored very low within overall priority ratings, with the exception of *Micranthus* in the Iridaceae. For the complete list of all genera together with their priority scores, see Supplementary table 1 online.

A number of South Africa's largest plant genera are among the top 50 research priorities (Table 3). However, not all large genera remain in need of revision: 14 out of 35 genera containing more than 100 taxa have recent, comprehensive revisions, including two of South Africa's five largest genera: *Aspalathus* (334 taxa) and *Helichrysum* (252 taxa). Research needs are also not confined to larger genera; there are many small genera that remain urgently in need of revision. Of the 16 genera with no revisions, 13 have ten or fewer taxa occurring within South Africa, and most of these genera are endemic or near endemic to the country (Table 4). Research needs within smaller genera are again linked primarily to the Aizoaceae subfamily Ruschioideae, with 12 of the top 20 priority small genera found in this subfamily. Please see online Supplementary table 1 for the complete list of research priorities.

Taxonomic output

An analysis of outputs of taxonomic revisions for each decade since the 1960s indicates that revisionary research peaked in the 1980s and 1990s, but that there has been a sharp decline in the past decade (Figure 2). During the 1960s, most revisions of South African plants were conducted by internationally based scientists, but since the 1970s, local researchers based at South African universities and SANBI have produced the majority of revisions. Independent local researchers, often amateur botanists, have also made small contributions. During the 1990s, South African universities took the lead in local revisionary research, but all groups show a drastic reduction in published revisions in the past 10 years.

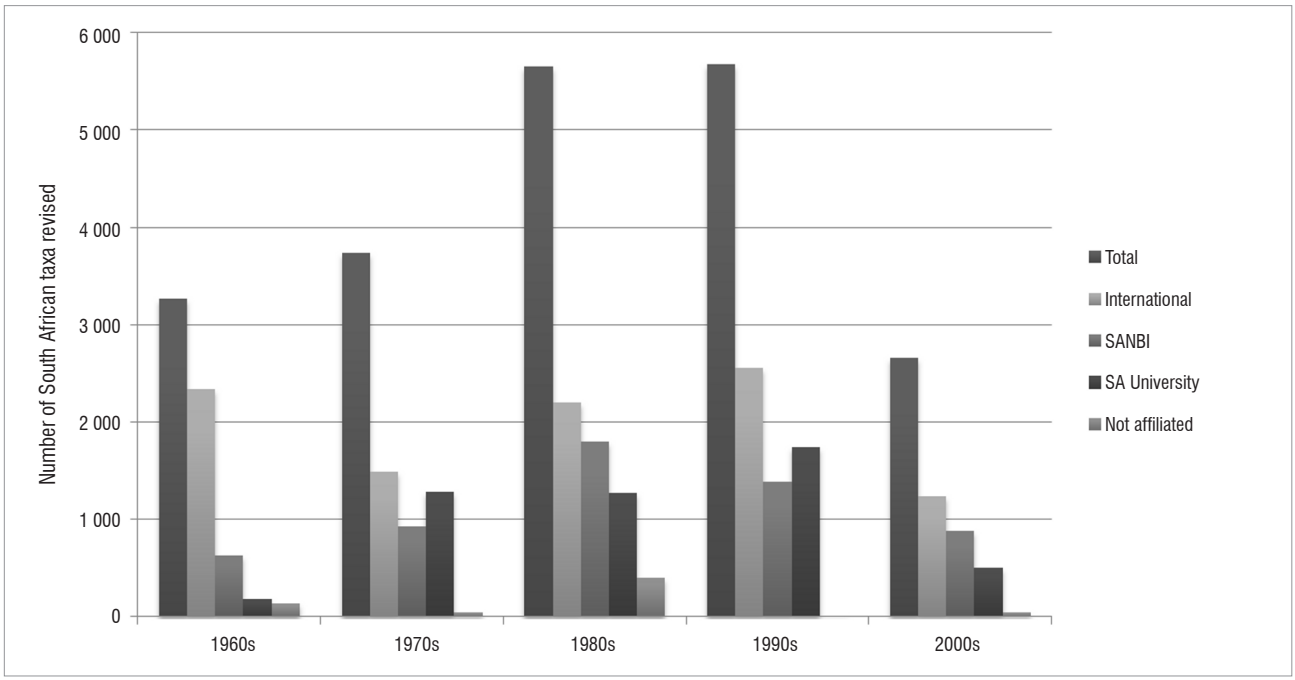

Figure 2: Number of South African plant taxa (species and subspecific ranks) revised in published taxonomic treatments per decade. Data is categorised according to the institutional affiliation of the senior author of each publication.

Table 3: Top 20 large (containing more than 10 indigenous taxa) genera of priority for taxonomic research

Genus	Family	Number of indigenous taxa	Endemism	Revision status	Latest revision	Taxa not revised (%)	Taxa Data Deficient (%)	Specimens not identified (%)	Taxa with five or fewer specimens (%)
Lampranthus	Aizoaceae	194	Near endemic	*Flora Capensis* only	Sonder W. Flora Capensis. 1861; II:386–460	82	62	21	77
Ruschia	Aizoaceae	206	Near endemic	Recently partially revised, but unpublished	Schoeman LL. Unpublished MSc. Potchefstroom University for CHE; 2000	80	35	84	92
Drosanthemum	Aizoaceae	107	Near endemic	*Flora Capensis* only	Sonder W. Flora Capensis. 1861; II:386–460	86	38	28	66
Delosperma	Aizoaceae	142	Near endemic	No revision			16	94	99
Stomatium	Aizoaceae	39	Endemic	*Flora Capensis* only	Sonder W. Flora Capensis. 1861; II:386–460	90	5	14	90
Trichodiadema	Aizoaceae	32	Near endemic	*Flora Capensis* only	Sonder W. Flora Capensis. 1861; II:386–460	88	25	17	59
Marasmodes	Asteraceae	13	Endemic	*Flora Capensis* only	Harvey WH. Flora Capensis. 1894;III:44–530	92	0	17	69
Hereroa	Aizoaceae	27	Near endemic	No revision			19	22	81
Malephora	Aizoaceae	16	Near endemic	*Flora Capensis* only	Sonder W. Flora Capensis. 1861; II:386–460	81	0	13	31
Antimima	Aizoaceae	96	Near endemic	No revision			21	19	76
Gethyllis	Amaryllidaceae	30	Near endemic	Recently partially revised	Zimudzi C, et al. Flora Zambesiaca. 2008;13(1):97–134	60	27	7	43
Alchemilla	Rosaceae	16	Widespread	Recently partially revised	Mendes EJ, Kupicha FK. Flora Zambesiaca. 1978;4:7–33	75	25	5	50
Lachenalia	Hyacinthaceae	126	Near endemic	Recently partially revised	Dold AP. Bothalia. 1998;28:141–149	63	0	4	25
Othonna	Asteraceae	94	Widespread	Recently partially revised	Hilliard OM. Compositae in Natal. Pietermaritzburg: University of Natal Press; 1977	36	18	7	32
Struthiola	Thymelaeaceae	34	Near endemic	Recently partially revised	Peterson B. Flora Zambesiaca. 2006; 9(3):85–117	12	32	4	41
Curio	Asteraceae	15	Widespread	*Flora Capensis* only	Sonder W. Flora Capensis. 1861; II:386–460	60	13	2	47
Syncarpha	Asteraceae	31	Endemic	*Flora Capensis* only	Harvey WH. Flora Capensis. 1894;III:44–530	32	0	1	10
Zyrphelis	Asteraceae	11	Near endemic	*Flora Capensis* only	Harvey WH. Flora Capensis. 1894;III:44–530	27	9	4	18
Ficinia	Cyperaceae	70	Near endemic	Recently partially revised	Gordon-Gray KD. Strelitzia. 1995;2:1–218	40	0	12	23
Erepsia	Aizoaceae	31	Near endemic	Recently partially revised	Hartmann H. Bradleya. 1998;16:44–91	71	0	4	42

Table 4: Top 20 small (containing 10 or fewer indigenous taxa) genera of priority for taxonomic research

Genus	Family	Number of indigenous taxa	Endemism to South Africa	Revision status	Latest revision	Taxa not revised (%)	Taxa Data Deficient (%)	Specimens not identified (%)	Taxa with five or fewer specimens (%)
Calamophyllum	Aizoaceae	3	Endemic	*Flora Capensis* only	Sonder W. Flora Capensis. 1861; II:386–460	0	100	0	100
Arenifera	Aizoaceae	4	Endemic	No revision			0	20	100
Dicrocaulon	Aizoaceae	7	Endemic	No revision			0	29	86
Cylindrophyllum	Aizoaceae	5	Endemic	*Flora Capensis* only	Sonder W. Flora Capensis. 1861; II:386–460	60	0	7	60
Rhinephyllum	Aizoaceae	10	Endemic	No revision			0	6	90
Corpuscularia	Aizoaceae	8	Endemic	No revision			0	6	88
Chasmatophyllum	Aizoaceae	8	Near endemic	No revision			38	0	62
Lichtensteinia	Apiaceae	9	Endemic	*Flora Capensis* only	Sonder W. Flora Capensis. 1861;II:524–567	22	0	7	56
Hippia	Asteraceae	9	Endemic	*Flora Capensis* only	Harvey WH. Flora Capensis. 1894;III:44–530	67	0	6	33
Lidbeckia	Asteraceae	3	Endemic	*Flora Capensis* only	Harvey WH. Flora Capensis. 1894;III:44–530	33	0	4	67
Gymnostephium	Asteraceae	8	Endemic	*Flora Capensis* only	Harvey WH. Flora Capensis. 1894;III:44–530	12	50	3	38
Peersia	Aizoaceae	3	Endemic	No revision			0	0	67
Steirodiscus	Asteraceae	6	Endemic	*Flora Capensis* only	Harvey WH. Flora Capensis. 1894;III:44–530	50	17	0	33
Rabiea	Aizoaceae	6	Near endemic	No revision			17	23	67
Apodolirion	Amaryllidaceae	6	Near endemic	*Flora Capensis* only	Baker JG. Flora Capensis. 1896;VI :171–246	33	33	1	50
Schwantesia	Aizoaceae	8	Near endemic	No revision			12	8	88
Nananthus	Aizoaceae	6	Near endemic	No revision			17	14	67
Lachnostylis	Phyllanthaceae	3	Endemic	*Flora Capensis* only	Brown NE, et al. Flora Capensis. 1920;V(II):216–516	67	0	4	33
Braunsia	Aizoaceae	7	Endemic	No revision			0	0	43
Mairia	Asteraceae	3	Endemic	*Flora Capensis* only	Harvey WH. Flora Capensis. 1894;III:44–530	33	0	33	0

There has been a steady increase in the number of individual researchers contributing to published revisions of South African plant taxa since the 1960s, and only a slight apparent decrease in the past decade (Figure 3). However, at least eight researchers who contributed to taxonomic revisions in the 1990s are still employed as taxonomists in local and international research institutions, but did not publish any revisions in the past 10 years. If they are included in the number of researchers, then there has been no decline in the number of taxonomists. Instead, the data indicate a sharp decline in the productivity of taxonomists in relation to their contribution to taxonomic revisions since the 1960s, from an average of 51 taxa revised per decade by a taxonomist in the 1960s to only 20 in the 2000s. The decline is linked not only to a decrease in the number of publications, but also to a rise in the proportion of co-authored publications, from 8% in the 1960s to 42% of publications in the 2000s, and smaller numbers of taxa revised per publication, from an average of 29 in the 1960s to 18 in the 2000s.

Discussion

It is encouraging that 62% of the South African flora has received recent taxonomic revision, particularly considering the large number of taxa. However, with 19% (ca. 4000 taxa) of the flora without revision or not revised since the last publication of *Flora Capensis*, there is clearly still much work to be done. The Aizoaceae family was highlighted as a research priority already in 1995,[28] and, although some progress has been made, significant research efforts are still needed to address its lack of taxonomic treatment, particularly for the subfamily Ruschioideae.

Taxonomic study of the Ruschioideae is challenging because of the large number of species (approximately 1585 in 111 genera[42]), many of which are poorly known,[43] and their very low phylogenetic resolution as a result of their very rapid, recent diversification.[44] For many type specimens, the majority of which are housed in the Bolus Herbarium at the University of Cape Town, information on where they were collected is lacking, or they are from cultivated plants, which may differ significantly from wild individuals, making identification with living populations difficult.[43] Genera in the Ruschioideae scored highly in the priority setting analysis not only because of a lack of revisions, but also because many species were represented by five or fewer specimens in SANBI herbaria and high proportions of specimens cannot be identified to species level. Except for *Calamophyllum*, which is probably South Africa's most poorly known plant genus, vygies are generally better represented in the Bolus Herbarium (Klak C 2012, written communication, March 13), highlighting the importance of this collection for ongoing study of the group.

In spite of these challenges, the Aizoaceae are nevertheless of high local research and conservation importance, not only because of their significant contribution to South African floral diversity and endemism, but also because of the insights they can provide into adaptations to an arid climate[42,44] and evolutionary drivers of high rates of speciation within winter rainfall biodiversity hotspots.[45] A strong research focus on this plant family needs to be encouraged and ongoing studies on this group should be given priority and sufficiently supported.

As significant long-term research investment is needed to study large genera, it is not surprising that many of South Africa's largest plant genera are still in need of revision. Smaller genera are presumably more attractive research subjects, particularly for short-term projects such as postgraduate studies, and therefore are expected to have better revisionary coverage. Yet, in this study, 33 of the top 50 priority genera consist of 10 or fewer taxa, and 25 of these are endemic to South Africa. Small genera may be problematic in that they were often created to accommodate morphologically derived taxa, and phylogenetic studies could show that they are embedded in larger genera or even polyphyletic, but these results may also simply indicate a lack of awareness of genera requiring revision, and that there is a need for a coordinated approach to taxonomic research on the South African flora.

Many examples of large genera and families that have been comprehensively revised (often by individual researchers), such as *Aspalathus* (334 taxa by R. Dahlgren), *Helichrysum* (314 taxa), the Manuleae (351 taxa) and Selagineae (233 taxa) tribes of the Scrophulariaceae (by O.M. Hilliard), the Crassulaceae (323 taxa by H.R. Tölken) and the Restionaceae (350 taxa by H.P. Linder), have demonstrated that revision of large groups is not an insurmountable challenge. For the production of *Flora of Tropical East Africa*, over 75% of the 12 000 species treatments were completed by only two taxonomists.[46]

The recent decline in taxonomic research has often been blamed on the decline in the number of taxonomists,[9,16,47,48] but our data indicate

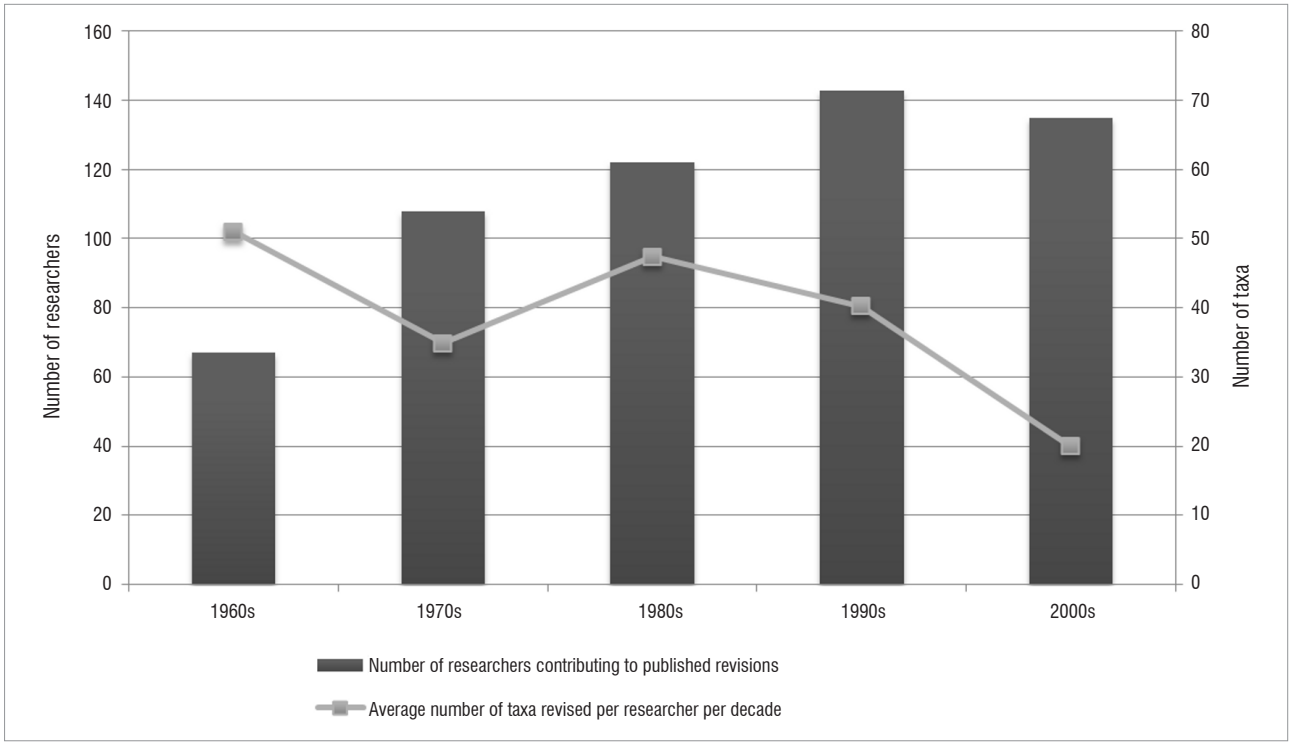

Figure 3: Changes in revisionary productivity over the past 50 years reflected as the number of individual researchers contributing to published revisions relative to the number of taxa (species and subspecific ranks) revised per researcher per decade.

that this is a false impression. Our results show that South Africa does not lack the capacity to complete a comprehensive flora treatment by 2020, but that a decline in revisionary productivity is the main stumbling block towards achieving this goal. A similar trend has been reported internationally for the publication of descriptions of new species across a number of plant and animal groups, namely an exponential increase in the number of taxonomists contributing to new species descriptions, coupled with a rise in co-authored publications, but a decline in individual productivity.[49] These results introduce an alternative question in addressing the 'taxonomic crisis': why is taxonomic output in terms of revisions decreasing in spite of increasing numbers of taxonomists?

To investigate the reasons behind the decline in taxonomic productivity, a workshop was held at the tenth meeting of the South African Society for Systematic Biology (SASSBX) on 18 July 2012. Participants indicated that taxonomic research has developed into a complex science where all possible species characters (including molecular) need to be investigated in order to arrive at good delimitations of species and genera, requiring more time-consuming, in-depth study, as well as collaboration of researchers with appropriate expertise in various analytical techniques to complete. A revisionary study requires the accumulation of what could amount to many years of research into a single publication, which typically is not accepted by high-impact journals, nor does it receive many citations. Academic performance assessment systems, however, demand a high publication output, and give less credit to multi-authored publications. In addition, academic career advancement is achieved through publications in high-impact journals and high citation ratings. The current academic merit system therefore actively discourages the publication of taxonomic revisions, by not giving researchers sufficient credit for the amount of effort required to complete such studies. This situation also means that increased funding and initiatives promoting taxonomic research are unlikely to have the desired impact, as has been the case in South Africa and around the world.

The consensus among the participants was that the best way forward would be to change to electronic publication, dissemination and curation of taxonomic information, as has been the trend in the international taxonomic community, for example through projects such as Solanaceae Source and GrassBase.[50] An interesting local example is the Restionaceae, one of South Africa's most well-studied large plant families (Table 1). This family was comprehensively treated in a conspectus published in 1985,[51] and the treatment was updated in an electronic, interactive identification key with descriptions and distribution information published on CD-ROM in 2001.[52] The interactive key was subsequently published online, and kept up to date with a generic level reclassification of the Restionaceae as well as newly described species, with the latest version published in 2011.[53] This example illustrates the efficiency of the electronic publication format, which allows for a less time-consuming maintenance of taxonomic information, rather than re-revising and republishing entire revisions which have become outdated, as well as the collation and integration of taxonomic information published across scattered journal articles. An open-access electronic publication format also has the potential for increasing the impact of taxonomic publications by making them more accessible.

Conclusion and recommendations

We have shown that the majority of the South African flora has recently updated, detailed taxonomic information available to include in an online flora. In addition, South Africa has adequate taxonomic capacity to address the remainder of the flora still in need of revision. If genera identified here are prioritised for taxonomic research and existing published taxonomic information is collated electronically, South Africa could provide high-quality taxonomic information towards the global online flora envisioned in Target 1 of the GSPC.

It is thus recommended that the *Flora of Southern Africa* be reinstated, but converted from a printed publication to an online flora. Electronic floras are a characteristic of the most advanced flora projects,[9] as they are more efficient to produce, easier to update, and would provide an accessible, centralised information resource much needed by all biologists studying the South African flora. SANBI has the mandate under South Africa's Biodiversity Act (*NEMBA Act 10 of 2004*) to coordinate and promote taxonomic research in South Africa. Within this role, South African taxonomists attending the SASSBX workshop suggested that SANBI should provide leadership in strategically guiding taxonomic research in South Africa. It was also suggested that SANBI establish an electronic platform where existing taxonomic information can be collated, and where taxonomists can contribute new content as well as curate existing information. Such a platform need not be limited to plants, but could be made available to all taxonomic groups, as they are likely to be facing similar obstacles to publishing.

However, merely providing electronic publishing infrastructure may not be enough to reverse the trend of declining revisionary productivity. As the obstacles to publishing revisionary studies centre around a lack of sufficient credit for effort, a more challenging aspect of developing an e-taxonomy system would be to maintain scientific credibility through peer review, as well as by providing a means to measure and reward impact, thereby giving researchers an incentive to contribute. If this challenge can be overcome, alpha-taxonomic research could once again gain ground as a highly esteemed and rewarding scientific discipline.

South Africa is one of few countries that made good progress towards achieving the GSPC 2010 targets.[54] In order for South Africa to keep up these high standards and fulfil our commitments to implementing the GSPC 2020 targets, a strategic approach involving strong leadership from SANBI, as well as concerted effort and cooperation of the taxonomic community, will be needed.

Acknowledgements

We, the grateful users of the products of taxonomic research but not taxonomists ourselves, thank Nicola Bergh, Benny Bytebier, John Donaldson, Michelle Hamer, Cornelia Klak, John Manning, Dee Snijman, Ben-Erik van Wyk, Tony Verboom and Janine Victor for insightful discussion and comments on earlier drafts of the manuscript, as well as the participants of the workshop held at the tenth meeting of the South African Society for Systematic Biology. We also thank two anonymous reviewers for suggested improvements.

Authors' contributions

D.R. was the project leader and contributed to writing the paper and research and data capture; L.V.S. designed and developed the database, analysed the data and contributed to writing the paper as well as to the research and data capture; A.D. was responsible for the majority of the research and data capture.

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