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A method for establishing taxonomic research priorities in a megadiverse country

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Abstract

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

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

Introduction

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

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

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

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

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

Methods

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

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

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

Approach at family level

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

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

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

Approach at genus level

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

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

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

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

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

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

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

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

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

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

Criterion 2: Quality of most recent revision

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

Criterion 3: Proportion of unidentified specimens in collections

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

Criterion 4: Proportion of DD or DDT species per genus

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

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

Criterion 5: Economic importance

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

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

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

Criterion 6: Proportion of species occurring in the country

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

Criterion 7: Ecological importance

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

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

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

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

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

Approach at species and infraspecific levels

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

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

Results

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

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

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

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

Discussion

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

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

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

Conclusions

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

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

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