A Biosystematics Research Strategy for Algae in South Africa

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Biosystematics research in South Africa faces challenges in terms of gaps in knowledge and capacity, and inadequate funding to appropriately address the needs of end-users. A strategic approach to direct research efforts towards priority areas is required to maximise on limited resources. Although most algae are classified in the plant kingdom, algal systematics has in particular been neglected in South Africa, largely due to not being prioritised along with other plants by the major employer of taxonomists in the country, the South African National Biodiversity Institute (SANBI). SANBI is mandated to lead and co-ordinate biosystematics research for all living organisms, and has therefore taken the lead in co-ordinating the Biosystematics Research Strategy, of which algal taxonomy is one component. Main priorities in algal systematics research are to develop a checklist of all known species in South Africa, database associated information, make this information accessible online, and to stimulate research projects addressing taxonomic problems.

Introduction

Background

Biosystematics research, or taxonomy, is the science that deals with description, naming and classification of organisms. In this strategy, the term taxonomy is used in the broad sense and therefore includes systematics and biosystematics. Taxonomy provides basic understanding about biodiversity that is a pre-requisite for all other biological research.

The existence of a “taxonomic impediment” has been acknowledged as an obstacle to effective management and decision-making with regards to conservation and sustainable

use of biological biodiversity. Through the establishment of the Global Taxonomic Initiative (GTI), one of the thrusts of the Convention on Biological Diversity (CBD), South Africa is obligated to attempt to remove the taxonomic impediment through strengthening of capacity to generate taxonomic information.

These challenges can only be addressed through a strategic approach to identifying needs and gaps in knowledge and capacity, and by prioritising these and making recommendations for addressing them. There has been a global call for taxonomy to be directed towards practical ends, including bioprospecting and ecological research on the conservation and sustainable use of biological diversity and its components. If this is to be achieved, then a strategy is required.

SANBI Biodiversity Strategy

The South African National Biodiversity Institute (SANBI) is a parastatal body falling under the Department of Environmental Affairs (DEA). SANBI is mandated by the National Environment: Biodiversity Act of 2004 to "promote and co-ordinate taxonomy in South Africa", and for this reason, the South African national Biosystematics Research Strategy is being developed. This algal taxonomy strategy forms part of that larger strategy. SANBI taxonomists currently have limited capacity to focus on algal taxonomy, but aim to establish a network of specialists in the field in order to achieve its mandate to lead taxonomic research in all fields. Researchers in algal taxonomy whom are responsible for implementing the strategy are stationed at South African universities, therefore implementation will depend on their buy-in of the strategy along with prioritisation of funding by funding agencies such as the Department of Science and Technology (DST) for research programmes developed in this strategy. This strategy thus serves to co-ordinate and promote taxonomic research in South African algae by identifying and highlighting priority activities for the next five years.

The algae

The term 'algae' does not refer to a taxon, and what are considered algae by those studying them (phycologists) are evolutionarily, and hence taxonomically, enormously diverse. As Guiry (2012) comments: "wishing for algal monophyly will not make it happen as algae are presently referred to four kingdoms: Bacteria, Plantae, Chromista, and Protozoa … (and include) 15 phyla and 54 classes". This is a simplistic viewpoint, with the taxonomic position of a number of groups of algae still unclear. While algae are traditionally defined as simple, non-vascular, photosynthetic organisms with simple vegetative and reproductive structure (Bold & Wynne 1985), many aspects of such definitions have exceptions: for example, many

large brown algae (Phaeophyceae, Ochrophyta) have vascular conducting tissue, albeit of simpler construction to that of trachaeophytes. Indeed, the concept of algal simplicity is at least partially a perception, because their life histories are more complex than those of land plants. For example, most Rhodophyta ('red algae') have three separate life history phases, and the dinoflagellate *Pfiesteria piscicida* (fortunately not yet recorded in South Africa) has a life history which includes phases which are photosynthetic, or amoeboid, or predatory, the latter killing large shoals of fish and living off the dead flesh. In addition, the algae include taxonomic groups which are partially non-photosynthetic, a good example being the dinoflagellates (Dinophyceae) which have fairly equal numbers of photosynthetic and non-photosynthetic members, as well as some species which can be both. The 'Plant and Animal Kingdoms', as represented by many biologists and generally understood by the public, is an enormous understatement of the tree of life. Algae are represented across the breadth of the eukaryotic domain, including representatives that are deeply rooted in branches that give rise to the land plants and animals.

Algae as discussed here encompass those organisms included in the major literature-based website on algal diversity, www.Algaebase.org (Guiry 2012: Table 1), and thus include members of better known phyla such as the Cyanobacteria, Chlorophyta, Charophyta, Rhodophyta, Ochrophyta, Glaucophyta, Haptophyta, Euglenozoa, but also an increasing number of previously unrecognised branches of the tree of life.

Algae carry out about half of global photosynthesis, and are truly ubiquitous, growing wherever there is light, water and nutrients, from Antarctic ice to hot springs, and from the canopies of tropical rain forests to cryptoendolithic species inside rock. Most importantly, they dominate the photosynthetic production in the oceans and many estuarine and freshwater systems as well as providing the energy input for deeper marine systems. Increasing number of terrestrial algae, in many evolutionary lines, are being discovered. Some algae fix nitrogen in nutrient-poor systems, from paddy fields to coral reefs, and others form symbioses with a large variety of organisms, including many groups of marine invertebrates (notably reef-forming corals), angiosperms, ferns and fungi (lichens).

Large marine macroalgae (seaweeds) are the dominant primary producers in the economically critical inshore coastal zone, and form the basis of a world aquaculture industry worth over US$7 billion annually (mostly for human food). Over 2000t of the green seaweed *Ulva* is grown annually in South Africa in commercial aquaculture operations, which is the highest figure by weight of any marine organism in South Africa. As well as being ecological engineer species dominating kelp forests on the west coast, more than 6000t of large brown

algae (kelps) are harvested annually in South Africa for use in aquaculture, agriculture and colloid extraction. It is not clearly demonstrated how many species of kelp occur in South Africa, or which species of *Ulva* are grown in commercial aquaculture systems.

Algae are excellent indicators and monitors of environmental conditions in aquatic ecosystems, and microalgae (especially diatoms) are widely used for this purpose, including in South Africa. There is an enormous world industry based on algae in medicine, health products and nutriceuticals, and there is active bio-prospecting of algae for drug discovery, including in South Africa. Algae are at the forefront of the global explosion in research and development into the production of biofuels. They are considered by many to be the organisms which will form industries to replace fossil fuels in the future. There are active research and technology groups in South Africa working on a variety of algae with the aim of biofuel production, some without proper taxonomic backup.

Taxonomy of algae is critical to the identification of growths of toxic microalgae (Harmful Algal Blooms) which kill large amounts of marine life each year on the South African west coast, and occasionally kill people. Harmful Algal Blooms are also prevalent in many local freshwater systems. Algae are problem organisms in water supply systems, a problem which will increase as water supplies diminish in the future.

Challenges in algal taxonomy

A great challenge in algal taxonomy is that there has been no specific Government support for algal taxonomy in South Africa over many decades. The Phycological Society of Southern Africa (see later) has officially approached the relevant authorities (National Botanical Institute and later SANBI) on a number of occasions over the last thirty years to question their lack of support, and were informed that algae are within the ambit of these organisations but “not a current priority”. The last algal biologist at these institutions was the seaweed taxonomist Prof Richard Norris at NBI (Kirstenbosch) more than twenty years ago, and following his departure the NBI divested itself of its seaweed herbarium. Terrestrial botanists often use the common term ‘plants’ to include only terrestrial Trachaeophyta, although on a strict taxonomic definition the kingdom Plantae now includes all Chlorophyta, Rhodophyta and Glaucophyta. More generally, the common term ‘plants’ is widely used to include all chlorophyllous photosynthetic organisms, as in the definition of phytoplankton as ‘microscopic plants’ often heard on television documentaries. The perception of officials in Government organisations that the term “plants” excludes algae, has had, and continues to have, negative effects on algal study in South Africa.

The range in form and size of algae (over 7 orders of magnitude from ca. 1 micron to 70m in length) requires a very large variety of techniques to study them. Most researchers tend to study a particular 'form group' and/or taxon of algae, e.g. seaweeds (marine macroalgae), coralline red algae, Harmful Algal Bloom algae, marine flagellates, diatoms, etc. All of these groups listed have at least some, often part-time, local expertise currently, but taxonomy of other important form groups/taxa have no active local expertise. The taxonomy of algae which dominate some entire ecosystems is poorly studied locally, with most freshwater algae and offshore phytoplankton being obvious large gaps. Many local scientists who study algae, including the first author of this document, are not full-time taxonomists, but generalists who feel it necessary to carry out some taxonomic studies in order to do their work.

The vast majority of descriptions of algal species use a 'morphological species concept', although molecular systematics is increasingly being used for many groups. This causes tension between traditional and molecular systematics and systematists, particularly as most algae have few obvious morphological characters and often considerable phenotypic plasticity. For a number of groups, including marine macroalgae (seaweeds) and diatoms, taxa thought to be widespread or cosmopolitan are being shown by molecular methods to exhibit considerable regional endemism. The discovery of numerous 'cryptic species' which are molecularly distinct but morphologically similar is undermining traditional species concepts in many groups. As a good example, the marine red seaweed *Portieriahornemannii* was thought to be widespread across the Indo-Pacific, but has been shown to comprise 21 species in the Philippines alone (Payo et al. 2013) and may include almost 100 species across its range, with at least 6 in South Africa (F. Leliaert and O. de Clerck, pers. comm.). The importance of this taxonomic research is clear when it is considered that red seaweeds, with *Portieria* being a significant example, are chemically important, with much literature on the potential of chemical constituents for drug discovery. Molecular studies are also often necessary to identify introductions of alien algal species (e.g. Bolton et al. 2011).

Review of current status of algal systematics in South Africa

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

South Africa is urgently needed, and could be produced by the current workers, if support is received.

The diatoms were well studied in the past, particularly by such researchers as Cholnoky, Giffen & Archibald, but there is no checklist available for species which have been recorded in South Africa.

Work has also been undertaken on inshore marine phytoflagellates, particularly the haptophytes (Pienaar, Inouye, Sym), dinophytes, especially those inhabiting tidal pools (Pienaar, Horiguchi), 'prasinophytes' (Pienaar, Inouye, Sym) and a broad survey of phytoplankton in shipping ballast as a potential means of alien introduction (Marangoni, Pienaar, Pitcher, Sym). There has also been a comprehensive survey of benthic marine cyanophytes by Silva and Pienaar. Taxonomic work has also included some more isolated forays into other groups (e.g. Chrysophyceae, *Sphaleromantis*). With the exception of work undertaken on the genus *Pyramimonas*, most investigations are as a result of serendipitous encounters with novel species or genera or dealings with problem algae, rather than due to in depth surveys and nearly all have been limited to inshore waters. Commonly encountered ubiquitous species (e.g. *Emiliania huxleyi*) tend to be unreported because of the lack of novelty and this is an important omission when assembling comprehensive lists of South African representatives.

How many algal species are there in the world? According to Guiry (2012), "Despite uncertainties regarding what organisms should be included as algae and what a species is in the context of the various algal phyla and classes, a conservative approach results in an estimate of 72 500 algal species, names for 44 000 of which have probably been published, and 33 248 names have been processed by AlgaeBase to date (June 2012)". According to Guiry (pers. comm. to John Bolton), there are about 8700 species of marine macroalgae described, globally, whereas Bolton & Stegenga (2002) estimated there to be around 800 species recorded for South Africa, around 9.5% of the global total estimate. Therefore, in the unlikely circumstance that seaweeds can represent a guide to algal diversity in general a very rough estimate of algal diversity in South Africa would be around 6900 species. No attempt has ever been made to list or add up the numbers of algal species recorded in South Africa.

Research capacity

Institutions and permanently employed researchers

The number of researchers in South Africa who are actively working on algal systematics, which includes documenting and describing species is very small and comprises a handful of university academics and their students. There is no algal taxonomic work being carried out in South Africa other than at universities. The majority of phycologists work with marine macroalgae (seaweeds) and none of them is a full time algal taxonomist. There are growing collaborations with authors overseas who work on specific groups of algae. For example the 'Guide to the Seaweeds of KwaZulu-Natal' (De Clerck et al. 2005) was the result of a Flanders/South Africa collaboration between scientists at the University of Gent (Belgium), University of Cape Town (UCT) and DAFF.

Table 1: Capacity for algal systematics in South Africa

List of academics at South African institutions who carry out some taxonomic research on algae (please note that none of these are full-time taxonomists, and that taxonomic activities are generally <10% of time).

NAME	INSTITUTION	FOCUS GROUP (TAXA)
Prof John J Bolton	UCT	Marine macroalgae
A/Prof Gavin Maneveldt	University of the Western Cape	Coralline red algae
A/Prof Stuart Sym	Wits	Marine flagellates
Dr. Jonathan Taylor	North West University	Diatoms
A/Prof Robert Anderson	DAFF	Marine macroalgae
Dr Grant Pitcher	DAFF	Harmful algal blooms
Emeritus Prof. Richard Pienaar	Wits	Marine flagellates
A/Prof Eileen Campbell	Nelson Mandela Metropolitan University (NMMU)	Surf diatoms
Dr Tommy Bornmann	NMMU	Phytoplankton ecology (diatoms/coccolithophores)

Human capital development

There have been two purely taxonomic theses on seaweeds at UCT in the last 10 years, and two PhD students are currently registered. A number of other theses over the last 30 years have had small seaweed taxonomic components. One seaweed PhD has been completed at UWC in this period, with another currently registered. Around seven PhD's were completed on taxonomic studies of macroalgae under Prof Richard Pienaar from the 1980's to the

2000's, and three are currently registered at Wits. The only recent PhD with a large diatom taxonomic component is that of Jonathon Taylor. Many other PhDs, at these and other Universities, have included some algal diversity aspects, which thus contain data which could be included in diversity datasets.

Professional societies

The Phycological Society of Southern Africa was formed in 1982, and has met almost every year since. There is thus a small group of people working with algae who regularly meet, and taxonomic papers have represented a small but significant part of these conferences over the last 30 years. Most of the taxonomic presentations have been concerned with marine flagellates and to a lesser extent seaweeds. A small number of South Africa phycologists attend their International Phycological Congress every four years.

The International Phycological Society (IPS) is very active, and publishes the journal 'Phycologia'.

Collections

All major algal collections are at Universities. The major collections of seaweeds are based at Rhodes University, UCT and University of KwaZulu Natal (UKZN), Pietermaritzburg. A diatom collection is housed at the North West University, and the University of the Witwatersrand (Wits) has a culture collection of marine flagellates.

Electronic resources

The major literature-based algal website is www.Algaebase.org run by Prof Michael Guiry (University College Galway, Ireland).

In South Africa, the seaweed herbaria at UCT, UKZN and Rhodes have been databased and data is available, with the latter two funded by SABIF.

Dr Jonathon Taylor has digitized all Cholnoky's and his own diatom records, which could be added to a proposed South African algal database

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

DNA barcoding of algae has received some attention because of the potential to address problems associated with species identification. There was a global initiative to barcode seaweeds, but it has run out of funds (G Saunders pers. comm.). The number of South African algae that have been submitted for barcoding is unknown, and many of the seaweeds which were submitted have not been sequenced and analysed.

Funding for Algal Systematics in South Africa

Over the last seven years the South African Biosystematics Initiative (SABI) provided funding for a seaweed systematics project, but this initiative has now been incorporated into a larger Department of Science & Technology Programme that has yet to be initiated. The South African Biodiversity Information Facility (SABIF) has provided funds for the digitization of two major seaweed herbaria.

There are limited funds available through the NRF, including the rated researchers open programme, the rated researchers incentives funding and several other programmes that target specific activities (such as international collaborations and conference attendance).

The Algal Taxonomy Strategy for South Africa

The vision of the strategy for algal taxonomy in South Africa is:

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

The three strategic objectives that have been identified are to:

1. develop an inventory of all species recorded in the literature and digitised from properly identified specimens in collections, with an online checklist as the ultimate goal;
2. develop an online algal database ("flora") with identification keys, to achieve dissemination of information to make it accessible to broader public; and
3. develop capacity in taxonomic research on algae.

The first objective would entail exploring and documenting algal biodiversity. Activities required to achieve the objective would be to collate and database taxonomic literature, develop a checklist, and liaise with SANBI to provide this as an online resource. To achieve

an online Flora, the database would need to be additionally populated with descriptions of all species, and these made accessible online.

In order to achieve the first two of these objectives, it is proposed that funding is sourced (possibly from SANBI) for post-doctoral students at UCT to undertake taxonomic research, collate and database taxonomic literature, develop a checklist, and link these to descriptions and keys of all species. The researcher should liaise with SANBI to provide this as an online resource on the SANBI website. Outputs would be an online checklist and online flora, and database of associated information.

The third objective would be achieved by initiating a taxonomic research programme to address taxonomic problems, beginning with those taxa of most relevance to society (i.e. taxonomically, economically and ecologically important taxa). It would be necessary to motivate for funding to be directed towards training young scientists at post graduate level to address pertinent taxonomic research questions in algae. Student projects to develop electronic identification tools should also be encouraged. Interns or students housed at Universities or SANBI can be used to database existing information, including descriptions and images.

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