# A Biosystematics Research Strategy for Bacteria and Archaea in South Africa

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## Summary

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. Bacteria and Archaea have historically been neglected or ignored from other biodiversity studies, and this has led to a disparity in knowledge and research approaches in this field of systematics. The South African National Biodiversity Institute (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, covering all three domains of life including Bacteria and Archaea. The main strategic priorities identified to enhance systematics research of bacteria are to explore the unique diversity of Bacteria and Archaea in South Africa, to promote research in priority areas to improve understanding of the function and impact of bacteria in specific ecosystems, to develop a database to capture all economically important species and to increase taxonomic capacity in South Africa by establishing a network of bacterial systematists.

## Introduction

As part of the growing international commitment to sustainable development and the realization that conservation of biological diversity is critical to the success of economic and social development, the Convention on Biological Diversity (CBD) was initiated at the Rio "Earth Summit" in 1992.[1] In order

to further raise worldwide awareness of the importance of biodiversity the United Nations declared 2010 the International year of Biodiversity. This was followed by a decision that 2011–2020 will be the Decade of Biodiversity. During this period the focus is on the implementation of the Strategic Plan for Biodiversity to achieve the Aichi Biodiversity targets.[2] These initiatives have a strong focus on the protection of biodiversity and ensuring that such efforts will benefit all people.

The existence of the "taxonomic impediment"[3] has, however, been identified by the CBD as one of the major challenges for the achievement of the Strategic Plan and Aichi Biodiversity targets. It is clearly evident that biodiversity cannot be conserved and managed sustainably without a detailed understanding of extant diversity and its role and interactions within specific ecosystems. In order to address this problem, the Global Taxonomic Initiative (GTI) was established by the CBD.[4] The main focus of this initiative is to encourage governments to assist in addressing issues such as inadequate taxonomic information and limited expertise. The Capacity-Building Strategy for the GTI iterates that by 2015, parties should produce taxonomic tools that will enable users to identify and analyse, amongst other things, "socio-economically important species, including microbial diversity". One of the outputs for this action is suggested to be species inventories.

In response to the dearth of expertise in biosystematics various countries have initiated funding programmes to support taxonomy. These include the "Partnerships for Enhancing Expertise in Taxonomy" of the National Science Foundation in the USA[5] and the "South African Biosystematics Initiative" supported by the National Research Foundation in South Africa.[6] There have also been regional efforts such as the GTI Africa Workshop[7] to address this issue. The focus of these and previous initiatives has, however, mainly been on eukaryotic organisms with no or little attention to the domains of Bacteria and Archaea.[8] This has been a major criticism[9] as these domains represent the "unseen majority" of life on Earth.[10-11]

In South Africa, the South African National Biodiversity Institute (SANBI) has been tasked by the National Environmental Management: Biodiversity Act (NEMBA) No. 10 of 2004 to address to "promote and co-ordinate taxonomy in South Africa". In response SANBI has initiated a national Biosystematics Research Strategy to provide coordinated guidance to all institutions involved in biosystematics research. The advantage of having a coordinated strategy is that it will focus the research towards addressing the critical needs of end-users, thereby improving the relevance and impact of research products that are delivered. In addition the strategy could be used to motivate for funding when opportunities arise.

Bacteria and Archaea are referred to obliquely in NEMBA, in that SANBI "may establish, maintain, protect and preserve collections of animals and microorganisms in appropriate enclosures." This is in

no way a unique situation and only indirect references to bacteria can be found in the biodiversity strategies of other countries. A decision was taken that the overall South African strategy will focus on specific groups of organisms and that a specific strategy focusing on the Domains Bacteria and Archaea will form part of the broader research strategy which will also deal with plants, algae, animals and fungi.

# Biosystematics Research Strategy for Bacteria and Archaea

## Diversity and relevance of Bacteria and Archaea

Grouped together, the Bacteria and Archaea (hereafter generally only referred to as bacteria) are the most abundant organisms on Earth, forming the largest component of the earth's biomass and genetic diversity. Bacteria play a crucial role in ecosystems, such as in nutrient cycling, primary production oxygenic photosynthesis, soil health and biodegradation. Bacteria play an essential role in animals (including humans) for digestion of food, protection against pathogens, vitamin production and disease resistance. In plants, bacteria contribute to growth promotion, nitrogen fixation bioactive compounds and biocontrol. They are also widely used in industry for food preservation and during the production of therapeutic proteins.[12]

Only a small fraction of bacteria are pathogenic to humans, plants or animals. Of the more than 1 900 described bacterial genera[13] only about 80 are known to contain human pathogenic species.[14] Despite the limited number of pathogenic bacterial species, they have significant economic impacts and the bulk of the available research funding is directed towards studying the systematics and epidemiology of these pathogens. Studies focusing on other environments where most of the world' bacterial diversity resides remain underfunded.

Currently there are about 12 900 formally describe species in these two domains[13], but it is estimated that the diversity is much larger. After the initial introduction of culture independent studies a review of the existing data estimated that more than 99% of the bacteria observed in nature may not be culturable using standard techniques.[15] While studies attempting to estimate the diversity based on modelling taxa abundance distributions remain inconclusive[16], it is widely accepted that the true species diversity of bacteria is between 1 and 10 million.

One of the reasons why bacteria have often been overlooked in biodiversity programmes with a strong conservation focus is the flawed perception that all bacteria are omnipresent, highly redundant and unlikely to be at risk to become extinct.[17] This perception is strongly driven by Baas Becking's paradigm "everything is everywhere but the environment selects".[18] Modern molecular techniques have enabled the accurate documenting of microbial diversity. Studies of the distribution of free-living bacteria have shown that bacteria may exhibit patterns of diversity that are qualitatively similar to those observed for plants and animals[19], but such studies are hindered by the difficulty of defining a bacterial species.[20-21] The prevailing hypothesis is that some bacterial species are cosmopolitan while other species or groups are restricted to specific environments.[22] Based on these clear signs of regional endemism for some groups of bacteria it is therefore important that they should be included in conservation strategies.[9]

## Key aspects covered by strategy

The proposed strategy for Bacteria and Archaea aims to assess the existing capacity and resources in South Africa, propose infrastructure to collate taxonomic and associated information, identify gaps and priority areas for research, and to propose a means to achieve this. Several strategic objectives have been identified that will need to be implemented to achieve this aim. These objectives focus on issues such as the advancement of research to assess the unique South African bacterial diversity and the role of bacteria in ecosystem functioning as well as creation of central databases and information resources for the benefit of various stakeholders. The strategy also addresses the need to increase taxonomic capacity and promote the interaction between researchers interested in bacterial systematics and diversity.

**Strategic objective 1: To document new species of bacteria that may represent a unique genetic resource for the country.**

As the national strategy has a strong focus on the unique biodiversity of South Africa, three niches / environments known to potentially harbour "endemic" bacteria will form the initial focus. These niches were selected based on the potential benefit these endemic bacteria could have to society. An important niche selected was indigenous plants harbouring beneficial bacteria such as the nitrogen fixing *Burkholderia* species associated with legumes in the Cape Floristic Region.[23] These bacteria have great potential as robust inoculants in acidic soils and

would be able to outperform the current commercial inoculants as they would be able to cope better with the increasing temperatures as a result of climate change. Another focus has been indigenous invertebrates harbouring symbiotic bacteria. Many of the symbiotic actinomycetes associated with invertebrates such as termites and mites have been shown to produce unique antibiotics that could be used to treat both bacterial and fungal infection.[24] Other unique ecosystems could include hot springs, deserts, deep mines and traditional fermented foods. Several unique enzymes and metabolites are excellent examples of the commercial and scientific benefit that could be obtained from the unique bacteria present in these environments.

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

Human, animal and plant diseases have a large impact on the economy in South Africa and the primary focus of the programme will be to create checklists of pathogenic bacteria previously reported for South Africa. These databases could be hosted on the SANBI website where it will be available for use by the various users including government departments such as Department of Health and Department of Agriculture, Fisheries and Forestry for dealing with import permits and quarantine measures. It will also be of benefit to plant pathologists, pathologists, veterinarians and farmers.

A book capturing this information for bacterial plant diseases in South Africa[25] already exists and can easily be converted to a searchable and regularly updated database. The focus will, however, not only be on pathogenic bacteria.

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

**Strategic objective 3: To create a database of relevant information and links to information that could guide identification.**

Many microbiologists without an interest in bacterial systematics need to identify bacteria on a regular basis. To assist these end-users of the taxonomic data, a data base will be created that will provide standard operating procedures, links to important databases (e.g Ribosomal Database Project[26], All-Species Living Tree project[27], List of bacteria with standing in nomenclature[13]) as well as a list of the latest references works that can be consulted e.g.

Bergey's Manual.[28] It is also envisaged that the database will also provide information on where bacterial cultures originating from South Africa can be obtained from recognised national and international culture collections.

**Strategic objective 4: To promote research investigating the impact of bacteria on biodiversity, conservation and the functioning of ecosystems.**

The primary aim of this objective will be ensure that studies dealing with biodiversity and ecosystems health all include a bacterial component. This will be achieved by participating in and initiating joint research projects addressing issues such as the role of bacteria in the radiation of plant diversity or the impact of bacterial on ecosystem services and diversity.

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

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

## Implementation challenges and future prospects

Implementation of all the Biosystematics Research strategies is in the first instance dependent on the willingness of the taxonomic community to endorse it. In the case of the strategy for Bacteria and Archaea this is even more of a challenge as the current expertise exists primarily at South African universities and work is mainly done within isolated research groups. SANBI, with its strong focus on plant taxonomy, has currently no direct influence on bacterial systematics research. It will be important for SANBI to initiate the establishment of a network of South African bacterial taxonomists which will have to take responsibility for the promotion and implementation of this strategy. Only through such a network and the funding of collaborative research projects will the institute be able to deliver on its mandate to promote and coordinate the taxonomy this group of organisms.

Implementation of the strategy could also be limited as there are currently only a small number of active South African bacteriologists (≤ 15 academics at 7 universities) that have recently published studies on the taxonomy or diversity of bacteria. Bacterial systematics is not the sole focus area of any of these academics and several of them are already above 50 years of age. It is therefore important that as part of the implementation strategy funding should secured for capacity development and student bursaries in line with the Capacity Building strategy for the GTI.

As this strategy does not form part of the current research focus of SANBI, external funding will have to be secured for its implementation. The Department of Science and Technology should be approached as they have the primary responsibility for research funding. Another possible source of funding could be the Department of Agriculture, Forestry and Fisheries involved in biocontrol efforts or the Department of Environmental Affairs as they have to ensure that South Africa complies with the requirements of the CBD and GTI.

From a national perspective it is important that a biosystematics research strategy for bacteria should be integrated and aligned with the other national strategies as there is no current governmental capacity or legal framework to deal with this group separately. One of the consequences of this decision was that the main research component of the strategy concentrated on bacteria unique to South Africa and which could be of benefit to society. It is, however, envisaged that once society experience the benefits of biosystematics research, more exploratory research could also be funded with public money.

## Conclusions and recommendations

Isolation of the disciplines of microbiology from plant and animal studies has resulted in different approaches in systematics studies, and to a neglect in this aspect of the discipline. We have attempted to bridge the gap between microbial studies and the rest of biodiversity by including the Bacteria and Archaea domains in the Biosystematics Research Strategy. It is hoped that this strategy may stimulate funding interest to be directed towards addressing priority areas in future, so that a cohesive approach can be achieved to maximise useful and practical outputs from limited resources.

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