Historical perspectives and new opportunities for Australian collections of microorganisms in the microbiome era

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A new microbiology support program for Australian microbial resources centres is essential to take full advantage of the exciting information and biological materials emerging from molecular studies of microbiomes. At a time when taxonomic capacity is in decline, culture collections, with the appropriate level of infrastructure support and funding, are well positioned to enhance the outcomes of microbiome research. The importance of microbial biodiversity and its contribution to life on earth have never been more appreciated in the history of science than now. This appreciation came initially through the systematic study of microbial cultures, their ecological interactions, evolution and genetics. But now in the genomics era, uncultured microorganisms and whole microbial biomes are increasingly being studied using advanced DNA sequencing and bioinformatic techniques bringing greater insight into complex microbial communities, revealing interactions between microbes and the host affecting health and wellbeing. However, it should be remembered that the inference of identity and interpretation of functions of members of these uncultured communities relies heavily on knowledge gained from the study of cultured microorganisms. Advances will be greatly enhanced by bringing novel, and other significant, species in these environments into culture for laboratory study and accession into collections for future biodiscovery.

While Australian biodiversity programs are world leading with respect to eukaryotic flora, fauna and fungi, they have not been sufficiently inclusive of prokaryotic microorganisms (bacteria and archaea), and also viruses. It is essential that Australian microbial biodiversity is more extensively studied, described, and protected securely in microbial collections for immediate and future research and biotechnological applications. Changes are needed so that microbial biodiversity studies and culture collections are integrated equally into Australian biodiversity studies and collections infrastructure. Several proposals have been made over a long period of time to achieve these goals[1–4] and to transition culture collections into Biological Resource Centres in line with OECD recommendations and guidelines[3–7].

Microbial biodiversity and culture collections in Australia

I have written previously in more detail on the importance of microbial diversity and the history and role of culture collections in Australia[1,3,4]. Microorganisms were the first forms of life on earth and have evolved into the most ecologically, genetically and metabolically diverse species known. Microorganisms belong to all three Domains of life: The Bacteria, Archaea and Eukarya (algae, fungi, yeasts, protozoa) as well as the Viruses. They have shaped the evolution of the planet and continue to nurture and sustain the environment, plants and animals on which the sustainability of the planet and society depends[4]. Culture-independent molecular studies of environmental samples using rRNA sequence information and metagenomics continue to confirm that the vast majority of microbial species remain so far uncultured thus limiting our knowledge of microbial functions and ecology[8]. A recent molecular estimate of the Earth's bacterial and archaeal diversity has been determined as 2.2–4.3 million species[9].

Currently there are 34 collections with 82 946 cultures listed for Australia in the WFCC World Directory of Culture Collections of Microorganisms (http://www.wfcc.info/ccinfo/index.php/home/content), down from 50 in 1998. These collections have mainly institutional roles and the host institutions are usually universities, CSIRO, hospitals, government laboratories, and industry. Most cultures within these collections are bacteria, fungi, yeasts, and microalgae with minor holdings of protozoa and viruses. The collections are engaged in medical, veterinary and plant pathology, agriculture, marine science, forest microbiology, Antarctic

microbiology, food science, wine research, ecology, taxonomy and education.

Due to the distributed nature of microbial culture collections in broadly different disciplines, the Heads and Curators of Australian microbial collections rarely had an opportunity to meet to discuss common objectives for the development of culture collection resources in Australia. These issues were addressed independently in various forums and special interest groups within separate scientific societies covering microbiology, medical sciences and plant pathology but a mechanism for all to meet together was missing.

Initially set up as an ARC Seed Funding Project for Research Networks in 2004, the Australian Microbial Resources Research Network (AMRRN)[2,3] was the first attempt to bring microbial collections and biodiversity researchers together and was involved as a partner with the Council of Heads of Australasian Herbaria (CHAH), Council of Heads of Australian Faunal Collections (CHAFC) and other stakeholders in the proposal to NCRIS (National Collaborative Research Infrastructure Strategy) which led to the Atlas of Living Australia (ALA) (https://www.ala.org.au/). The vision of AMRRN was to develop a world class research network to discover and exploit Australian microbial resources and to make these resources and associated information available for applications in science, research, industry and education. The AMRRN would link and support researchers working in a range of disciplines, including microbial diversity, taxonomy, evolution and genomics, ecology, identification, culture collections, bioinformatics, biodiscovery and biotechnology[2–4]. The AMRRN proposed three mechanisms to deliver this vision:

- ACM: an integrated network of Australian Collections of Microorganisms to conserve and supply cultures;
- AMRIN: the Australian Microbial Resources Information Network to facilitate access to information on Australian microbial resources; and
- AMRS: Australian Microbial Resources Study to undertake taxonomic research on Australian microbial diversity.

Unfortunately, the proposal was not funded as it did not meet the criteria for ARC Research Networks. However, the exercise allowed some progress to be made. The later development of the ALA has meant that the data aggregation and search functions proposed for AMRIN can be delivered through the ALA Natural Collections Hub (https://collections.ala.org.au/) and now also through the Global Catalogue of Microorganisms (http://gcm.wfcc.info/) at the WFCC World Data Centre for Microorganisms. Although by no means complete there is an open-ended opportunity for collections to expand the information available on their holdings and for new collaborating collections to join these initiatives. Australian collections are encouraged to register with the World Data Centre for Microorganisms and the Atlas of Living Australia and to connect their entries.

In 2009, the AMRRN held a meeting in Brisbane with representatives of the ALA to establish the Council of Heads of Collections of Microorganisms (CHACM). This marked the first comprehensive meeting of Heads and Curators of Australia's microbial collections. The meeting established the minimum standards for data in Australian microbial collections compliant with international standards to facilitate sharing of data through the ALA. A few collections had suitable database software, but the meeting identified that the lack of modern database software was a major impediment for many collections to digitise their collection records which would allow sharing of information and the ALA is commended for providing BioloMICS software to those collections in need. The WDCM Global Catalogue of Microorganisms now provides a complementary means to assist with the generation of digital catalogues.

There are 31 collections of microorganisms listed with the ALA (https://collections.ala.org.au/) but not all have committed to provide strain data at this stage of its development usually due to lack of staff within the collection to carry out the work and sometimes due to patient privacy concerns in some medical collections, biosecurity issues in some plant pathology collections and commercial sensitivity in others. Information on Australian collections is available through the ALA (https://collections.ala.org.au/) and the WFCC World Directory (http://www.wfcc.info/ccinfo/index.php/home/content).

A new era for Australian collections

The microbiome era opens up new opportunities and challenges for microbial collections, not only for the conservation of complex genetic material but also for collaborative research on the microbial taxonomy and ecology of the expanding number of microbiomes across a wide range of environments. The completion of genomic analysis of microbiomes is not the end of the story for scientific discovery. Rather, it is the beginning, an insight into the microbial complexity of different environments revealing novel microbial diversity and significant microbial functions and interactions. Current statistics indicate that 15% of 154 904 microbial genomes belong to uncultured microorganisms (https://gtdb.ecogenomic.org/stats) compared with 85% based on 16S rRNA surveys[8,10]. This apparent discrepancy is simply a reflection of the limited number of genome sequences available (P. Hugenholtz, pers. comm.).

Clearly, a more complete knowledge of Australian microbial diversity and microbial taxonomy will be achieved by encouraging the systematic microbial study of Australian microbiomes. To achieve

this, previous recognition by government biodiversity policy[11] and reviews[12] to accelerate Australian microbial diversity studies and recommending the need to strengthen and support collections of microorganisms will need to be urgently achieved.[4] Many government ministries and agencies support programs in agriculture, trade, food, health, quarantine, industry, science and education which depend on accurate taxonomic decisions and access to standard cultures for quality assurance and regulatory compliance. New long-term infrastructure funding mechanisms are needed to support microbial collections to improve their security, meet OECD guidelines[6,7], and help reverse the loss of collections and microbial biodiversity when researchers retire, or host institutes change direction and priorities.

As a matter of principle, representative Australian microbial diversity obtained in publicly funded research must be accessioned into permanent national Australian collections and protected as part of our natural scientific heritage as occurs with the native flora and fauna. As well, it would not be unreasonable to expect that cultures described in publications from publicly funded research be accessioned in the same way as a condition of funding. The OECD is strongly promoting that biological resource centres are essential to underpin advances in biotechnology, the life sciences and the bioeconomy[6,7]. Microbial resource centres are more than collections. They preserve and provide authenticated, genetically stable microbial and cell cultures, provide access to information on cultures and their characteristics, and undertake identification and description of new species. They work within the framework of the Convention on Biological Diversity (CBD) (https://www.cbd.int/convention/) implemented to support the conservation and utilisation of biodiversity and recognising the principles of fair and equitable benefit sharing. With the coming into force of the Nagoya Protocol on Access and Benefit-Sharing (https://www.cbd.int/abs/), culture collections and microbiologists generally are addressing best practices to adhere to the Protocol for the receipt, supply and management of biodiversity material and associated information and records[13,14].

There is an urgent need to train and mentor the next generation of taxonomists and curators in collections[4]. Many curators are approaching retirement and many who have already retired are not being replaced. The Taxonomy Australia (https://www.taxonomyaustralia.org.au/) initiative is calling for accelerated research on describing Australian biological diversity over the next decade and highlights the slow progress being made with microorganisms, particularly bacteria, archaea and viruses. This is an excellent initiative but brings no additional funding, an issue which must be addressed by funding agencies if realistic progress is to be made.

There is also a need to reverse the decline in teaching and postgraduate research training in microbial taxonomy and ecology in universities. One model[4] for consideration is the establishment of research centres of excellence in microbial diversity, taxonomy and ecology either within or in collaboration with microbial resource centre collections to investigate microbial diversity in Australian microbiomes. This would accelerate discovery and assist in training the next generation(s) of research scientists and academics in microbial biodiversity and taxonomy and will be important for providing high-level research training and careers in taxonomy and identification for PhD and postdoctoral scientists.

Historically, Australian Collections of Microorganisms have made a significant contribution to microbiology. They have supported research and essential functions in their host institutions, but also provided essential service across the broader scientific community. Many microbiologists associated with these collections have been proactive advocates and responsible for some key advances. Notably, the establishment of the WFCC World Data Centre for Microorganisms by Professor Vic Skerman at the University of Queensland in 1966 and now hosted by the Institute of Microbiology at the Chinese Academy of Sciences in Beijing, has matured into a vital well respected global repository of digital information and support for collections.

Improved infrastructure for collections and microbial taxonomy has been a fundamental driver of the Australian Microbial Resources Research Network. Culture collections have always needed to adapt to advances in microbiology and changes in regulatory compliance and scientific priorities to remain relevant to current and future needs. This will be even more important in the future adapting to new technologies which are rapidly expanding information on the vast scale of microbial diversity in microbiome genomic research. This provides significant opportunities for collections to engage and collaborate in this research bringing microorganisms into culture for taxonomic study and biotechnology.

Culture collections will always remain the conservators of our natural microbial heritage. With proper funding arrangements to transition collections into OECD compliant microbial resource centres and centres of excellence for microbial taxonomy, collections will have important roles in adding significant value to Australian biodiversity knowledge and the outcomes of microbiome research. Collections and the microbiology community are encouraged to engage through CHACM to maximise the future success of Australian Collections of Microorganisms and help make the vision of AMRRN a reality.

Conflicts of interest

The authors declare no conflicts of interest.

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Biography

Emeritis Professor Lindsay Sly was Professor of Microbial Systematics and Microbial Ecology, Director of the Centre for Bacterial Diversity and Identification, and Curator of the Australian Collection of Microorganisms at the University of Queensland where he undertook research and teaching of the biodiversity, physiology, metabolism and ecology of bacteria from natural and industrial environments. He has made major contributions to knowledge of microbial diversity, to the understanding of phylogenetic relationships amongst species in diverse bacterial and archaeal divisions, and to the development of molecular tools for the identification of bacteria and archaea. He was awarded Fellow of the Australian Society for Microbiology (FASM) in 1989, and Fellow of the Australian Institute of Biology (FAIBiol) in 1992. In 2001 his outstanding contributions to systematic bacteriology were recognised with the prestigious international Bergey Award and in 2010 he received the WFCC Medal for outstanding contributions to the World Federation for Culture Collections. He was president of the World Federation for Culture Collections from 1996 to 2000 and Foundation Chair of the Council of Heads of Australian Collections of Microorganisms in 2009.