Australian Microbial Resources[1]

Exploring the need for a priority research program on Australian Microbial Diversity incorporating support for a network of Australian Collections of Microorganisms and Genetic Resources, and an Australian Microbial Resources Information Network

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Summary

This paper addresses the urgent need for a national review of culture collections of microorganisms and genetic resources in Australia, the need for an accelerated research program on microbial diversity and its conservation as recommended in the *National Strategy on the Conservation of Australia's Biological Diversity*, and the need for a computer inventory and information network for the location of microorganisms and genetic resources. Australian culture collections lack the minimum critical staff numbers and resources to meet these objectives and to provide the services required by users in the science, technology, and industry sectors. While the uniqueness and species richness of Australian flora and fauna has been recognized and studied thoroughly, the more extensive genetic and metabolic diversity of Australian microbial diversity has been largely unexplored. There is currently no adequate research funding mechanisms for the systematic and taxonomic study of microorganisms in Australia and this deficiency needs to be redressed. Considerable scientific and commercial benefits will be derived from a thorough study of Australia's microorganisms. It is proposed that a Microbial Diversity Program be established which integrates an Australian Microbial Resources Study (AMRS) with the development of a network of Australian Collections of Microorganisms (ACM), and an Australian Microbial Resources Information Network (AMRIN).

The importance of microbial diversity

Microorganisms, those organisms (bacteria, fungi, algae, protists, and viruses) not normally visible to the naked eye, are an essential component of biological diversity, without which there can be no sustainable ecosystems (6,7,9,18,23,26). Fifty percent of the living biomass on the planet is microbial (18) and microorganisms provide a major source of genetic information for molecular biology and biotechnology (3,16,18,26). Very little is known about microbial species and functional diversity, and decisions about the role of microorganisms and their influence on sustainable ecosystems are being made on the basis of very incomplete information. Without a thorough knowledge of microbial diversity and ecology, the outcomes of "black box" ecological studies concerned with sustainability are flawed. All animals and plants have evolved from microorganisms and are dependent on their activities for their survival.

Recent advances in molecular methods (1,11,14,17,25,32,33) have revealed the inability of traditional culturing methods to fully show the diversity of bacteria and other microorganisms and have shown that the species' diversity in most terrestrial and aquatic environments is far greater

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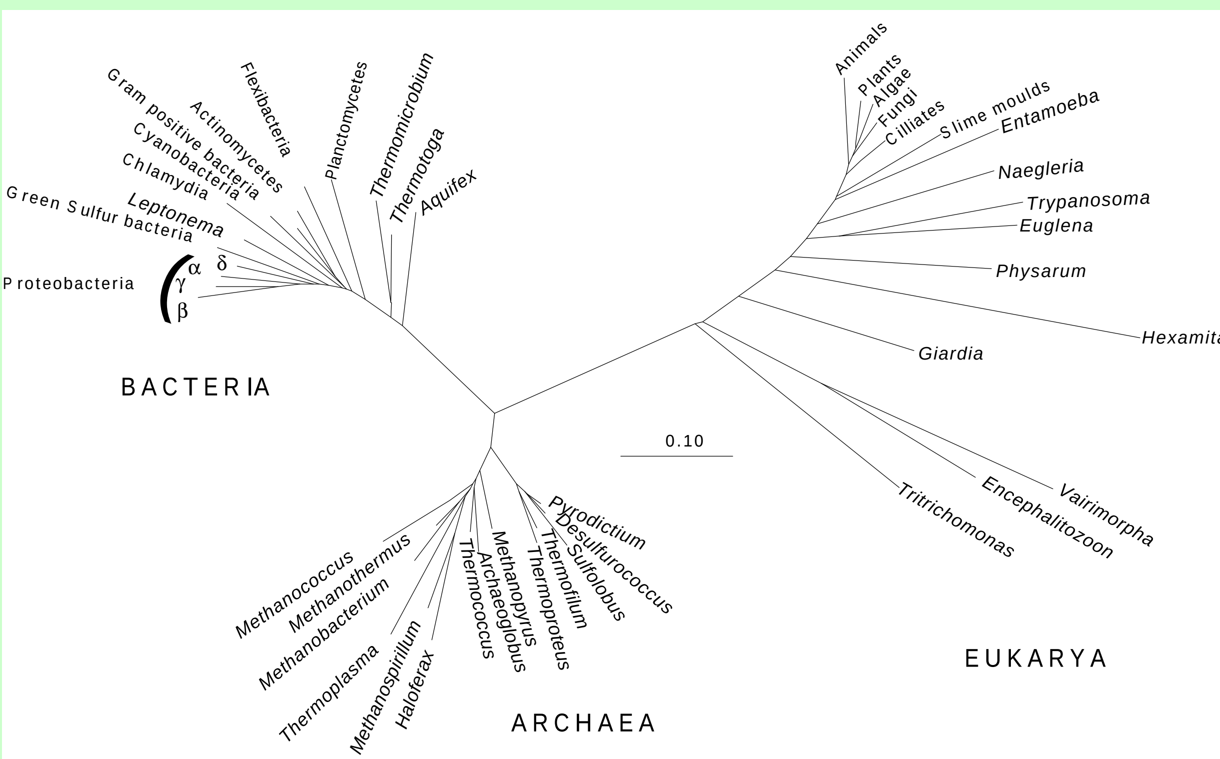
than expected. The vast majority of microbial diversity (>95%) remains to be discovered. The decline in so called 'megadiversity' regions and 'hot spots' of endemic flora, fauna, and microorganisms has focussed scientific and commercial attention on the remaining regions, particularly in the tropics. However, extreme environments such as acidic, thermophilic, hypersaline, and arid regions, are equally important 'hot spots' of microbial 'megadiversity'. These are habitats of microorganisms which have the genetic and physiological capacity to survive and grow under these harsh or extreme conditions through which they have evolved while shaping the environment as we know it today.

Microorganisms including the prokaryotes (bacteria and archaea), the eukaryotes (fungi including lichen-forming species, slime moulds, and yeasts; algae and protozoa), and viruses occupy important niches in all ecosystems, are responsible for much of the recycling of the elements in nature (e.g. the decomposition and recycling of organic matter in forest ecosystems), and are important components of the food chain. Microorganisms often have unique functions (e.g. nitrogen fixation, nitrification, denitrification, chemolithotrophic carbon dioxide fixation, methane formation, and sulfate reduction) in the biogeochemical cycles, in soil formation, in climate regulation, and influence atmospheric composition [including greenhouse gases (19)]. The first microorganisms evolved over 3.8 billion years ago and consequently exhibit the greatest breadth of genetic and metabolic diversity on the planet, far greater than that of the plants and animals combined (18,26). Microorganisms dominate the evolutionary lines of the three domains of life now known as the Bacteria, Archaea, and the Eukarya (see Figure 1). Microorganisms occur in all ecosystems. Some are able to grow under extreme conditions, and also in anaerobic environments that cannot sustain plant or animal life. On the other hand, natural terrestrial and aquatic ecosystems depend on microorganisms to sustain their nutritional requirements, sometimes through microorganisms which exhibit symbiotic relationships with plants (e.g. *Rhizobium*, *Frankia*, and mycorrhizal fungi in plant roots) and with animals (e.g. tube worms and

Figure 1

Universal phylogenetic tree of life based on rRNA sequences
(Reconstructed from the aligned sequence dataset of Barns *et al*. 1996)



mussels). Animals depend on microorganisms in their intestinal tracts for digestion and for the production of nutrients and essential vitamins.

The genetic and metabolic diversity of microorganisms has been exploited for many years in biotechnological applications such as antibiotic production (e.g. streptomycin from the actinomycetes, penicillin from the fungus *Penicillium*), food (e.g. mushrooms), food processing (e.g. cheese, yoghurt, vinegar), alcoholic beverages (e.g. wine, beer), fermented foods (e.g. soy sauce, tempeh), and waste treatment (e.g. sewage treatment, landfill). Originally cultures used in traditional fermented foods were selected by chance, but through advances in basic scientific research, cultures with novel metabolic attributes have been discovered and exploited. Microorganisms are the major sources of antimicrobial agents and also produce other important pharmaceutical and therapeutic compounds including antihelminthics, antitumour agents, insecticides, immunosuppressants, immunomodulators, and vitamins worth $35-50 billion annually in global sales (18). However, the majority of applications await exploitation.

The scientific benefits of microbial diversity research include a better understanding of the role and function of microbial communities in various terrestrial, marine, and aquatic environments, a better understanding of the sustainable ecology of plants and animals, improved capacity to maintain soil fertility and water quality, and a better understanding of the full consequences of animal and plant extinction, and of perturbations on ecosystems. The economic and strategic benefits are the discovery of microorganisms for exploitation in biotechnological processes for new antibiotic and therapeutic agents, probiotics, novel fine chemicals, enzymes and polymers for use in industrial and scientific applications, for bioremediation of polluted environments, and bioleaching and recovery of minerals, as well as preparedness against exotic and emerging pathogens of humans, animals, and plants.

NATIONAL POLICY

The value of microorganisms has been recognized in the *National Strategy for the Conservation of Australia's Biological Diversity* developed following ratification of the Convention on Biological Diversity in 1993.

Specifically in objective **4.1.5 Inventory** the strategy recommends the need to:

"Accelerate research into taxonomy, geographic distribution and evolutionary relationships of Australian terrestrial, marine and other aquatic plants, animals and microorganisms, priority being given to the least known groups, including non-vascular plants, invertebrates and microorganisms ……... This can be best achieved by strengthening the role of the Australian Biological Resources Study, including an extension of the Study program to cover microorganisms."

Status: **No apparent progress has been made towards this objective. ABRS has begun to provide limited funding for taxonomic research on targeted species of fungi, algae, and protozoa. However, the low level of funding for these groups is not allowing significant advances in knowledge in the short term. There is no funding for the taxonomy of bacteria and viruses which are excluded.**

Australian microbial diversity

Australian scientists have made major contributions to the knowledge of microbiology. Contributions have been made in the areas of bacteriology, virology, mycology, protozoology, and industrial microbiology. Generally the emphasis has been on practical needs such as the diagnosis and treatment of human, animal, and plant diseases, but has also addressed fundamental issues of pathogenicity and virulence, genetics, physiology and biochemistry, fermentation, and microbial taxonomy. Much of this research is beyond the scope of this paper and readers are referred to the excellent review, *History of Microbiology in Australia*, edited by Fenner (5) for further details.

During the course of microbiological research, knowledge of the diversity of Australian microorganisms is often revealed. Frequently, diversity and geographic distribution at the strain level are important for epidemiological studies of pathogens. Amongst the human and animal pathogens, work has been undertaken with *Salmonella*, *Shigella*, *Haemophilus*, pneumococci, *Staphylococcus*, *Pasteurella*, *Campylobacter*, *Yersinia*, *Vibrio cholerae*, and a number of the arboviruses (5). Strain diversity and variation is very important for the design of effective vaccines, diagnostic tests, and quarantine assessment. Sometimes during this research new species are discovered, although this is often not the main goal of the research. Basic taxonomic research usually provides a more comprehensive understanding of species diversity.

Examples of species or varieties first isolated and described in Australia are listed in the boxed text. Some of these species such as *Rickettsia australis*, Ross River virus, and Murray Valley encephalitis virus are endemic pathogens of Australia. Others, such as the Q fever agent, *Coxiella burnettii*, and the peptic ulcer bacterium *Helicobacter pylori*, have since been found elsewhere, but the initial discovery in Australia led to research in other countries. Frequently new species are isolated but are never described due to the low priority of taxonomic research.

Knowledge of the distribution of microorganisms also has important implications for quarantine and surveillance of pathogens. It is essential that representative type material is conserved in permanent

EXAMPLES OF NEW MICROBIAL SPECIES OR STRAINS FROM AUSTRALIA AND TERRITORIES

MICROORGANISM	FEATURE
Algae	
Batrachospermum diatyches	mountain lake, Tasmania
Chrysonephele palustris	swamp, Tasmania
Coelarthrum decumbens	habitat for invertebrates
Exallosorus olsenii	habitat for invertebrates
Vaucheri gyrgyna	coastal salt march, Victoria
Bacteria	
Agrobacterium vitis	watery decay of grape vine roots
Beijerinckia derxii	nitrogen fixation in soil
Cellvibrio mixtus	cellulose degradation in soil
Chlamydia psittaci	Koala infections
Clavibacter toxicus	annual ryegrass toxicity
Coxiella burnetii	Q fever
Desulfotomaculum australicum	sulfate reducer, Great Artesian Basin
Dichelobacter nodosus	sheep foot rot
Halomonas subglaciescola	salt tolerant, Antarctica
Helicobacter pylori	gastritis, peptic ulcer
Legionella adelaidensis	air conditioner cooling tower water
Leptospira pomona	red water of calves
Methanogenium frigidum	psychrophilic methanogen, Antarctica
Morococcus cerebrosus	brain abscess
Porphyrobacter neustonensis	aerobic chlorophyll synthesis
Rhizobium spp.	legume nodulation
Rickettsia australis	tick-borne typhus
Salmonella adelaide	salmonellosis
Streptococcus gallolyticus	intestines of koalas and kangaroos
Telluria mixtus	dextranase enzymes
Fungi	
Acrocalymma medicaginis	root and crown rot of lucern
Armillaria luteobubalina	root rot of woody plants
Castoreum tasmanicum	food for mycophagous marsupials
Cryptococcus neoformans var. *gattii*	cryptococcosis of horses, humans, and koalas
Fistulina spiculifera	brown rot of eucalypt heartwood
Mesophellia glauca	food for bandicoots and potoroos
Mycena nargen	white rot of eucalypt wood
Mycosphaerella cryptica	leaf spot of eucalypts
Phomopsis leptostromiformis	lupinosis of grazing animals
Piromyces spp.	decomposers in marupial guts
Smittium angustum	commensal on larval diptera
Xantoparmelia austroalpina	environmental indicator
Protists	
Naegleria fowleri	meningitis
Tritrichomonas foetus	serovar Brisbane, cattle
Viruses	
Equine morbillivirus	bats; pneumonia in horses, humans
Murray Valley encephalitis	human encephalitis
Kunjin virus	fever, encephalitis
Lettuce necrotic yellows	aphid transmitted
Lyssa	rabies-like
Ross River virus	human polyarthritis
Tomato spotted wilt	thrips transmitted

culture collections for future reference and that biogeographic databases are available for interrogation and analysis. It is unfortunate that valuable type material from past studies is often not available or is not accessible owing to the lack of a national inventory. Regrettably, the easiest or sometimes the only way to obtain cultures is to re-import them from permanent overseas collections if the cultures have been accessioned in the past. Frequently, valuable collections of isolates are discarded or neglected on the retirement of a researcher, because of changes in institutional priorities.

Despite its importance, the knowledge of Australian microbial diversity is extremely limited outside the areas of human, plant, and animal pathogens. Most taxonomic research on environmental species has been carried out in universities, CSIRO, and government laboratories. There has been some funding by the Australian Biological Resources Study (ABRS) which has allowed commencement of studies on the taxonomy of algae, and fungi (5b). Of these taxa the algae and lichenised fungi are best known. Bacteria and viruses appear to be excluded from the ABRS program. Bacterial taxonomy was also excluded from study under the Australian Research Grants Scheme (ARGS) and there was no category for bacterial taxonomy in the Australian Research Council (ARC) grants scheme for many years. However, the ARC has recently introduced categories for microbial systematics, taxonomy and phylogeny and microbial ecology consistent with research categories in animals and plants. This welcome change should hopefully stimulate research in microbial diversity and is in line with research trends in Europe, Japan, and the USA (4,26).

Nevertheless, several microbiologists have undertaken taxonomic studies often as part of postgraduate research. Amongst the non-pathogenic bacteria, for example, the major groups studied are the *Azotobacteriaceae*, *Pseudomonas*, *Rhizobium*, myxobacteria, sulfate reducing bacteria, *Saprospira*, *Herpetosiphon*, *Vibrio*, some actinomycetes, and the methanotophs in localized areas. There is sufficient evidence already that most environments studied have abundant novel taxa of culturable microorganisms of potential value (5a) and this finding has also been confirmed in a number of recent molecular studies of Australian environments (e.g. 14,25).

There has been a decline in opportunities for taxonomic research because of reduced funding and the low number of practicing taxonomists. This situation threatens our future capacity to fully investigate microbial diversity in Australia and to create a comprehensive national inventory.

The role of culture collections

Access to cultures of microorganisms, cell lines, and genetic material, is an essential requirement for the conduct of microbiology and related disciplines. In Australia microbiologists and molecular biologists working in industry, quality assurance, human, animal, and plant health, research, and education are disadvantaged compared with those in most developed countries. Australia has no adequately resourced national collections of microorganisms, and it is difficult to easily access information on microbial resources in Australia (including standard reference and type cultures and conserved Australian microbial diversity). Microbiologists are also disadvantaged by delays in obtaining cultures from overseas (caused by our geographical

NATIONAL POLICY

The *National Strategy on the Conservation of Australia's Biological Diversity* acknowledges the important role of culture collections of microorganisms in the context of *ex-situ* conservation:

1.9.1 Strengthening *Ex-situ* conservation

"Strengthen *ex-situ* conservation, including the provision of adequate resources to relevant institutions and organisations, by:

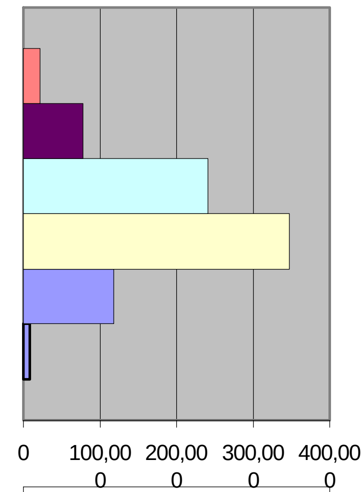
(b) establishing or strengthening networks of culture collections of microbial species, including those of medicinal, agricultural and industrial importance;

***Status*: No progress has been made towards this objective.**

isolation and by necessarily stringent quarantine restrictions) and therefore require extensive reference collections in Australia to overcome these difficulties.

A national policy on the conservation and supply of microbial cultures in Australia has been proposed on a number of occasions (15,21,22,31) and is long over due. It is in the national strategic interest to develop a national policy which ensures that adequate resources are allocated to collections that conserve Australian microbial diversity and which provide support services for science, technology, and industry. It must also ensure that there is an electronic means to access information resources at a national level. It is time for microbiologists in all sectors to make their requirements known to government at national and state levels in order to develop resources to meet these basic requirements. On its part, government needs to recognize the economic and strategic advantages that would follow from providing the necessary infrastructure to meet these requirements. Government also needs to recognize that many current government funded programs depend on the supply or conservation of microbial cultures and genes arising from research, and that advantages will be realized by coordinating and funding these activities nationally.

Figure 2
COLLECTIONS IN WORLD REGIONS

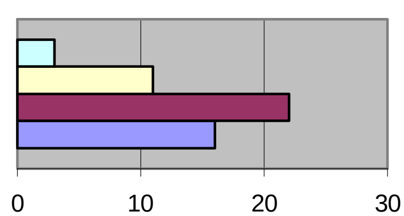


	CULTURES
SOUTH AMERICA (54)	22,175
OCEANIA (60)	78,323
NORTH AMERICA (70)	241,434
EUROPE (140)	347,241
ASIA (147)	118,034
AFRICA (13)	8,361

Data from the World Data Centre on Microorganisms

Culture collections of microorganisms have a particularly important role in the *ex-situ* conservation of microbial diversity. Cultures of microorganisms form part of their description and as such are as important to microbiologists as museum collections are to zoologists, botanists, or entomologists, or as libraries are to those working in the humanities. Culture collections may be considered as living libraries of our natural scientific heritage. However, maintaining living microbial cultures requires specific conservation skills and quality assurance to ensure genetic stability.

Figure 3
AUSTRALIAN COLLECTIONS



	COLLECTIONS
INDUSTRY	3
CSIRO	11
GOVERNMENT	22
UNIVERSITY	16

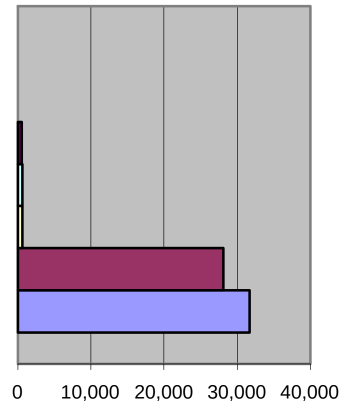
Data from the World Data Centre on Microorganisms

Culture collections in Australia

Worldwide there are almost 500 culture collections of microorganisms registered with the WFCC World Data Centre on Microorganisms (24,27). These collections hold nearly one million cultures of microorganisms and cultured cell lines, with by far the majority being held in Europe and North America (Fig. 2). There are approximately fifty collections in Australia maintaining 65,000 cultures. Culture collections in Australia primarily have institutional roles and the host institutions are usually universities, CSIRO, and government laboratories, together with a few industries (Fig. 3). The majority of cultures are bacteria and fungi with minor holdings of protozoa, algae, viruses, plasmids and vectors, and animal cell lines (Fig. 4). The major scientific interests of Australian culture collections and their host institutions are listed as general, medical, and agricultural microbiology, followed by veterinary microbiology, microbial taxonomy, plant pathology, applied microbiology, and industrial microbiology (Fig. 5). There are also a number of specialist collections engaged in insect microbiology, forest microbiology, food science, and ecology, as well as plant breeding, biodeterioration, mariculture, marine biology, and Antarctic microbiology (Fig. 6).

Unlike most developed countries and an increasing number of developing countries including Thailand, the Philippines, and Indonesia (28), Australia has not developed national collections of microorganisms. Consequently, microbiologists have relied on a few institutional collections to provide cultures to meet their needs.

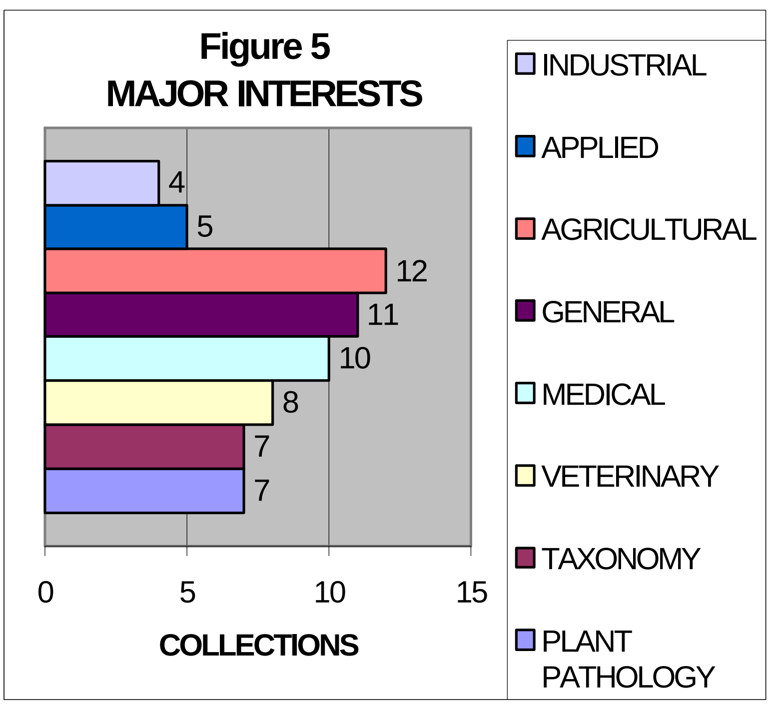
Figure 4
MICROBIAL CULTURES IN AUSTRALIA



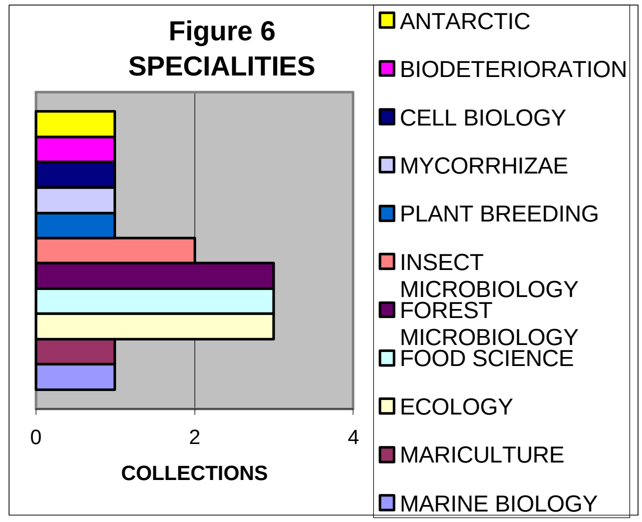
	CULTURES
ANIMAL CELLS	84
PROTOZOA	22
ALGAE	579
VIRUSES	592
PLASMIDS	600
FUNGI	28,115
BACTERIA	31,733

Data from World Data Centre on Microorganisms

Access to information on cultures held in Australian culture collections is extremely limited. Few collections have the resources to publish catalogues and those which exist are often out of date. The species directory of Australian culture collections at the WFCC World Data Centre on Microorganisms (WDCM) in Japan is nearly ten years old in many cases, and contact details for the collections are often out of date as well. This is no fault of the WDCM, but rather reflects the lack of staff resources in Australian collections to provide the information. There are also many valuable personal research and industrial collections not listed by the WDCM which should be documented resources of Australian microbial diversity. The Australian Collection of Microorganisms at the University of Queensland has provided a bioinformatics service for many years but this service is under threat due to cutbacks in funding. It is worth noting that the WDCM on which



Data from World Data Centre on Microorganisms we rely to locate microbial species in Australian collections was originally established in the 1970s at the University of Queensland to document microbial diversity in culture collections around the world, but was transferred to Japan in 1986 owing to a lack of financial support in Australia.



Data from World Data Centre on Microorganisms

International benchmarks

Microbial diversity. The value of microorganisms as sources of genetic information for molecular biology and biotechnology is well recognized (3,16,18,26), but the signing of the Convention on Biological Diversity in 1992 (29) focussed attention on this area. At about the same time the development of molecular methods for detecting microorganisms in the environment revealed the poor state of knowledge of both cultured and non-cultured microbial diversity (e.g. 1,11,14,25,32). Subsequently, extensive research effort and substantial research funding has been directed to the areas of microbial diversity, microbial ecology, and biotechnology in Japan, the European Community, and the USA (4,26). North-South attention has also been directed towards collaborations with developing countries in the tropical ‘megadiversity’ regions. In addition many developing countries have become appreciative of the need to explore, protect, and exploit their own microbial resources. Australia is in a unique position to take advantage of the wide range of ecological habitats of microbial diversity within its own boundaries and in the Asia-Pacific region through collaboration (8). Access to microbial resources and sovereign rights with respect to microorganisms in environmental samples and cultures in collections have been the focus of recent international meetings (12,13,20), and it would be prudent for Australia to develop a national policy in this area in the near future.

Culture collections. It is essential that microbial cultures are considered as a global resource for the orderly progress of science and technology. However, such a strategy necessitates that each country meets its obligations wherever possible. There are strategic advantages for the *ex-*

MAJOR ROLES OF CULTURE COLLECTIONS

***Ex-situ* conservation (preservation)**
- Microbial species diversity
- Evolutionary and genetic diversity
- Physiological diversity
- Ecological and biogeographic diversity
- Strain diversity of human, animal, and plant pathogens
- Gene clone libraries
- Taxonomic type cultures
- Reference cultures for standard methods of analysis
- Safe storage of valuable strains for industry and research

Supply of cultures
- Research
- Education
- Health surveillance
- Molecular biology
- Quality assurance methods
- Industrial starter cultures
- Biotechnology applications

Identification
- Research
- Industry
- Emerging pathogens
- Publications
- Patents

Taxonomic research
- Description of novel endemic species
- Clarification of taxonomic relationships
- Evolution of Australian microbial diversity

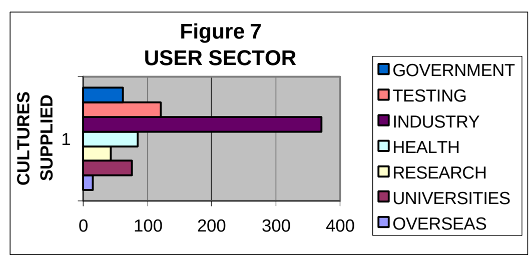
Bioinformatics
- Location of cultures with specific characteristics
- Taxonomic characterization
- Nomenclature
- Preservation methods
- Importation and quarantine procedures
- Shipping of cultures

situ conservation of microorganisms within the country of origin although this may not be practical for some types of microorganisms that require specialist facilities. Many countries have developed national collections to meet their scientific and industrial needs. Australia has depended on institutional collections to meet the needs of their host institutions without any coordination and has not appreciated the national perspective. This is particularly evident with respect to the Standard Methods prepared by Standards Australia, which in the absence of a national alternative, have generally designated USA and UK quality control cultures for use in the Australian Standard Methods. The economic impact on laboratories using these and other methods, and research and teaching laboratories requiring reference and type cultures has not been appreciated. Much of the testing of the microbiological quality of food, water, and pharmaceuticals is carried out in small laboratories that do not have the need, resources or skills to maintain extensive collections of microorganisms. The data in Table 1 compares the average resources of Australian collections with a number of respected overseas collections frequently used by Australian microbiologists as sources of cultures. It is clear that collections in Australia do not have the minimum critical number of staff to undertake the range of conservation, quality assurance, identification, taxonomic, and supply functions which users require.

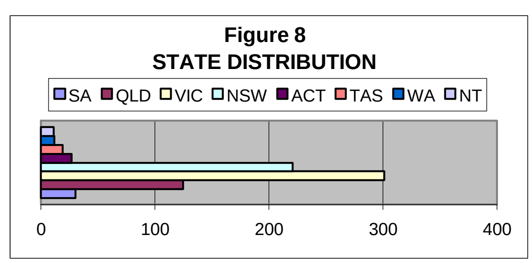
Table 1
Comparison of average Australian culture collection resources with international benchmarks

Country	Culture collection	Number of staff	Number of cultures
Australia	Average	~ 1	50 – 5,000
UK	NCTC	8	5,500
UK	NCIMB	11	7,500
Japan	JCM	20	8,800
Germany	DSMZ	26	10,000
USA	ATCC	215	85,000

Nearly four hundred laboratories around Australia have turned to the extensive Australian Collection of Microorganisms at the University of Queensland to meet their needs for bacterial cultures and to avoid the delays and expense of importation. The demand for cultures has steadily increased over the past ten years, but the collection requires additional resources to provide a comprehensive service comparable with overseas service collections. The information in Figures 7 and 8 demonstrates that cultures are supplied to all States of Australia and to all sectors of the scientific community, including health, quality assurance testing, education, research, and industry. Subsidization of this service by the University has been stopped owing to cutbacks in funding to the Department of Microbiology and continuation of the service is now at risk unless alternative funding is obtained. The cutback in funding has resulted in



Australian Collection of Microorganisms 1996



Australian Collection of Microorganisms 1996 the reduction of staff from two full-time persons to one half-time person on a full cost recovery basis. Overseas service collections recover around 25 per cent of their operational costs from sales and the balance is provided by government as an essential infrastructure requirement of science and industry. Unfortunately the reduction in support for culture collections in Australia is common and has increased over the past decade as scientific infrastructure support has diminished and administrators seek soft targets for cost cutting. Other institutional collections in Australia also provide valuable supply services, and these have been reviewed elsewhere (10).

Requirements of a Microbial Diversity Program

It is in the national interest to recognize the current and future value of Australian microbial diversity and to establish a means to maximize the benefits to science, technology, and industry. There is no adequate current funding mechanism for the thorough taxonomic study of microorganisms in Australia and this deficiency needs to be redressed. The recommendations of the *National Strategy on the Conservation of Australia's Biological Diversity* (30) for accelerated research on microorganisms and for the establishment of a network of collections of microorganisms of medicinal, agricultural, and industrial importance need to be implemented urgently. Consideration should also be given to microorganisms of taxonomic, environmental, medical and veterinary importance as well. Attempts to achieve a national policy on culture collections and coordination and financial support to meet national needs and goals have been made several times in the past without success (15,21,22,31). The current institutional model for culture collections of microorganisms in Australia has failed to appreciate the national perspective, but with adequate support provides the framework for further development by building on existing strengths. The Belgian Coordinated Collections of Microorganisms provide an excellent example of how this strategy could be successfully implemented in Australia. A national Microbial Diversity Program is required which integrates the following three components under one umbrella:

Australian Microbial Resources Study (AMRS).

The core of the proposed program should be the development of an Australian Microbial Resources Study as foreshadowed in principle in the *National Strategy on the Conservation of Australia's Biological Diversity* (30). Research funding is required to investigate the diversity and taxonomy of Australian microorganisms as has been carried out for the flora and fauna of Australia under the ABRS. A thorough study would lead to a comprehensive description of microorganisms and their ecology. If properly integrated with other research programs this research would also lead to benefits for biotechnology and industry. Research priorities should be determined by the AMRS in wide consultation and research funded by competitive project and program research grants. The research should encourage postgraduate training and research to build the pool of microbial taxonomists. It is recommended that the AMRS provide postgraduate scholarships for PhD study, as well as postdoctoral and senior research fellowships to provide a career structure which will retain the expertise gained.

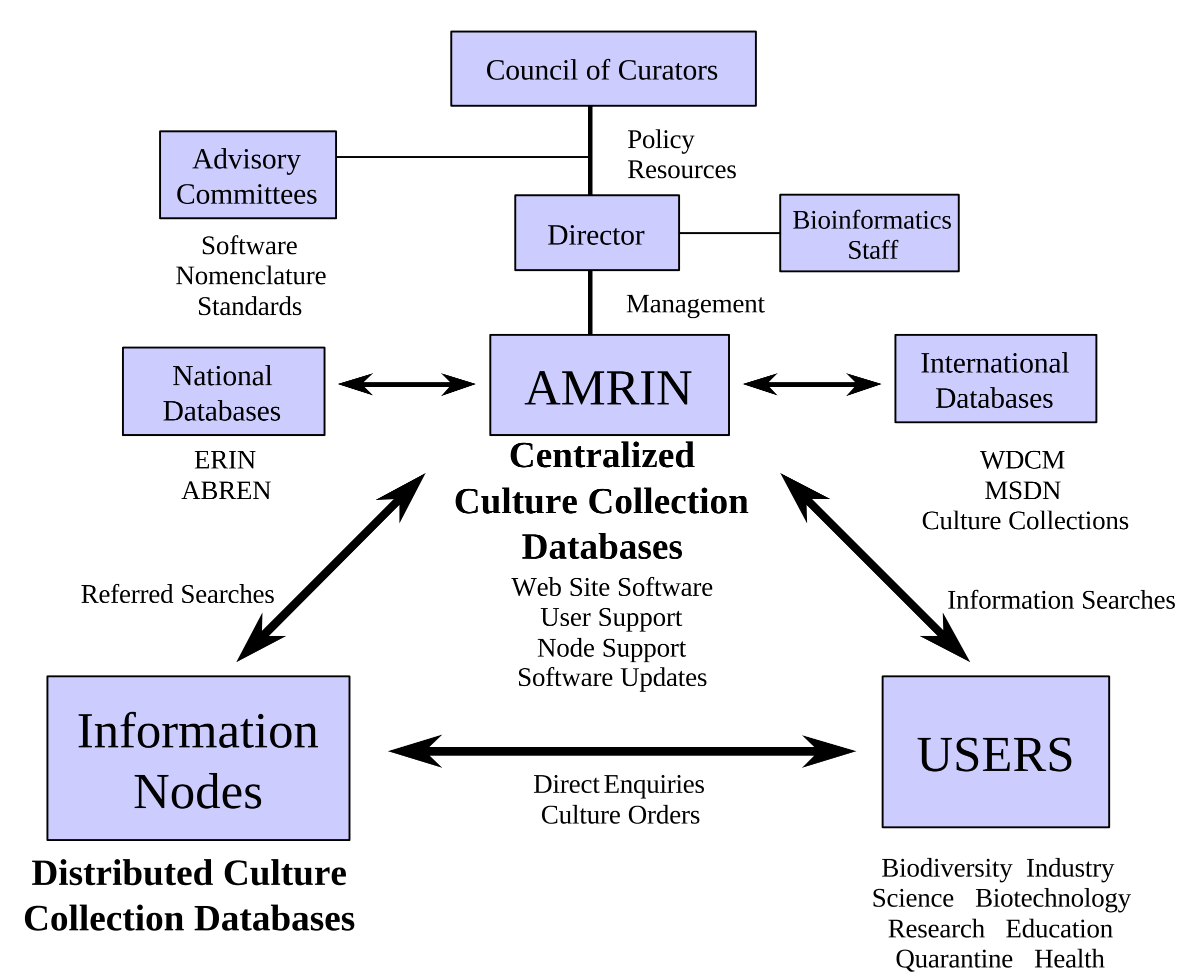
Australian Collections of Microorganisms (ACM).

As recommended in *the National Strategy on the Conservation of Australia's Biological Diversity* (30) a network of culture collections of microorganisms is required to meet the needs of science and technology. These collections would maintain and preserve representative cultures derived from the Australian Microbial Resources Study to meet current and future needs. *Ex-situ* conservation of cultures should encompass the need to have cultures representative of species, metabolic, genetic, epidemiological, and evolutionary diversity. These collections should preferably be associated with microbial diversity research laboratories funded by the AMRS and have a strong taxonomic expertise. The long-term continuity and security of these microbial diversity collections should be ensured by national infrastructure funding and legislative protection. The collections need to be coordinated at the national level to ensure that adequate resources are available to meet the needs of science, technology, and industry. The collections would provide a range of services such as the supply of cultures, and would also act as reference centres for the identification of isolates. The collections could also act as repositories of gene clones required for molecular biology research.

Australian Microbial Resources Information Network (AMRIN).

Electronic access to information on the location of microbial cultures in Australia is essential for the supply of cultures for research, education, standard methods, human, animal and plant pathology, and industrial applications, but also for an up to date inventory of the biogeographic distribution of Australian microbial and genetic resources, a key element of the Convention on Biological Diversity (20,23,29). The Australian Microbial Resources Information Network (AMRIN) proposed in Figure 9 would use standardized web-based software for the management of culture collection databases and resources, the retrieval and analysis of data, and the printing and publication of catalogues. Large collections may elect to maintain their own distributed databases using the standard software, while small culture collections may elect to accession their

Figure 9 PROPOSED AUSTRALIAN MICROBIAL RESOURCES INFORMATION NETWORK



data directly on the AMRIN centralized database via the Internet. Information searches would automatically include all databases on the AMRIN network. There are considerable resource and scientific advantages in the development of common software and a common standard for data recording and retrieval. Each collection would have access to the software programs via the Internet to manage the data in their own collections. Microbiology laboratories and individual microbiologists would also be able to use the software to maintain databases of their isolates, representatives of which would be accessioned into the Australian Collections of Microorganisms at the completion of the research. AMRIN would also provide a single point of entry and a gateway to other national and international databases of information on microbial and biological diversity and culture collection databases.

Benefits for science and technology

Major benefits that will be derived by science and industry through the elements of the Microbial Diversity Program described include:

- Implementation of the national policy on Australian microorganisms (bacteria, yeasts, fungi, algae, viruses, genetic vectors) and their *ex-situ* conservation.
- Accelerated taxonomic description of Australian microbial species.
- Improved knowledge of cultured and uncultured Australian microorganisms and their ecosystem function.
- Rapid electronic access to information on Australian microbial and genetic resources via the Australian Microbial Resources Information Network (AMRIN).
- Discovery of novel microorganisms of biotechnological value.
- Designated culture collections to conserve Australian microorganisms of scientific and industrial significance.
- Infrastructure support and legislative protection of Australian Collections of Microorganisms.
- Access to reference cultures for Australian standard methods of analysis, for export and import quality assurance requirements, and for human, animal, and plant pathology requirements.
- Reference culture needs for teaching and research in Australian universities and research laboratories.
- Strategic preparedness for the identification of emerging and exotic human, plant, and animal diseases.
- Access to rapid and accurate taxonomic and identification services to meet the needs of industry, biotechnology, and research.
- An increased pool of microbial taxonomists through postgraduate training, and a career structure to meet future needs.

POTENTIAL STAKEHOLDERS

Scientific and Technological Academies

Scientific Societies and Associations
- Biochemistry
- Biology
- Biotechnology
- Environment
- Immunology
- Medical science
- Microbiology
- Molecular biology
- Plant pathology

Federal Government Policy Planners
- Australian Science, Technology, and Engineering Council

Federal and State Government Departments
- Agriculture
- Education
- Environment
- Fisheries
- Health
- Natural resources
- Primary industries
- Quarantine
- Water

Government Research Funding Councils
- Australian Biological Resources Study
- Australian Research Council
- National Health and Medical Research Council

Industry Research Funding Corporations

Universities

CSIRO

Research Institutions and Centres

Quality Standards and Laboratory Accreditation
- Australian Standards
- National Association of Testing Authorities
- Water
- Food
- Therapeutic goods
- Testing laboratories
- Pathology laboratories

Biotechnology industry
- Biopolymers
- Enzymes
- Pharmaceuticals
- Starter cultures

Manufacturing industries
- Fermentation
- Food and beverages

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