Integrated research priorities for algae, protists and fungi with a focus on microorganisms

A Summary Report for the Australian Biological Resources Study

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Summary Report

Introduction

This report summarises the findings of a consultation process on microorganisms undertaken by ACIL Consulting for the Australian Biological Resources Study (ABRS).

The purpose of the consultation process was to support development of integrated research strategies to advance knowledge of micro-algae, protists and microfungi.

The terms of reference are at Attachment A1. The project proceeded under the guidance of a Steering Committee drawn from the Advisory Committee of ABRS.

The project was undertaken over a six-month period from February 2002 to August 2002.

At a workshop conducted at the beginning of the project it was agreed that the review would address algae, protists and fungi with a focus on microorganisms. It was agreed that blue green algae also be included in the study because of their economic and environmental importance.

Over 150 stakeholders were contacted over the period of the study.

Current Situation

The microorganisms under consideration all have significant economic and environmental importance. However in each case it was found that there is great uncertainty surrounding estimates of the possible size of the groups.

Blue green algae

Blue green algae or Cyanobacteria are a distinct Phylum of oxygenic photosynthetic bacteria. While there is now no doubt that they belong to the Domain Bacteria, they have traditionally been studied as if they were algae. Species names have been published under either the International Code of Botanical Nomenclature or under the International Code of Nomenclature of Bacteria.

The majority of the research in Australia has focused on the characterisation of blue green algal blooms and their consequent toxic effects on water supplies. This is being conducted at many Australian Universities, CSIRO Marine Research, CSIRO Fisheries, the Australian Water Quality Research Centre, and the water forum Cooperative

Research Centres (CRCs). The National Eutrophication Management Program deals with cyanobacterial blooms and their causes.

There are few institutes and workers with active research programs in symbiotic associations of cyanobacteria, the formation of soil crusts or the ecological roles of cyanobacteria. Work on recovery of genes and biotechnology products from cyanobacteria is conducted at the Australian National University, the Australian Institute of Marine Science and several private companies.

Cyanobacteria are sometimes the key organisms in threatened environments that have been accorded conservation status. Several groups, notably at the University of NSW, have been working on the population structure of cyanobacterial mounds.

Identification of the species involved is a requirement of work on harmful algal blooms. This may be accomplished by cultural, molecular or microscopical means. However the time devoted to discovery and description of new species is understood to be minimal. Additions to knowledge of the diversity of and evolutionary relationships between cyanobacteria are likely to arise incidentally from the molecular characterisation of new or environmental strains.

The majority of species of cyanobacteria in Australia is yet to be described

There is no definitive estimate of the number of species of cyanobacteria currently identified in Australia -estimates range from the low hundreds to several thousand.

An estimate made during consultations suggests that the total number of species could be between 12,000 and 40,000. – based on cyanobacteria being around 4% of total number of bacteria species potentially to be found in Australia. It is concluded that the majority of the species are yet to be described.

Microalgae

The microalgae considered in the report are microscopic, photosynthetic eukaryotes. Most groups of microalgae that have been described in the past have been identified and described by morphological features.

Research programs involving microalgae, not necessarily entirely devoted to taxonomy, are conducted at the Royal Botanic Gardens, Sydney, CSIRO Marine Research, Universities (Monash, Macquarie, Melbourne, Murdoch, Queensland, James Cook, Curtin, Deakin, New South Wales, Northern Territory), various State Departments of Fisheries, the Australian Institute for Marine Science, CSIRO Division of Land and Water, and various state water quality laboratories.

Most of this work is concerned with characterisation of harmful algal blooms and their toxic effects on water supplies. There are a few workers in Australia with active research programs on the symbiotic associations of microalgae with fungi or marine invertebrates.

Work on the recovery of genes and biotechnological products from microalgae is conducted at the Australian National University, the Australian Institute of Marine Science and several private companies.

There could be up to 100,000 species of microalgae in Australia. However it is more accurate to say that the majority of the species are yet to be described

The pursuit of pure taxonomic research in these areas is minimal.

Some three thousand species of freshwater algae have been recorded in Australia. Estimates of total numbers of microalgae worldwide vary and it is generally accepted that the accuracy of such estimates is poor. There is considerable uncertainty surrounding the possible total number of microalgae species that exist in Australia. Estimates in the report range to as high 100,000. However it is more accurate to say that the majority of the species in Australia are yet to be described.

Microfungi

Microfungi discussed in the report are fungi that have small, generally microscopic, sporocarps. They are a polyphyletic assemblage of organisms placed taxonomically in three kingdoms – Protoctista, Chromista and Eumycota.

Classification of microfungi has historically relied on a comparison of the morphological variation of microfungal reproductive structures, from field collections and/or pure cultures. While this method provided a useful system that allowed names to be assigned under the International Code of Botanical Nomenclature, the classification rarely reflected phylogenetic relationships.

Electron microscopy, biochemical analysis and molecular techniques now augment microscopic methods of data collection. Modern taxonomy, at least at the Order level and below, is beginning to reflect morphological and phylogenetic relationships.

Microfungal research is undertaken at agricultural research centres, plant pathology laboratories, CSIRO, universities, many hospitals, biotechnology companies and herbaria.

The larger Australian microfungal herbaria are attached to agricultural research centres and focus primarily on plant pathogens, insect and livestock pathogens, fruit and root rots and mycorrhizae.

Foodscience Australia has a culture collection of microfungi implicated in food spoilage, the Australian Institute of Marine Science holds some microfungal specimens and the Australian Collection of Microorganisms at the University of Queensland holds a small number. Bioprospecting and biotechnology companies also maintain microfungal culture collections.

A survey undertaken at the beginning of this review revealed that 80% of mycologists surveyed devoted less than five hours per week to microfungal taxonomy. The principal areas of research were plant pathogens, human pathogens, food processing, pharmaceutical screening

The number of microfungi species could range from 150,000 to 240,000 — an estimated 2,300 have been described

plus miscellaneous areas related to agricultural and native plants, soils, leaves, dung and wood.

It has been estimated that at least 2,300 species of microfungi from Australia have been described. The report cites estimates of the total number of fungi in Australia ranging from 150,000 to 240,000 species.

Protists

The protists are a taxon of convenience that includes a wide diversity of microscopic eukaryotic forms. There are at lease sixty distinct lineages of protists worldwide that include organisms that are considered microalgae as well as multicellular and unicellular non-photosynthetic organisms. Most of the discussion in this review related to protozoa (a subset of protists that include all unicellular, non-photosynthetic and non-fungal eukaryotes).

Protozoa are not monophyletic. Their classification has historically been based on relatively simple observations of gross morphology. This resulted in a traditional view of four groups – Flagellates, Ciliates, Amoebae, and Sporozoa. Subsequent refinements to this have principally been to the Sporozoa. It is probable that the major lineages of organisms likely to be considered protozoa are now documented.

There are active research groups located at a number of Australian institutions including the Universities of Sydney, New South Wales, Tasmania, Western Australia, Macquarie, University of Technology Sydney, Western Sydney, Queensland Dept of Primary Industries, Queensland Institute for Medical Research. Research activity in these groups is heavily biased towards parasitic protozoa.

The only research group identified as working with non-protozoan protists was at Sydney University.

Current techniques used by Australian researchers in protistan taxonomy span those that are presently used worldwide – light and electron microscopy, DNA sequencing and bioinformatics. The diversity discernable with these techniques varies and the choice of appropriate methodology is apparently influenced by availability of equipment/technology, cost, tradition and the application of the data.

Estimating the number of known species of protists and those yet to be described is difficult. ABRS has commissioned a bibliography of species actually recorded in Australia but it has not yet been published. One researcher suggested that there could be up to 80,000 species of protists in Australia.

An achievable goal for research into the taxonomy of protists, as a component of a ten-year program, could be the adequate phylogenetic circumscription of all higher taxa of protists occurring in Australia. The major component of such a project would be the collection of

representative organisms from all predicted major lines of evolutionary descent. Since morphology appears to be a good predictor of distinctiveness (if not always relationship) the existing ABRS dataset provides a guide for the collection of a representative set of organisms.

Summary Table

Table 1 summarises the current situation.

Table 1: Current situation

Group	Number of described species in Australia	Estimated total number of species	Possible time to describe
Cyanobacteria	Estimates range from around 200 to 2000.	12,000 – 40,000 This is a conservative estimate based on cyanobacteria being around 4% of total bacteria species. Conclusion: the majority of species are yet to be described.	>50 years and most likely considerably more.
Micro algae	3000 freshwater algae which would include some microalgae.	10,000–100,000 assuming one tenth of all algal species occur in Australia. Conclusion: the majority of species are yet to be described.	>50 years and most likely considerable more
Micro fungi	Around 2300 based on a survey of herbaria	150,000–240,000 Conclusion: less than 10% of the total number of species has been described.	>50 years and most likely considerably more
Protists	No estimate of protists.	No definitive estimate for protists. Potentially 80,000.	>50 years and most likely considerably more.

Note: The estimates of the length of time to describe the total number of species occurring in Australia are based broadly on past rates of description, embodying past levels of resources and technologies. The potential numbers of species are so large that completion of the description would be well outside the working lives of the current group of taxonomists in Australia.

Stakeholder Consultations.

The stakeholder list was first developed at an initial workshop and subsequently expanded by ACIL in the course of consultations. Consultations were initially by email and telephone contact, followed by face-to-face interviews in some cases.

Over 150 stakeholders were contacted over a three month period.

The sectors canvassed included agriculture, aquaculture and fisheries, food processing, forestry and wood products, soils and water, environmental agencies, mining and petroleum, construction, bioprospecting, biotechnology, pharmaceuticals, medicine, museums and art galleries. Organisations in the public and private sector, research and collaboration were approached.

The priorities identified are discussed later in this document. The common themes to emerge were –

Low awareness of ABRS

There was a low level of awareness of ABRS amongst the broader stakeholder group. Many organisations and industry sectors that derived value from taxonomic information in one way or another were not aware of ABRS or did not consider ABRS activities relevant to their interests.

This trend was more evident for end users than for research organisations. CSIRO, for example, has close links with ABRS. However many officers of agricultural and resources research and development organisations were not aware of ABRS or did not consider it relevant to their interests.

It is also evident that ABRS is frequently regarded as a funding source only and not as a potential partner in progressing taxonomic research of interest to end-users.

Low level of response from some stakeholders despite acknowledged relevance

Some stakeholders took a long time to respond even though there were obvious areas of relevance. In some cases organisations were not willing or able to respond despite acknowledging the relevance of taxonomic research to their interests.

Taxonomic data valuable when integrated

There were many examples where sound taxonomy had or could create significant value

There were many examples provided by stakeholders where sound taxonomy created significant value for the community and for industry sectors. Examples included biosecurity, management of disease threats in agriculture and in aquaculture and fisheries, in water quality as well as in business development opportunities in biotechnology and related industry sectors.

The Cryptosporidium incident in Sydney in 1998 for example was estimated to have cost the water authorities around $74 million. Had it

been possible to discriminate between non-human and human host specific cryptosporidia earlier, the crisis might have been avoided.

The social and economic cost of potential outbreaks of diseases in agriculture was reasonably expected to be in the hundreds of millions of dollars. The value of products developed from biotechnology was quoted to be higher still. Stakeholders reported that taxonomic information has the potential to create considerable value in all of these cases.

Taxonomic research should be integrated into broader research objectives to attract additional funding

Many institutions recognised the need to document the biodiversity but saw this as a public good and therefore a government responsibility. Many viewed taxonomy as basic research that should be funded by ABRS or the Australian Research Council.

When pressed, many stakeholders indicated that additional funding for research into taxonomy of microorganisms would only be considered as part of an integrated research project with outcomes of direct relevance to their industry.

In many cases organisations were not able to advise of longer term strategic priorities that would be helpful in prioritising research by ABRS. For example, animal and plant heath priorities tend to be developed in response to disease threats as they occur. This, however, may change as strategic threat assessments are completed.

Potential decline in taxonomic resources in Australia

Some researchers expressed concern that the resources available to undertake taxonomic work in Australia were in decline.

No consensus that taxonomic resources are inadequate – but some concern for the future

This was not the universal view of users. However it was agreed that problems could emerge as the current group of taxonomists retired. There was a perceived lack of incentive for younger scientists to pursue taxonomy partly because of lack of career opportunities.

There has been some assessment of the adequacy of taxonomic resources by the plant health sector and it might be expected that further assessment will occur as diagnostic needs are further reviewed.

Access to taxonomic information

Many end users placed a high priority on getting early and easy access to taxonomic information. Some suggested that ABRS should be a central repository of information on taxonomy.

Early access to taxonomic information important to end-users

They expressed the need for access to information on identified organisms and their description over the internet, through monographs and CDs as well from books. There was general agreement that delay in releasing information while books were in preparation was not consistent with the contemporary needs of users.

There are some electronic databases that could provide information on microorganisms. The Australian Virtual Herbarium and the Australian Plant Pests Data Base are examples. However there is no repository or gateway at the moment. Some stakeholders suggested that there could be a role for ABRS to provide a central portal, possibly through Australian Biodiversity Information Facility (ABIF) or a similar system with links to relevant databases where more detailed information is held.

Methodology

Choice of methodology should take into account the needs of the user

There was no single view regarding the appropriateness of morphological or molecular techniques. In the case of end users the technique of choice would be defined by their needs and the problems they were addressing.

In some cases morphological techniques were regarded as too limited or too slow. Diagnostics, pathogen identification and pest management often required rapid identification where molecular techniques could assist.

However in bioprospecting and disease control access through taxonomic keys and an understanding of functional relationships required morphology.

In many cases a trade off was necessary between the need to identify species quickly at an acceptable cost and the desirability of having a full functional description. Accuracy of the information obtained needed to be balanced against timing, cost and application.

In most cases a taxonomist using morphological methods working full time might, potentially, describe about 100 species in a year – although experience with ABRS funded projects suggests that lower rates are likely.

Some research institutions saw the potential for molecular techniques, used either on their own or as an adjunct to morphological methods, to provide higher rates of discrimination (though not necessarily identification and description in the same way that traditional taxonomists would anticipate). Differences in the information produced by the various techniques and the specific needs of users would determine the choice of methodology in the future.

Global Coordination of Research

Globalisation of research does not necessary imply lack of research opportunities in Australia

In some industries research is coordinated at the global level, leaving little scope for Australian activity. This is true to varying degrees for example in fertilisers, pharmaceuticals, food processing and petroleum and minerals.

This does not necessarily imply that there would be no interest in research into microorganisms in Australia. However to be considered relevant the Australian research would need to be targeted and efficient to compete globally. There are prospects, for example, in the mining and petroleum

industry despite the fact that these industries tend to address research and development from a global perspective.

Strategy Framework

Value

Taxonomic research produces use and non-direct use values

When developing priorities it is essential to clarify the different values that investment in taxonomic research creates. These may change over time.

Taxonomic research produces both non-direct use and use values. ACIL concludes that the value of taxonomy is created in three ways:

- As an endeavour its own right (cultural value – mainly non-direct use);
- As an investment in knowledge infrastructure of strategic value to further research and development (use and non-direct use); and
- As a component of research to attempt to realise identified commercial benefits the have been in part facilitated through the underlying research infrastructure (use value).

Non-direct use is not necessarily an indication of absence of value

Some of these benefits are non-direct use and are by their nature intangible. This does not necessarily imply an absence of value. The essence of value is a willingness on the part of society to reveal a preference for one outcome over another and an associated willingness to make sacrifices or trade-offs in order to achieve that outcome.

When assessing the benefits of the more intangible outcomes it is often necessary to be guided by the expressed preferences of society. While this is difficult it is not impossible– current concern over the economic and environmental sustainability of Australia's water resources is an example.

In some respects taxonomic knowledge creates information that has value in the form of an option – that is an option to realise value at some time in the future from the information.

Prioritisation approach

Priorities should be seen as outcomes from a strategic planning and negotiation process, not as targets in their own right

ACIL's recommended approach to prioritisation of ABRS taxonomic R&D, against this background, is based on several important principles:

- The purpose of prioritisation should be to allocate the resources available to ABRS to maximise the net value to society of its activities and involvement.
- Priorities should be seen as *outcomes* from a strategic planning and negotiation process, not as targets in their own right.
- The primary *purpose* of ABRS activity in this area should be to address areas of market failure — areas where socially beneficial

taxonomic research is not being pursued, or is being pursued in a sub-optimal manner.

- This is consistent with seeking increased joint activities and/or shared funding, whether this be with government agencies, research institutes or commercial entities.

Activities must also clearly meet agreed Government priorities across a range of programs from conservation to sustainable use of natural resources.

Infrastructure Model

Taxonomic work on algae, fungi and protista in Australia is still at a quite early stage. Useful levels of identification have been achieved — though only to the point of scratching the surface — while access arrangements remain uncoordinated and difficult to use effectively.

Demand is emerging, but predominantly from potential users who want access to an established product, rather than from entities keen to fund basic research. The risks for those users willing to fund such basic research are high – indicating a likelihood of market failure, and hence a difficult area to generate significant spending on research by individual organisations.

ABRS's role should be to establish the basic taxonomic infrastructure

Against this background there is a clear role for ABRS as the driver of a long-term program directed at establishing the basic taxonomic infrastructure in relation to algae, fungi and protists.

The infrastructure creation task is likely to involve both:

- The assembly of a system or systems to provide easy access to the coordinated range of taxonomic information now available, subject to any necessary controls over intellectual property; and
- Progressive expansion of the available body of taxonomic information that would not otherwise be supplied as a result of commercial and government incentives, or that would only be supplied at a slower rate than that which would deliver the greatest social benefits.

Priorities for building the available information could sensibly be largely driven by balancing perceptions of likely demand and value against available skills and resources.

Specific areas of stakeholder priority could be advanced selectively with contributions from or in partnership with stakeholders

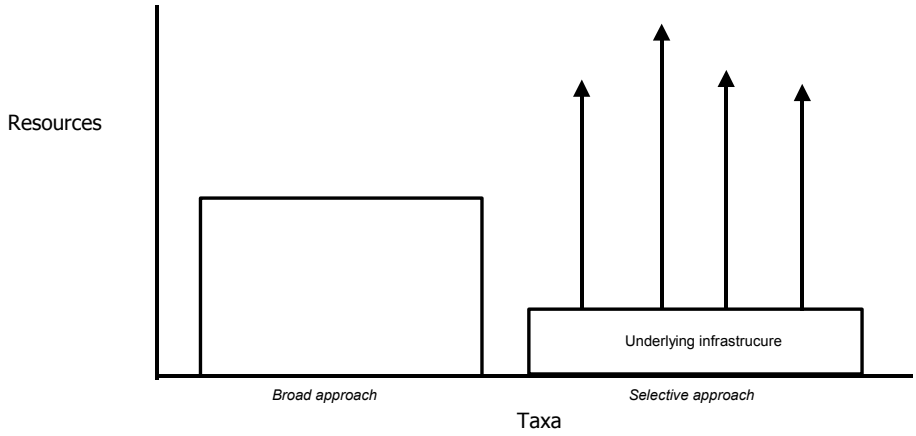
In areas where users perceive a benefit that would justify selectively advancing an area of specific value to them ABRS could reasonably seek a contribution from that group on the ground that the benefits can be captured from the investment. Given that the lines may be blurred between the public and the private good it may be appropriate for contributions to be made by both ABRS and the users in partnership.

The infrastructure model is illustrated in the diagram below.

This approach implies a more proactive approach by ABRS in relation to key user groups. This could include:

- Working with a potential client or group of clients to scope a program of activities of significant strategic, and possibly commercial, value.
- Identifying 'priority' projects and calling for expressions of interest;
- Greater use of 'mixing and matching' of skills across agencies to define coordinated research that better contributes to ABRS values, and scope for developing commercially or socially attractive products;
- Building greater conditionality into funding approvals, guiding the detailed design of the work programs to enhance their support for ABRS priorities, while maintaining their value to the funding agencies.

Figure 1: Infrastructure Model



The alternative approaches for ABRS could be to either advance the taxonomic description across a broad front as shown on the left of this

diagram or to advance selected areas as shown on the right of the diagram.

Priorities

In assessing priorities ACIL applied the above methodology to the information that was received through the stakeholder consultations.

A key issue was balancing the perceived value that could accrue from the different investments and the expected response from different groups of stakeholders in the immediate, medium and longer term.

A table at the end of this section summarised the main areas of priority and the discussion below outlines the arguments behind the prioritisation.

Establishing marketing and stakeholder liaison – immediate priority

Improved stakeholder liaison is an immediate priority

ACIL recommends a more proactive approach to improve key stakeholder awareness of ABRS activities and programs, to provide a mechanism for forming partnerships and for receiving feedback on user needs.

Establishing an electronic data base – immediate priority

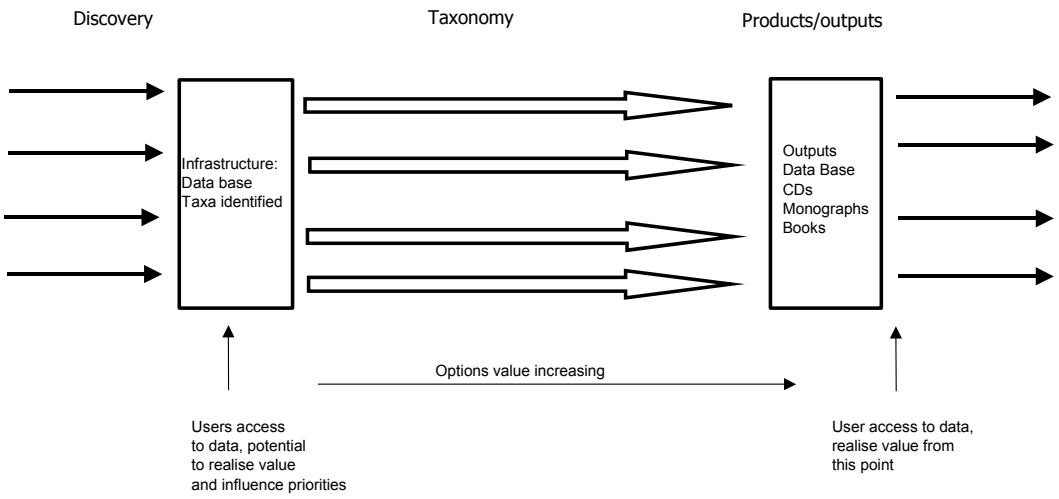
ACIL recommends that ABRS review the possibilities for creation of an electronic database that as a minimum provides information on microorganisms that have been identified and a description, where available, linked to other electronic data bases. This could initially be based on an expansion of ABIF but may also encompass a distributed database.

ABRS's electronic data bases should be developed to improve user access to taxonomic data

This would address a number of objectives. Firstly it would provide information on species as soon as it is ready for public release. Secondly it would provide a single point of access to the information that is available. Thirdly it would provide an opportunity for ABRS and other research institutions to receive feedback from researchers and stakeholders on the value of the data that are being assembled. Finally it would provide an opportunity for ABRS to increase awareness of its activities amongst users.

An illustration of the role of this database in the value chain for ABRS is shown in Figure 2.

Figure 2: Suggested taxonomic process



This diagram shows in concept a taxonomic value chain where information is made available to users at the documentation stage. This provides user access to what is known as soon as it is documented. Users can influence priorities and extract value at this point. Selective groups progressed according to priorities – the nature of the methodologies used, the form of funding and the final output would be determined according to specific circumstances. This model would require a minimum level of infrastructure including an accessible database. Over time the information in the database would expand as specific groups were described, reviewed and reported.

Documentation of biodiversity has public good characteristics

Biodiversity – immediate priority

There is a public good argument for ABRS support for taxonomic research in the interests of documenting biodiversity. The value of such investment lies in part in the cultural value associated with greater knowledge of Australia's biota that is unique in many aspects. It also lies in the value the information creates for activities such as biotechnology, biosecurity and development of natural resources.

The value of such research is also in the implementation of sustainable resource management policies such as the National Strategy for the Conservation of Australia's Biological Diversity. It can easily be argued that the underlying mission of ABRS is to support the implementation of such strategies.

Australia's participation in international activities under the Convention on Biological Biodiversity and the Global Taxonomy Initiative also illustrate the importance and value of investment to increase knowledge of the micro biota in Australia.

There are many areas that may be able to be progressed in partnership with other agencies. These are listed in

Table 2 below.

Water quality – immediate priority

The water sector has a clear set of priority issues for which taxonomic research is relevant and it has research institutions and funding mechanisms to be able to respond if approached in an appropriate way.

Research on protists in relation to human health is one priority

Priorities identified related to the impact of microorganisms on water quality and were:

- Research on protists for human health related issues.
- Although cyanobacteria issues have ebbed for the time being, there is a continued need for adequate research.
  - In particular, coastal estuary and lake problems are leading to 'algal bloom' studies where protist knowledge will be required.

There is an opportunity to develop a program of research activities on protists incorporating a significant taxonomic component that could be marketed to a range of utilities and resource management agencies.

ACIL recommends that an initial contact be made with the CRC for Water Quality and Treatment in Adelaide and possibly the CSIRO (Land and Water Division) preferably with a concept at a useful stage of development.

ACIL also recommends that an approach be made to the CRC for Wastewater and Pollution Control. While this CRC is close to the end of its term, the possible development of a bid for a new CRC into Environmental Biotechnology would be worth exploring. Involvement of ABRS in the bid may be a way of achieving a stronger integration of taxonomic services into its program. It could also serve to maximise the bid's commercial appeal.

Plant Health – immediate priority

Government and industry programs to address plant health issues are well established. While the industry is not yet in a position to identify longer-term strategic priorities certain sectors are already addressing specific problems. In addition the industry through Plant Health Australia is planning to undertake strategic threat assessments.

Plant health programs high priority but strategic priorities still emerging

This industry sector is likely to be in a position to respond positively provided that taxonomic work can be integrated into the overall research outcomes sought.

Two areas are recommended for immediate development:

- Research into organisms associated with cereal rusts. We suggest that a project be formulated for submission to the Grains Research and Development Corporation as part of the National Cereal Rust Control Program.

- Research into soil biology under the Soil Biology R&D Initiative. One area of potential interest would be work into the microfungi causing root rot in agricultural crops.

In the following five years of the program projects should address the taxonomic research needs arising out of the biosecurity plans to be issued by Plant Health Australia.

ACIL recommends that ABRS consult with Plant Health Australia to explore and develop research proposals for submission to the appropriate research and development corporations for funding with cost sharing to be determined according to the nature of the accrual of benefits and the funding bodies involved.

ABRS could also seek to co-operate with a review of future requirements for taxonomic capabilities foreshadowed by Plant Health Australia.

Animal Health – immediate priority

Longer-term strategic priorities for animal health will take time to define — some immediate priorities identified

The animal health sector appears to be slightly less prospective for partnership on taxonomic issues than the plant health area. However that is not to say that it does not have clear priorities on animal health and productivity. The industry has a well-organised structure for funding research and development.

Two areas are identified as of immediate focus:

- Research into microfungi associated with control of parasites in sheep.
- Research into microfungi involved in determining the emission of methane from ruminants.

Other priority areas for subsequent exploration include target groups of microorganisms involved in development of immunogens and vaccines to replace the current use of antibiotics to control pathogenic organisms, the role of toxic algae in grazing loss and the role of microorganisms in production efficiency in animals. Development of these areas will require consultation with Agriculture Fisheries and Forestry Australia, Animal Health Australia and Research and Development corporations including Meat and Livestock Australia, the Dairy Industry Research and Development Organisation and Australian Wool Innovation.

ACIL recommends that ABRS consult with these organisations, the Australian Greenhouse Office and CSIRO Livestock Division to assess the need for taxonomic research in these areas, to formulate research proposals for funding consideration.

Aquaculture and aquatic animal health – immediate priority

The aquaculture and aquatic health sector is well organised in setting priorities for research on aquatic animal health. There are also mechanisms in place for funding priority research areas. The industry has

the capacity to implement agreed research and development programs to address priority research issues.

AQUAPLAN provides the context for developing priorities in aquaculture and aquatic animal health

The AQUAPLAN Business Group/Scientific Advisory Committee has formulated priorities for research into microorganisims relevant to aquatic animal health — these are set out in the main report.

FRDC is already investing in Kudoa (Tuna) and Microsporidia (oysters) and will be investing in some Amoeba in relation to amoebic gill disease in salmon. This year it will also be investing in flagellates in yellow tail kingfish.

ACIL recommends that ABRS approach the AQUAPLAN Business Group and the FRDC to identify and clarify funding of work in these areas as an immediate priority.

Mining and Petroleum – immediate priority

Prospective areas for taxonomic research in the mining and petroleum sector – more specific project formulation required

The mining and petroleum sector was able to identify issues of relevance to taxonomic research. Many companies outsource research and in several areas expressed an interest in an approach from ABRS.

While the companies and research bodies did not identify immediate proposals for funding support for ABRS activities, they identified a number of broader prospective research and partnership opportunities. It is expected that taxonomic work will be needed to underpin such research but more specific priorities could not be provided at this stage. Several organisations consulted indicated a willingness to respond constructively to discussions with ABRS.

The areas that were of potential interest included:

- Researching the practical role of microorganisms and their relevance to environmental management associated with mining
  - The role of microorganisms in managing environmental degradation
  - Gene discovery for bioprocessing, pollution control, land remediation and rehabilitation.
  - Role of soil microorganisms, including interactions with higher plants in sustaining ecological process/ecosystems.
- Lifecycles under varying conditions
  - Tolerance of microorganisms to saline water and the potential to improve water quality in tailings storage facilities.
- Bioprocessing
  - Biological leaching of low grade ore dumps and waste material
  - Removal of sulphides from waste dumps
  - Enrichment and large-scale culture of microorganisms.
- Biodiversity and minesite rehabilitation

  - To gain a better understanding of the ecological impact or relevance of mining processes.
- Role of fungi in ore treatment and remediation
  - Mainly bacterial but research into fungi of interest.
- Greenhouse gas mitigation
  - Research to better understand the carbon dioxide biofixation process of microalgae and higher plants over time.

These opportunities are worth exploring in detail with the industry and associated research programs.

For petroleum the priority areas identified were:

- Growth patterns of microorganisms to find more efficient and cost effective methods of controlling their behaviour .
- Corrosion control.
- Conversion or catalytic behaviours.
  - To identify microorganisms with catalytic behaviours.

The petroleum industry invests very heavily in research globally. Research investment in Australia is likely to increase as petroleum production activities increase. A significant proportion of research is in areas that involve microorganisms. There could be reasonable opportunities for ABRS to participate.

ACIL recommends that the ABRS:

The Australian Resources Research Centre is one option for co-ordination of taxonomic research in the resources sector

- Arrange a briefing for the mining and petroleum industries or series of briefings in groups (group briefings and discussion will help stimulate ideas and participation)
  - As a first step ABRS should approach the new Australian Resources Research Centre that has recently been established at Curtin University to undertake cooperative and contract research in mining and petroleum.
  - ABRS should also consult CSIRO Land and Water and Mining Divisions, and the companies identified in the main report.
- Contact the Australian Minerals Industry Research Association (AMIRA) to discuss its approaches to coordinating research and how AMIRA and ABRS may be able to cooperate;
- Provide tailored information material to stakeholders (and place on the ABRS website) about relevant ABRS activities and how these can help stakeholders in their businesses;
- From initial discussions, identify high potential funding and/or cooperation activities and discuss these with individual organisations, coordinating where appropriate between them;

- Where interest by several organisations is shown, explore possible syndication of research funding with the Australian Minerals Industry Research Association, which is experienced at brokering and project managing cooperative research projects (for a management fee);
- Discuss with existing research organisations (eg CSIRO mining, land and agriculture divisions) the opportunities for cooperation to deliver better value through ABRS complementing their research, for example by working closely with them in characterisation and identification of microorganisms that have particular uses; and
- Publicise research projects to the mining industry nationally and internationally to generate further interest.

Food Safety – medium term priority

Formulation of projects relevant to the priorities of the food industry likely to require time

Food safety is a high priority for Australian agriculture as well as processed food manufacturers. However ACIL was advised that programs under the National Food Industry Strategy are earmarked mainly for industry development and not basic research.

ACIL expects that any funding for work on food safety would ultimately be sourced from the existing research and development organisations with the CSIRO Division of Food Science playing a major role. Formulation of projects could expect to require a longer time frame than other agriculture sectors identified above.

ACIL recommends that ABRS consult with the AusToxNet and with CSIRO with a view to exploring how taxonomic research could be integrated into research contemplated on these toxins.

Biotechnology – medium term priority

Significant potential value in biotechnology – ownership of intellectual property an issue and benefit sharing policies still evolving

Biotechnology is a sector where significant commercial developments are in prospect. On this basis alone it is an important area for consideration by ABRS.

However without clear mechanisms available for protecting intellectual property, it is difficult to argue that the commercial gains could not be appropriated by the developers.

A key issue was availability and documentation of data. This relates to the underlying infrastructure discussed earlier in this section.

ACIL recommends that these contacts be explored with the organisations identified.

ABRS should also consider participation in the application for the creation of a CRC for Environmental Biotechnology. This would appear to be a logical prospect in this area in the shorter term and has been already discussed under the section on water quality.

Forestry and wood products – medium term priority

The priority areas identified as a result of consultation were associated with research into microorganisms as they affect timber growth and preservation in industrial and consumer products.

Potential interest in preservation of wood products but formulation of a project likely to take some time

The consultations suggested that examination of these issues is at a very early stage. The Forest and Wood Products Research and Development Corporation (FWRDC) was not in a position to respond with strategic priority areas despite expressing interest. This was despite an extended period of consultation. More time and evidence of the value of taxonomic research in microorganisms is likely to be necessary before it will be possible to formulate a project in this area.

Development of a proposal for taxonomy in this field would ultimately require further development of an integrated research project whose objectives complied with the commercially related criteria set out in the allocation criteria of the FWPRD.

While this area is promising the lack of a clear response at this stage suggests that its development should be in the medium term, not immediate, category.

Pharmaceuticals – medium term priority

Commercial research in pharmaceuticals is focussed on early returns

There is a major industry developing pharmaceuticals products from microorganisms. The benefits in terms of improved health, food safety and medical procedures are high.

Industry research is focussed on early commercial returns – partnerships difficult but not impossible in the medium term

Research and development is driven by the prospect of early returns. Much of the research is undertaken by medical research institutes in Australia sometimes in collaboration with international pharmaceutical companies.

Given the networks already in place it is ACIL's judgement that it will be difficult for ABRS to establish a significant role or attract partnership funding in the short term.

However one research institution is looking for commercial partners for fungi related medical research including co-funding for new products. ABRS should explore possibilities for collaboration in such cases.

Horticulture – medium to long term

Value in horticulture but will require time

Although there are areas of priority relating to plant diseases and toxins, it was not possible to obtain a clear response from Horticulture Australia as to priorities or interest in funding. Many of the areas of interest are already covered in other agriculture areas.

Consultation with the horticulture industries would require a separate approach to each sector. Horticulture Australia was not able to provide a positive response during the consultations.

On this basis ACIL does not suggest specific priorities in this area for immediate development.

Horticulture however has similar issues as general agriculture (eg fireblight in the apple industry) and research with potential significant benefits might be more easily identified over the medium to longer term.

Soils – medium to long term

According to CSIRO the annual cost of landscape degradation in Australia is around $1.66 billion, current cleanup costs of contaminated sites approach $5 billion to $8 billion and soil acidification and erosion has associated costs of $580 million.

Research into the management of soils, improving the capacity to predict biophysical behaviour of landscapes and appropriate methods, technologies and policies to address the management challenges of sustainable management of soils is a high a priority.

However a focus of the funding by governments under programs such as the National Action Plan for dryland salinity and programs funded under natural resources management programs appears to be more on institutional and management arrangements than on basic research.

The CSIRO Divisions of Land and Water and Entomology are key organisations in research in this field. The Australian Resources Research Centre at Curtin University is also potentially an interested party.

Work in soils addressed in other areas — specific soils related research is likely to take time to formulate

Many of the research issues relevant to soils are addressed under agriculture and mining. ACIL considers that ABRS should approach these institutions in due course to discuss priorities and potential collaboration. However the consultations indicated that it could require some time to formulate workable proposals that would attract funding, which suggests that this area should be progressed over the medium term.

Conservation of Artefacts – medium to long term

Conservation of artworks and museum exhibits has a high cultural value. Although the museums can generate some revenues there is nevertheless a large public good component of their work. The museums indicated that research priorities included:

- Distinguishing harmful moulds from inactive ones.
- Effects of exposure to moulds.
- The best protection of people handling materials affected by mould

Lack funding for research relevant to conservation for museums and art galleries

- How to remove or kill mould without harming the affected collection item.
- The most effective way of preventing mould – or dealing with it – in the event that a large amount of collection material becomes wet.

ACIL's consultations indicated that there is little likelihood of funding from the museums. However ACIL recommends that ABRS make contact with the Australian Institute for the Conservation of Cultural Materials (AICCM) to explore research requirements.

This work may be attractive for funding from bequests and foundations. However we do not rank this as a priority for immediate development given the lack of clear funding potential.

Bioprospecting – longer term

Potential but not immediate interest – benefits sharing and intellectual property rights are issues to be clarified

The bioprospecting industry has significant potential commercial outcomes. Because of the commercial nature of their work it was difficult to identify potential partnership work with ABRS funded activities.

A key issue for the bioprospecting industry was ownership of intellectual property and benefit sharing arrangements. Development of a consolidated database that could act as a repository of information with fast access to the data was identified as important for one company.

While the organisations approached were willing to consider possible partnership arrangements none were in a position to respond in detail. In the case of the marine sector one stakeholder suggested that work should be funded out of the National Biotechnology Strategy — there appears to be little prospect for this in the short term.

It is possible that joint funding under a partnership arrangement might be attractive. However ACIL does not consider that the chances of developing such partnerships are high in the short term. Specific priority areas are not therefore identified for this sector.

Bioremediation – longer term

Microorganisms important for research in bioremediation but research is at an early stage

ACIL consultations indicated that research in this area is still at an early stage and while the role of microorganisms was recognised as important there was a general consensus that basic research was needed to understand the lifecycle of microorganisms better and how they function under different environments.

In light of these observations ACIL considers that this area should be pursued in the medium term. Contacts are listed in the main report.

Table 2: Prioritisation of activities

Priority	Activity area	Likely stakeholders	Action	Funding possibilities
Immediate	Marketing and liaison		Formalise marketing and liaison resources in ABRS	ABRS –seek additional funding
Immediate	Information dissemination	Research community, industry, government agencies	Establish internet data base to include current information on microorganisms	ABRS- seek additional funding
Immediate	Biodiversity ▪ Environmental Threats ▪ Coral diseases ▪ Endangered species	State Parks and Wildlife organisations Marine Park Authorities	Contact ▪ NSW Parks and Wildlife ▪ GBRMPA ▪ Environmental agencies	ABRS (seek additional funding) with potential for collaborative funding from environmental agencies
Immediate	Water quality ▪ Research on protists in relation to human health ▪ Coastal, estuary and lake algal bloom problems involving knowledge of protists.	Water and catchment management authorities CRC's for Wastewater and Pollution Control and Water Quality and Treatment	Approach CRC for Water Quality and Treatment. Explore possibility of participating in the application for a CRC for Environmental Biotechnology	Water authorities and catchment management authorities through research institutions and CRC's with ABRS
Immediate	Plant health ▪ Initially cereal rusts and root rot in crops. ▪ Review of taxonomic resources with Plant Health Australia. ▪ Later sugar, bananas, viticulture and stone fruit industries.	Plant Health Australia Grains and horticulture industries Agriculture departments Plant pathologists	Contact Plant Health Australia, CSIRO and other research institutions to formulate research projects integrating taxonomy.	Grains Research and Development Corporation Plant Health Australia ABRS
Immediate	Animal health ▪ Parasite control ▪ Microfungi associated with methane emissions ▪ Subsequently immunogens and vaccines, toxic algae and rumen microorganisms	Sheep, cattle and horses Australian Wool Innovation Meat and Livestock Australia Australian Greenhouse Office	Initially contact CSIRO Livestock Divisions, Australian Wool Innovation Ltd and the Australian Greenhouse office to formulate research projects	Australian Wool Innovation Ltd Australian Greenhouse Office
Immediate	Aquaculture and aquatic animal health ▪ Microorganisms related to fish and shellfish pathogens identified by the AQUAPLAN Business Group	Fishing industry Aquaculture industries Shellfish industries	Contact the AQUAPLAN Business Group and the Fisheries Research and Development Corporation	Fisheries Research and Development Corporation

Priority	Activity area	Likely stakeholders	Action	Funding possibilities
Immediate	Mining and petroleum ▪ Role of microorganisms in environmental management ▪ Lifecycles under varying conditions ▪ Bioprocessing ▪ Biodiversity and minesite rehabilitation ▪ Fungi in ore treatment ▪ Greenhouse gas mitigation ▪ Algal growth patterns ▪ Corrosion control ▪ Conversion or catalytic behaviours	Mining and petroleum companies ▪ Woodside ▪ Chevron Texaco ▪ Rio Tinto ▪ Titan Resources ▪ Micron research Research associations notable the Australian Resources Research Centre at Curtin University	Contact the Australian Resources Research Centre initially to formulate research proposals in the areas identified Other organisations to contact include CSIRO land and mining divisions to explore opportunities for cooperation Publicise research projects to mining and petroleum industry to generate wider interest.	Mining and oil companies through research collaboration arrangements.
Medium term	Food safety ▪ Mycotoxins and marine algal toxins	Food, agriculture and shellfish industries.	Contact National Residue Survey Group in Agriculture Forestry and Fisheries Australia and join the AusTox consultative group.	Research and development corporations in concert with ABRS
Medium term	Biotechnology ▪ Fungi in medical research ▪ Environmental biotechnology (see water quality) ▪ Diagnostics ▪ Genomic research	Biotechnology companies Medical and pharmaceutical companies	Contact ▪ Bioz Australia ▪ Q Centrics ▪ Applicants for CRC on environmental biotechnology	Biotechnology companies in concert with ABRS
Medium term	Forestry and wood products ▪ The role of microorganisms in timber growth and preservation.	Timber and wood products companies.	If work in this area is to attract funding support it would need to be formulated within a research project – likely to involve CSIRO.	Forestry and Wood Products Research and Development Corporation
Medium term	Pharmaceuticals ▪ Development of innovative medicines to treat disease in particular infectious, neurological disease, allergies and inflammation.	Pharmaceutical companies, medical research institutes.	Contact ANUTECH in the first instance.	Funding likely to be difficult. Global nature of some research involves IP issues.
Medium term to long term	Horticulture	Horticulture industries including grapes, fruit, flowers etc.	These industries are fragmented and it was difficult to gain focus as a group. Some of the work in plant health would also be relevant. Contact Horticulture Australia in due course to explore possibilities but only after the database is established and work is well underway in plant health issues.	Horticulture Australia Rural Industries Research and Development Corporation.

Priority	Activity area	Likely stakeholders	Action	Funding possibilities
Medium to long term	Soils ▪ Biophysical behaviour of landscapes and methods for sustainable management	Agriculture, mining, natural resource management agencies	Initial consultation with CSIRO and Australian Resources Research Centre	Possibly Mining industry, agriculture research and development corporations.
Medium term to long term	Museum conservation ▪ Identifying harmful moulds ▪ Managing or preventing mould infestation	Museums and art galleries	Contact the Australian Institute for the Conservation of Cultural Materials to explore research possibilities.	Likelihood of funding low. Would need a clear coordinated research program
Long term	Bioprospecting	Bioprospecting companies and organisations	Development of the data base will be a key development in attracting the interest of bioprospecting organisations Subsequent contact with Cerylid, Astra Zeneca and Australian Institute of Marine Science may identify prospects but it will be essential to have clearly defined project goals and benefit sharing arrangements.	Possible joint funding with bioprospecting companies with appropriate IP protection
Long term	Bioremediation	Mining companies, catchment management organisations, natural resource managers	Contact with the Australian Resources Research Centre with a view to exploring potential projects. CSIRO divisions concerned with land, water and agriculture would be appropriate avenues for formulation of integrated research projects. Contact with the West Australian Museum in regard to plant regeneration.	Natural Resource Management Agencies. Mining industry.

Ten-Year Program

Program Approach

Our suggested approach to a ten-year program comprises the following actions:

- Establish a marketing and stakeholder liaison capability in ABRS.
- Develop an interactive (distributed) database to provide users with access to a centralised information resource on species description.
- Seek additional funding for basic research into biodiversity.
- Address a small number of sector specific priority areas to be funded in total or in part from other sources in the early years.
- Move to medium and longer-term specific priority areas to be funded either in total or in part from other sources as the program consolidates.

Program Size

ACIL was not given any indications of the likely budget arrangements.

The annual budget for ABRS is currently around $3 million. On the basis of information provided to ACIL by stakeholders and ABRS it was estimated that a program designed to describe around 1500 species per year could cost of the order of $1 million per year.

An indicative cost breakdown of a program of this order would is shown in the following table.

Table 3: Possible initial program funding structure

Activity	Funding source	Annual Expenditure
Marketing and stakeholder liaison	ABRS	$100,000
Infrastructure support	ABRS	$100,000
Research, workshops and training	ABRS	$700,000
Potential stakeholder funded priorities	Stakeholders	$100,000
Total		$1,000,000

Note: Estimates for illustrative purposes only.

ABRS should seek additional resources for basic infrastructure and work on biodiversity – and seek additional contributions from potential beneficiaries

Such a program would require additional expenditure of around $900,000 per year by ABRS. ACIL has assumed total initial expenditure by users at $100,000 per year. This may be more or less depending on the success that ABRS has in formulating collaborative projects.

The additional expenditure by ABRS could be sought through a new policy proposal justified by the benefits accruing to the community in terms of biodiversity and natural resources management plus potential economic benefits in the agriculture, aquaculture, mining and petroleum and biotechnology related industries.

The proposal would include the intention that ABRS would seek contributions from potential beneficiaries. It would be the longer-term aim to increase such contributions as benefits are realised.

Program structure

An important objective underlying ACIL's proposed structure for the program is achieving early success in one or two key areas of high end user priority. By focussing on a limited number of high priority areas initially, the program will maximise the likelihood of realising benefits in a reasonable time frame.

Program should focus initially on the immediate priority areas — review every three years

As the program proceeds, this experience will provide important information to guide evaluation of other opportunities and revise and refine priorities.

For these reasons ACIL recommends that the program be developed in three year stages with an assessment of progress and adjustment of priorities at the end of each stage.

A possible agenda for a ten-year program is illustrated in Table 4 below. The program includes a core component of ABRS funded work supporting the basic infrastructure and undertaking work on biodiversity. In addition to this, activities in high priority areas funded (fully or in part) from other sources are proposed.

As the program proceeds there should be potential to increase the share of the total program funded from other sources. Achieving this goal will depend on early successes in priority areas.

It is possible that pursuit of joint funding may not be fully consistent with the current role of ABRS as research funding body. To pursue the program described above it may be necessary to broaden the mandate of ABRS to include participation in joint research funding activities and joint information dissemination programs.

Reviewing priorities

An important output of periodic reviews of the proposed microorganisms program will be guidance on ongoing program priorities in the light of experience.

Case studies will assist priority reviews

To support such reviews, the program administrators should draw on case studies and examples of the direct and indirect benefits that accrue from investment in taxonomy.

ACIL recommends that ABRS include, as part of its program management, a process that will collect information and case studies to assist its future program review and priority development throughout the course of the ten-year program.

The methodology discussed in this report provides a framework for the ongoing development of priorities.

Table 4: Program agenda

Stage 1	Year 1	Establish marketing and liaison function. Establish data base Develop and implement biodiversity program. Develop programs for animal and plant health, aquaculture, and aquatic animal health water quality and mining and petroleum Review collaborative opportunities through involvement in or collaboration with CRC's and research centres.
	Years 2-3	Continue biodiversity program. Liaise with medium term priority stakeholders to formulate research – food safety, biotechnology, forestry and wood products, pharmaceuticals and medical. Establish involvement with CRC's and research centres. Evaluate program outcomes and review priorities Develop case for ongoing funding of overall program.
Stage 2	Years 4-7	Refine and extend work on immediate priority areas– for animal and plant health, aquaculture, and aquatic animal health water quality and mining and petroleum Develop medium term priority programs food safety, biotechnology, forestry and wood products, pharmaceuticals and medical. Commence development of collaborative projects medium to long term priority areas – horticulture, soils (not already covered in agriculture), museums. Liaise on longer term priority areas – bioprospecting, bioremediation Review program outcomes and revise priorities the next three years
Stage 3	Years 8-10	Refine and extend work on immediate and medium term priorities subject to priorities review. Implement longer term priority areas of biotechnology, bioremediation and other areas identified by a priorities review..

Attachment A1. Terms of reference

- An initial workshop will be held with the successful consultants, ABRS staff and Advisory Committee taskforce members to agree on taxonomic overlap, scope of the study, and agreement on the timetable for completion of the consultancy.
- Initial Research Phase – documenting the way research and documentation is currently undertaken (including existing ABRS activities), plus alternate ways on how it could be done.
- Synthesise existing estimates of the size and taxonomy of the groups;
- Analysis of how long it would take to document the groups using existing methods, and with suggested new methods;
- Analysis of what groups are currently being worked on;
- Broad stakeholder consultation and analysis – what information and services are required, and an indication of priorities for future research;
- Analysis of how to achieve desired stakeholder outcomes;
- Development of a ten-year work plan including research strategies, tiered recommendations and suggested levels of activity.