

A Model for Assessing the Health of Kakadu's Streams

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Contents:

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A Model for Assessing the Health of Kakadu's Streams

Background

The Environmental Research Institute of the Supervising Scientist (*eriss*), part of the Supervising Scientist Group (SSG) of Environment Australia, conducts research into environmental issues relating to mining and wetland management. It is located at Jabiru in Kakadu National Park, in Australia's Northern Territory.

In 1987, *eriss*, established a research program to develop biological monitoring techniques that would be used by mining companies to assess the impact of their activities upon aquatic ecosystems of the Alligator Rivers Region (ARR). Progress in this program has been reported by Humphrey et al. (1990, 1995) and Humphrey and Dostine (1994). The objective of this paper is to provide (i) some background to the development of this program, including the environmental setting and the key components of the biological assessment program, (ii) information on how the data gathered to date have been used to assess environmental performance of the Ranger Uranium Mine, and (iii) information on how the biological assessment procedures are being used as templates for regional and national use. It is important to note that the biological monitoring program does not include an assessment of the impact upon people and ecosystems of radionuclides associated with uranium mining and milling in the ARR. (These issues are covered in another *eriss* research program not discussed in this paper - see Johnston (1990).)

Mining in Kakadu National Park

The ARR in Australia's Northern Territory encompasses Kakadu National Park, an area renowned for its rich cultural and natural values (Finlayson & von Oertzen 1996). Ecosystems of the Park are recognised under international conservation conventions including World Heritage listing, and the Ramsar Convention for Internationally Important Wetlands. The ARR also contains important mineral reserves, including uranium, which has been mined and milled in the Region since 1979.

The intense and highly seasonal wet seasons of the northern part of the NT pose problems for the management of excess water that accumulates over this time at mine sites. If allowed to drain uncontrolled, these waters could pose a potential environmental risk to downstream aquatic ecosystems. Given the conservation values of the Region, high standards of environmental protection from the effects of any dispersed mine waters are required by the Commonwealth Government and are demanded by the Australian public. To satisfy these needs, the Supervising Scientist has recommended that strict control and monitoring regimes be put in place to ensure the safety of any release of waters from mine sites in the ARR.

Biological assessment of mining impact

Supervisory and regulatory authorities have couched the environmental protection objectives for mining in the ARR around two important principles of Ecologically Sustainable Development (ESD) as described by the national ESD Steering Committee (1992). For off-site environmental impact acceptable to the Commonwealth, the SSG has proposed the following environmental protection objective:

“Environmental protection in the Alligator Rivers Region requires that the biological diversity of aquatic and terrestrial ecosystems, including ecological processes, is maintained, and that a precautionary approach is exercised in environmental management and interpretation of monitoring data” (SSG unpublished).

The ESD tenets of (i) precautionary management, and (ii) conserving and maintaining biological diversity that are incorporated in this objective are closely allied to the Ramsar obligation to maintain the ecological character of internationally important wetlands and to make wise use of such sites (Davis 1994; Finlayson 1996). In addition, they also conform to a large extent to the aims of the World Heritage Convention, to encourage nations to protect and conserve natural and cultural heritage of worldwide importance (Environment Australia: http://www.erin.gov.au/portfolio/dest/wha/what_what_what.html).

The animals and plants resident in streams downstream of mine sites have been identified as those most at risk from mine wastes that may be dispersed to the environment because of their continuous exposure to any such wastes. Only studies conducted on organisms from these aquatic ecosystems can define and assess the overall effect of contaminants on the ecosystems. For this reason, the most critical components of the control regime and monitoring program developed to ensure that environmental protection objectives have been attained, are those based upon biological criteria. This is not to say that biological approaches should replace chemical standards and monitoring. Rather, in water quality assessment programs, both approaches are highly complementary and interdependent.

Biological assessment is the key process for meeting the environmental protection objective and incorporated ESD tenets and to this end, different biological indicators have been developed for each of these needs. Macroinvertebrate and fish communities, or representative species therein, have been selected as key indicators for study in the ARR. These groups have been shown in biological assessment programs conducted elsewhere to be particularly sensitive to mine-related disturbances (Humphrey & Dostine 1994). Fish communities also have the advantage in holding a high public profile: they may be an important food resource for some communities and provide important social and cultural amenity.

Context of the monitoring program

The ensuing discussion focuses on the monitoring program developed for Magela Creek, the seasonally-flowing stream in the ARR that passes near the Ranger Uranium Mine.

The Ranger mine waste waters are complex and, relative to adjacent natural surface waters, contain enhanced concentrations of naturally-occurring substances (metals including uranium and magnesium, radionuclides, suspended solids) and exotic chemicals (hydrocarbons, process chemicals including manganese and sulphate). In this report, reference to any Ranger mine waste waters that have so far been dispersed to the environment, is in relation to runoff from waste rock dumps, as opposed to waters that have been in contact with uranium in the Restricted Release Zone (RRZ). RRZ waters have never been released to Magela Ck.

For studies in Magela Creek, all parties involved in the management of mine water discharges have agreed that creek waters downstream of the gauging station GS8210009, located several kilometres downstream of Ranger, constitute the ‘receiving’ water in which ‘observable impacts’ upon aquatic organisms should be absent. It is convenient that apart from naturally-occurring changes, water quality upstream of this point is otherwise influenced by mining activities alone. (Thus, unlike a number of billabongs included in the monitoring program, anthropogenic changes at the GS8210009 site are not confounded by effects arising from Jabiru township.) It is also assumed that the effects of any exotic plants and animals on the

sandy channels of Magela Ck near Ranger would be felt equally at both control sites upstream of the mine and those downstream.

Key components of a biological assessment program

In line with the key principles of ESD described above, the components of the *eriss* biological assessment program have been selected to meet two important objectives of environmental protection, (i) *early detection* of effects (laboratory and field bioassays), and (ii) information on the *ecological importance of any impact* (studies of natural populations and communities). These components are described below.

Precautionary management

The essence of precautionary management is the instigation of conservative environmental controls together with responsiveness to changes in early detection indicators measured in a monitoring program. Such management is pre-emptive or preventative in order that large and ecologically important impacts are avoided. Whether the indicators are chemical or biological, the intervention takes place when pre-determined 'triggers' are reached; the criteria for management decisions are conservative in the sense that, in many cases, the ecological relevance of the measured responses has not been established. For example, a small percentage decline in the reproductive output of a test species (caused by mining) may be inconsequential to the maintenance and continued existence of the species in the wild.

Precautionary management begins prior to any release of waste waters to the environment by way of a regime of chemical and biological controls. This involves the setting of conservative chemical standards, and a program of pre-release laboratory toxicity testing, of any waters that are considered for discharge to streams. Pre-release toxicity tests determine discharge rates at which no harm should occur to animals in downstream ecosystems. Animals involved in these toxicity tests include fish fry, water fleas and hydra, with the test protocols being fully documented by Hyne et al. (1996). The test animals were chosen from approximately twenty local aquatic species originally trialed for laboratory-based toxicity testing (Holdway et al. 1988). Selection was based on their sensitivity, representation from different trophic levels (i.e. vertebrate predator, invertebrate predator and invertebrate herbivore, respectively), and suitability for laboratory culture (Holdway et al. 1988).

Together with the control regime, an environmental monitoring program is conducted in downstream ecosystems to demonstrate that the expected high level of environmental protection has been achieved. Creekside monitoring is used for early detection of effects in the creek arising from any release of mine waters during the wet season. The technique is described in Humphrey et al. (1995). Reproduction and survival of freshwater snails and survival of fish fry exposed to creek waters pumped to creekside shelters are measured during each wet season. These species have been shown to be particularly sensitive to mine waste waters. Responses of the test animals are measured at two sites, one located upstream of Ranger (a control) and the other several kilometres downstream. Information gathered for both species over past wet seasons shows that responses are very similar at the upstream and downstream sites, indicating no effects of mine water releases (e.g. Fig. 1).

Early detection of effects are also sought in the sediment at sites of any potential deposition of mine wastes in Magela Ck, such as the upper floodplain zone. For this purpose, the concentrations of chemicals in the tissues of long-lived animals, including mussels and fish, are being measured (bioaccumulation) at strategic locations between Mudginberri and

Jabiluka billabongs. If they occur, changes in tissue concentrations over time would be cause for concern. However, such effects at remote sites would be expected to show up (if at all) only in the very long term.

In any field monitoring program, locating sites in a potential 'disturbance gradient' - such as in a mixing zone, or on the mine site itself, may enhance early warning capabilities. While effects in these zones might not in themselves be cause for concern, the information obtained at these sites may enhance predictive capabilities when extrapolated to the future and to sites in the receiving waters. Biota from billabongs on the Ranger mine lease are sampled by *eriss* for this purpose.

Maintaining biological diversity in the system

More often it is not sufficient simply to have 'detected' change in an 'early detection' indicator for the reason that such information cannot easily be linked (if at all) to effects at the population, community and/or ecosystem level. Hence, there is a need for measurement of another suite of indicators that serve as suitable surrogates of 'ecosystem-level' and 'biodiversity' change, where important effects might be reflected in:

- changes to species richness, community composition and/or structure;
- changes to species of high conservation value or species important to the integrity of ecosystems;
- changes to ecosystem processes of a physical, chemical or biological nature (NWQMS In draft).

Control locations (unaffected by mining) for the studies in Magela Ck are situated both upstream of the Ranger mine site and in separate streams. In the streams, studies of natural populations and communities of benthic macroinvertebrates and fishes are used to provide information about changes to biological diversity and hence, the ecological importance of any impacts in Magela Creek arising from the mine. In a practical sense, this involves counting and identifying macroinvertebrate (eg insect larvae, molluscs, shrimps) and fish species in the creek systems, downstream of the mine in Magela Creek and at the control sites.

The ability to correctly infer impact

In the best monitoring programs, information on natural populations and communities is collected at control sites and at potentially disturbed sites before and after any possible changes to the quality of surface waters (NWQMS In draft). The advantages of designs that incorporate such spatial and temporal control data are that they are able to incorporate inherent natural variability, and they permit the testing of formal hypotheses (using conventional statistical procedures) about the nature and extent of impact. For landowners potentially and directly affected by developments, such controls or points of reference provide a necessary 'comfort' in the event of correctly attributing cause to any possible future disturbance to elements of the landscape. Formal experimental designs that incorporate the necessary controls require at the outset, decisions to be made by key stakeholders on:

1. The size of impact that is to be detected, and
2. The rates of two types of error:-
 - inferring an impact when there is none (Type I error), and
 - failing to correctly detect an impact (Type II error).

In highly-valued regions such as Kakadu, it is important that monitoring programs be designed to detect small changes with low error rates - particularly the Type II error rate (Faith et al. 1991). The Type II error rate will be reduced either by increasing the amount of reference site and baseline data or by accepting a larger Type I error rate. As a consequence, the *power* of statistical tests for change - or probability of correctly rejecting the null hypothesis of 'no impact' - is enhanced. The National Water Quality Management Strategy (NWQMS) Guidelines for Fresh and Marine Water Quality (NWQMS In draft) recommend a process of stakeholder negotiations at the outset for either ratifying conservative default values for effect sizes (= amount of acceptable change) and error rates, or negotiating alternative criteria (NWQMS In draft). Mapstone (1995) describes detailed procedures for setting critical sizes of Type I and Type II errors through this process.

Increasing the number of control sites and occasions with which these are sampled provides the best and fairest means of detecting small changes with low Type II error rate. The amount of replication required to detect a given change with prescribed error rates can be determined with knowledge about the natural variation (in the absence of disturbance) of the indicator response being measured. Where such information is unavailable, the NWQMS Guidelines (NWQMS In draft) make the recommendation that baseline data be gathered from at least 3-5 control or reference locations (for 'biodiversity' indicators at least) over a period of at least 3 years (all indicators) wherever possible.

It is rare to find in planning, assessment and approval processes for developments in Australia adequate priority attention (and resourcing) by proponents for the gathering of relevant baseline data. Up to the late 1980s, lack of attention to this need could largely be attributed to the infant state in Australia and abroad of biological monitoring techniques and the necessary experimental design for measurement of biological responses. Since the late 1980s, however, enormous advances have been made worldwide to develop biological monitoring techniques. In our opinion, deficiencies in baseline data collection since then are symptomatic of lack of foresight, political expediency or other aspects of a socio-economic nature - factors also drawn attention to by other expert environmental scientists in Australia (e.g. Australian Broadcasting Commission 1992; Lake 1992). These inadequacies have also been attributed to a flawed Environmental Impact Assessment process (Fairweather 1989; Buckley 1989, 1993; Lake 1992). In particular, proponents have not been required to stipulate the power, nor meet minimum power requirements, in monitoring designs and associated statistical tests that they would use to detect impact. Johnston (1993) also drew attention to the lack of government involvement in baseline data collection, a factor expanded upon below.

As with other developments in Australia and elsewhere, and following from above, much of the biological data gathered in the ARR up to the mid to late 1980s, whilst useful for assessing possible impact, do not necessarily stand the scrutiny of rigour and quantification (nor necessarily, stakeholder acceptance,) required to properly infer impact. Hence, the development of uranium mines in the ARR has proceeded with little in the way of valid, pre-disturbance biological baseline data gathered. Fortunately, only mildly contaminated waters containing relatively benign salts have ever been released from Ranger to the environment whilst generally, the concentrations of potentially hazardous substances in the receiving waters have been almost indistinguishable from background. Further, current data are still able to be collected from control sites in Magela Creek and adjacent streams unaffected by mining activities - an important requirement of experimental design. Hence, the current biological data may still be regarded as serving a 'baseline' need and are gathered according to best-practice designs in biological monitoring (Humphrey et al. 1995).

Where there are limited opportunities for gathering baseline data, a number of strategies are

available to compensate (or partially compensate) for the weakened inferences and increased risk of Types I and II error rates that necessarily follow. If there was a guarantee of a total containment of mine waste waters, at least prior to the gathering of necessary baseline data from streams, then the lack of pre-disturbance data becomes less of an issue. However, we also need to consider the effect of disturbance involved in constructing bunds necessary to contain mine waters. It has been shown elsewhere in the ARR that even small increases in loads of suspended solids to streams can adversely affect resident benthic macroinvertebrate and fish communities (Stowar 1997; Stowar et al. 1997).

The NWQMS Guidelines for Fresh and Marine Water Quality (NWQMS In draft) recommend that where opportunities for gathering baseline data are limited, partial compensating aspects of design and adoption of a 'weight of evidence' approach to inference be incorporated in monitoring programs. Thus, there is an emphasis under these circumstances of expanding the sampling of suitable control areas from adjacent streams for best possible characterisation of a 'reference condition'. Data from these sites can be used to describe how typical or atypical the areas that might be potentially disturbed appear. The assumption is made that the indicator responded similarly in control and 'test' areas before development. In addition, questions are often framed around the extent of any potential impacts and here, recommendations are made that data be collected from a comparatively larger number of potential impact sites than would otherwise be gathered (eg along a 'mixing zone'), so that stronger inferences may be drawn about impact by way of disturbance gradients (NWQMS In draft). A 'weight of evidence' approach to inference (e.g. Suter 1996) places emphasis on enhancing the monitoring battery, i.e. selecting and including additional biological indicators, chemical monitoring, and toxicological and other experimental data in which concordance is sought between field results and controlled experimental findings.

Lack of baseline information may be at least partially compensated for by modifying experimental designs and adding components to the measurement program that would not otherwise be considered, so that there is some confidence to the conclusions that are drawn. Such modifications and additions, however, are inferior and such an approach should never be deliberately opted for when opportunities for gathering of baseline data exist. Moreover, such an approach will add substantially to the costs of a monitoring program. The highlighting of these deficiencies to proponents in planning and assessment processes would provide important incentives for gathering of adequate baseline data.

Proponents might also be under a false allusion that gathering of such baseline data at an early phase of a proposal – for example, in the exploration phase for minerals – is an unjustified expense, particularly if a potential deposit is unproven. In reality, gathering and preserving of macroinvertebrate samples (the group most widely used for biological monitoring in Australia) is relatively inexpensive. Such samples could be stored and either processed at a later date if a deposit is proven, or otherwise left or discarded. Government could also play an active role in funding the gathering of such samples for prospective purposes. Johnston (1993) also proposed a strategy in which government would fund both generic information (e.g. taxonomic base, inventories) required to underpin the usual baseline data, as well as actual baseline data from selected streams representative of the different bioregions that were known to be particularly prospective for minerals.

The environmental record at Ranger

Mining companies in the ARR are fortunate that the ore associated with the major uranium-bearing deposits contains little in the way of acid-generating sulphides and associated metals.

Such combinations and poor mine waste water practices elsewhere in Australia, have lead to severe ecological degradation of a number of rivers, including the Finnis R in the NT (Jeffrey & Williams 1975) and the Queen and King rivers (Davies et al. 1996) in Tasmania. The relatively benign nature of the Ranger ore bodies and good environmental practices, including biological assessment of mine waste waters, have restricted any effects of water releases to Magela Creek from Ranger to the short-term and to either mixing zones or waterbodies on the mine lease.

The *eriss* biological monitoring program has been primarily concerned with technique development and hence, the period since the program inception has represented a research rather than routine monitoring phase. Despite this, valuable data have accrued over time from which conclusions have been drawn about the extent and degree of mining impact in Magela Creek.

Since 1985, only localised effects of water releases have been observed. In the 1985 releases of retention pond water, suppression of breeding of freshwater mussels and avoidance behaviour of some migrating fish populations were observed in a short mixing zone (Humphrey et al. 1990). Further, after a wet season of particularly high rainfall and consequent discharge of Ranger retention pond waters in 1995, macroinvertebrate community structure and taxa richness appeared to be altered in waterbodies, including billabongs, on the Ranger mine lease (O'Connor et al. 1996). However, no effects have ever been observed off-site (creekside, and macroinvertebrate and fish community data).

Putting the biological assessment procedures into practice

The development and refinement of methods for biological monitoring in the ARR are near completion. The key elements of this program are being used as templates for regional and national use.

A regional model

A period of implementation is now beginning where core elements of the biological monitoring program will be used in a demonstration model for streams potentially affected by uranium mining operations in the ARR. Protocols and procedures for data management and documentation used in the demonstration projects by *eriss* are being made available to mining companies, regulatory agencies and other interested groups. Energy Resources of Australia (ERA), owners of the Ranger mine, have for some years now incorporated laboratory toxicity testing in their environmental control regime. With some *eriss* supervision and check monitoring, they have also trialled over the past two wet seasons creekside monitoring procedures with a view to routine and ongoing application of the method as part of their monitoring program. ERA and *eriss* are working closely towards incorporating other core components of the *eriss* program in ERA's monitoring program. Some cooperative sampling and sample processing by both parties are already in place for the Ranger and proposed Jabiluka projects. The demonstration model incorporates the following aspects:

Program design

All data collection procedures are subject to strict design criteria guided by internationally accepted practices. The design and documentation, including quality assurance, are crucial steps in the model.

Field procedures

Rigorous and novel experimental design is applied to collection of data. Quantitative sampling and sorting methods are used for the collection of macroinvertebrates from the beds of aquatic plants in the seasonally-flowing sections of Magela Creek and control streams. Fish data are gathered using non-destructive, quantitative procedures: visual counting of resident and migrating fish in the high clarity waters of the creek channels and billabongs, and 'pop-netting' procedures in billabongs containing high densities of aquatic plants.

Laboratory procedures

Laboratory procedures include sample registration, sorting and identification of macroinvertebrate samples, and chemical analyses, as well as the pre-release toxicity testing described above. Streamlined processes supplying precise, accurate and rapid results are required for a monitoring program that will provide early warning of unacceptable impacts.

Data management, documentation and reporting

Critical to the success of a biological monitoring program is efficient storage of data and the appropriate reporting of results. To enable rapid feedback to management and interested stakeholders of monitoring results, data must be easily accessible and stored in a manner compatible for use in statistical software packages. Protocols are being prepared for all field and laboratory procedures.

Stakeholder involvement

Stakeholders include the Aboriginal Traditional Owners of the area, Commonwealth and Northern Territory governments, ERA and the general public. Through groups such as the Alligator Rivers Region Advisory Committee (ARRAC), *eriss* will report on the development of the demonstration model for biological monitoring in the ARR. Further consultation and reporting of monitoring results to other stakeholders and the wider community will ensue.

It is fortunate that the demonstration program described here is proceeding simultaneously with a revision by supervisory and regulatory authorities of the entire Ranger monitoring program and framework. Each of the tasks stands to benefit from developments in the other. The demonstration program will benefit from the revision, in which stakeholder input and agreement are being sought at key steps:

- Re-defining (or confirming) the environmental protection objectives (environmental values, goals, level of protection);
- Identifying the water quality issues of concern and pathways; and
- Developing chemical and biological monitoring programs (including identifying and deciding upon assessment objectives, indicators, statistical design, level of acceptable impact, statistical decision criteria and devising a management action plan).

A template for biological assessment elsewhere in Australia

An external review of the *eriss* biological monitoring program was conducted in 1993 in the form of a workshop (Finlayson & Humphrey 1998). This review recommended that the *eriss* program be used as a template for situations elsewhere in Australia where such comprehensive monitoring was required. (This monitoring 'package' and associated documentation are described above.)

The *eriss* has responsibility for carrying out the current revision of the Australian and New Zealand water quality guidelines for marine and freshwaters (NWQMS In draft). The draft

guidelines recognise three ecosystem conditions - modified, substantially natural and high conservation/ highly valued ecosystems - warranting progressively higher standards of protection respectively. Through the NWQMS guidelines, the principles and elements of the *eriss* biological assessment programs for the ARR - toxicity testing and biological monitoring - are being used as the model for similar areas of high conservation value in Australia.

The *eriss* biological assessment programs are also being used to develop a conceptual framework for wetland risk assessment (Finlayson et al. 1998) and monitoring (Finlayson 1996) for the Ramsar Wetland Convention and have influenced approaches being tested by *eriss* for vulnerability assessment of wetlands due to climate change and sea level rise (Bayliss et al. 1997).

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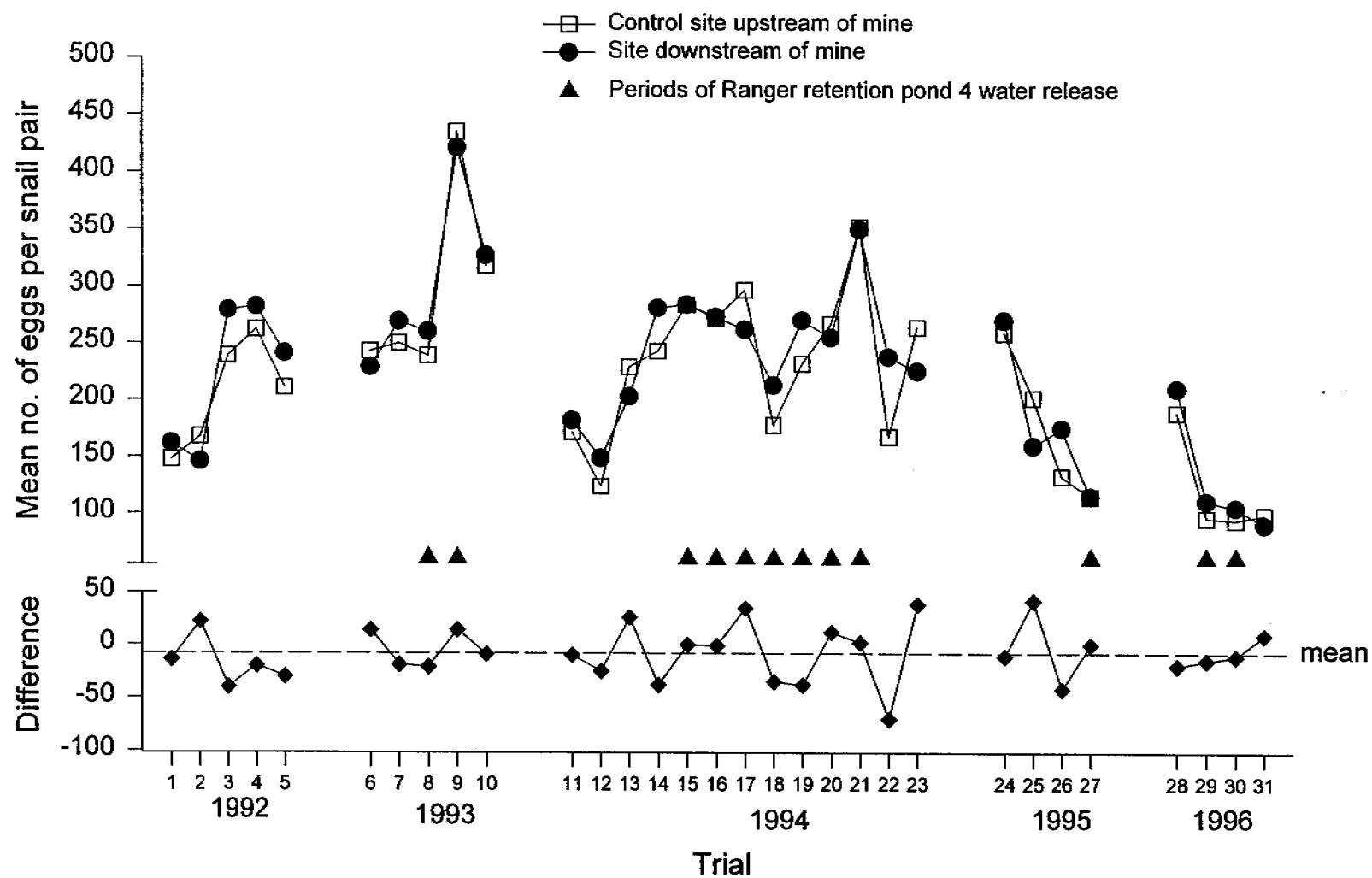
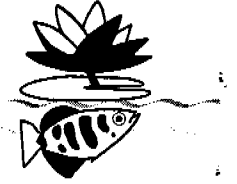


Figure 1. Freshwater snail egg production in creekside monitoring trials conducted in Magela Ck near the Ranger Uranium Mine. Some of the tests coincided with releases of low contamination mine runoff waters to the creek.

A Model for Assessing the Health of Kakadu's streams:

Outline of talk



◆ The setting

- Biological assessment of mining impact in Kakadu National Park

◆ Key components of a biological assessment program

- Indicators that serve key tenets of Ecologically Sustainable Development

◆ Experimental design and analysis

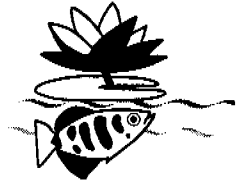
- How much baseline (pre-disturbance) data can be gathered?

◆ The environmental record at Ranger

◆ Putting the biological assessment procedures into practice

- Templates for regional and national use

Biological assessment of potential mining impact



- ◆ High conservation value of Kakadu National Park

KNP ecosystems, including wetlands, recognised under international conservation conventions:

- World Heritage listing, and
- Ramsar Convention for Internationally Important Wetlands

- Management of waste waters at ARR mines:

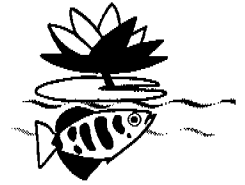
Concern: Environmental protection of aquatic ecosystems from possible dispersion of mine waste substances to the environment.

Need: High standards of environmental protection required by the Commonwealth Government and demanded by the Australian public.

- ◆ Biological assessment of mining impact

- Studies conducted on *aquatic organisms* required to define and assess the overall effect of contaminants on ecosystems.
- Chemical and biological monitoring highly complementary and interdependent

Meeting the environmental protection objective



- ♦ Proposed environmental protection objective for mining in the ARR formulated around key principles of Ecologically Sustainable Development (ESD):

Environmental protection in the Alligator Rivers Region requires that the biological diversity of ecosystems, including ecological processes, is maintained, and that a precautionary approach is exercised in environmental management and interpretation of monitoring data.

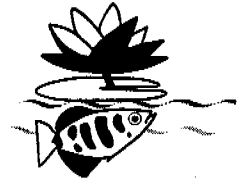
This objective closely allied to 'Wise Use' monitoring and assessment guidelines for wetlands as developed by the Ramsar Convention.

- ♦ Biological assessment an essential tool for providing ESD through two principles directly relevant to ecosystem protection:

- Precautionary management,
- Conserving and maintaining biological diversity.

Selection of biological indicators to meet these principles

Precautionary management



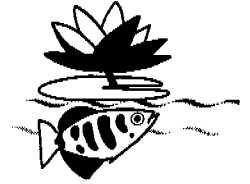
Key principles

- ◆ Gathering of information that may be a precursor to important ecosystem-level change, using 'early detection' indicators
- ◆ Responsiveness to this information, even if ecological relevance not established

Key elements

- ◆ Strict control regime for release of mine waste waters
 - conservative chemical standards,
 - pre-release biological testing.
- ◆ Field monitoring for early detection
 - effects in the *water*: creekside monitoring,
 - effects in *sediment* (deposited mine wastes): bioaccumulation in long-lived animals,
 - locate sites in *potential disturbance gradients* (mixing zones, on the mine site) to enhance predictive capabilities.

Maintaining biological diversity in the system



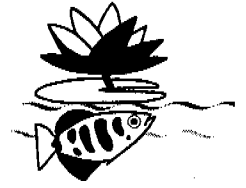
Biological indicators required to assess the *ecological importance and relevance* of any observed impact.

Need for indicators that are suitable surrogates of 'ecosystem-level' and 'biodiversity' change, where important effects might be reflected in:

- ◆ changes to community structure;
- ◆ changes to species of high conservation value or species important to the integrity of ecosystems;
- ◆ changes to ecosystem processes of a physical, chemical or biological nature.

In the ARR, use of *benthic macroinvertebrate* and *fish* communities as suitable indicators of 'ecosystem-level' and 'biodiversity' change.

Experimental design and analysis:



Detection of change in biological indicators

Up-front decisions required on:

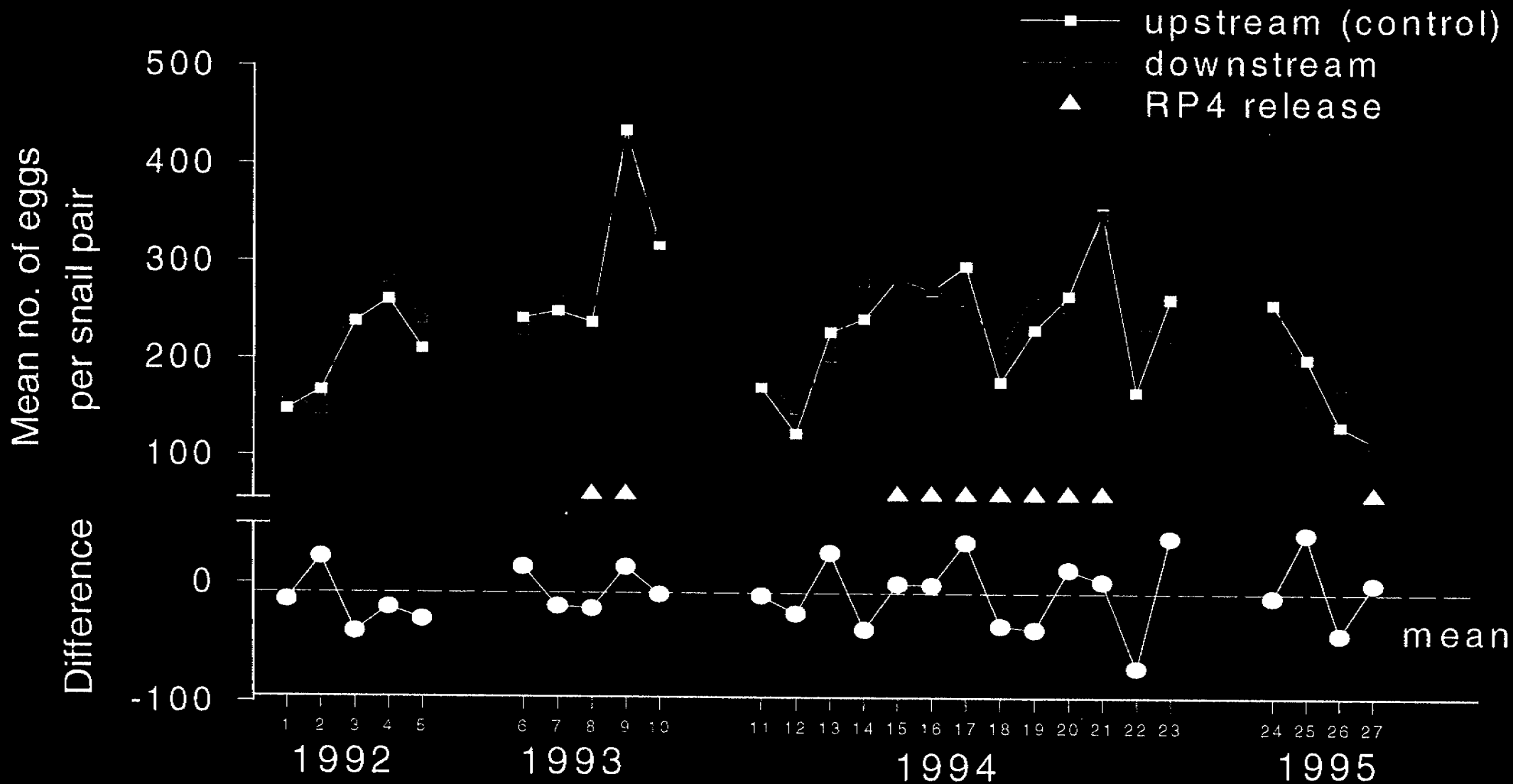
1. Experimental design to apply, and
2. Important decision criteria including:
 - ♦ The size of impact to be detected,
 - ♦ The acceptable rates for two types of error:-
 - inferring an impact when there is none, and
 - failing to correctly detect an impact.

Ideal: Detection of small changes with error rates kept low requires sufficient data collected before any potential impacts, at both 'test' sites and from comparable undisturbed 'control' areas.

Greater the amount of control and baseline data, stronger and fairer will be the test of the effect of the impact.

In reality: Few 'idealised' situations. Rather, a continuum from adequate designs to inadequate designs where the strength of the inferences much weaker and higher risk of errors.

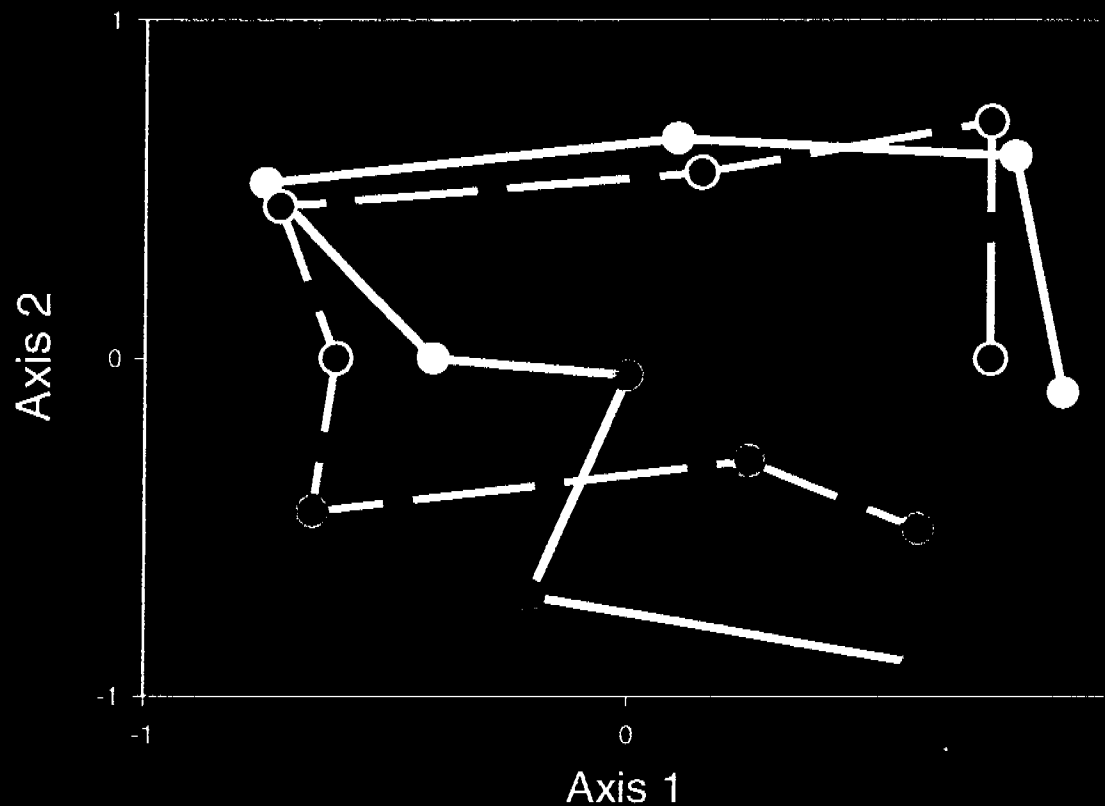
Opportunities for gathering baseline data: creekside snail egg production tests (early detection)



Principle of monitoring using community structure (Hypothetical scenario illustrated by multivariate ordination)



eriss

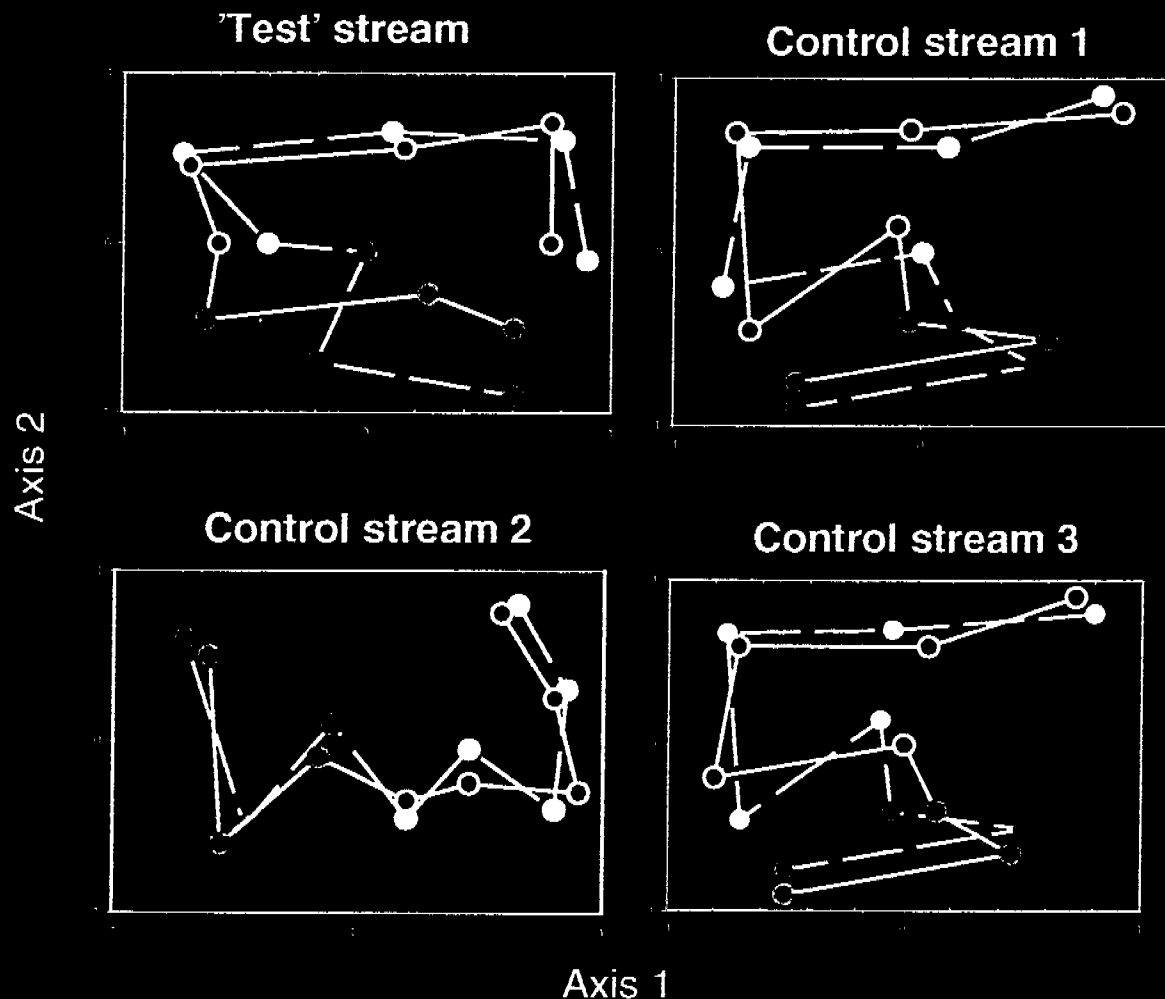


- upstream site, before impact
- downstream site, before impact
- ◐ upstream site, after impact
- ◑ downstream site, after impact

Principle of monitoring using community structure (Hypothetical and idealised scenario)

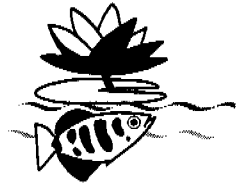


eriss



- upstream site, before impact
- downstream site, before impact
- upstream site, after impact
- downstream site, after impact

Limited opportunities for gathering baseline data



Insufficient baseline data:

- ◆ Weakens inferences and increases risk of either missing an impact or falsely concluding that an impact has occurred.
- ◆ Can be symptomatic of lack of foresight, political expediency, flawed Environmental Impact Assessment process or other socio-economic factors.

What can be done to compensate for lack of baseline data?

EITHER:

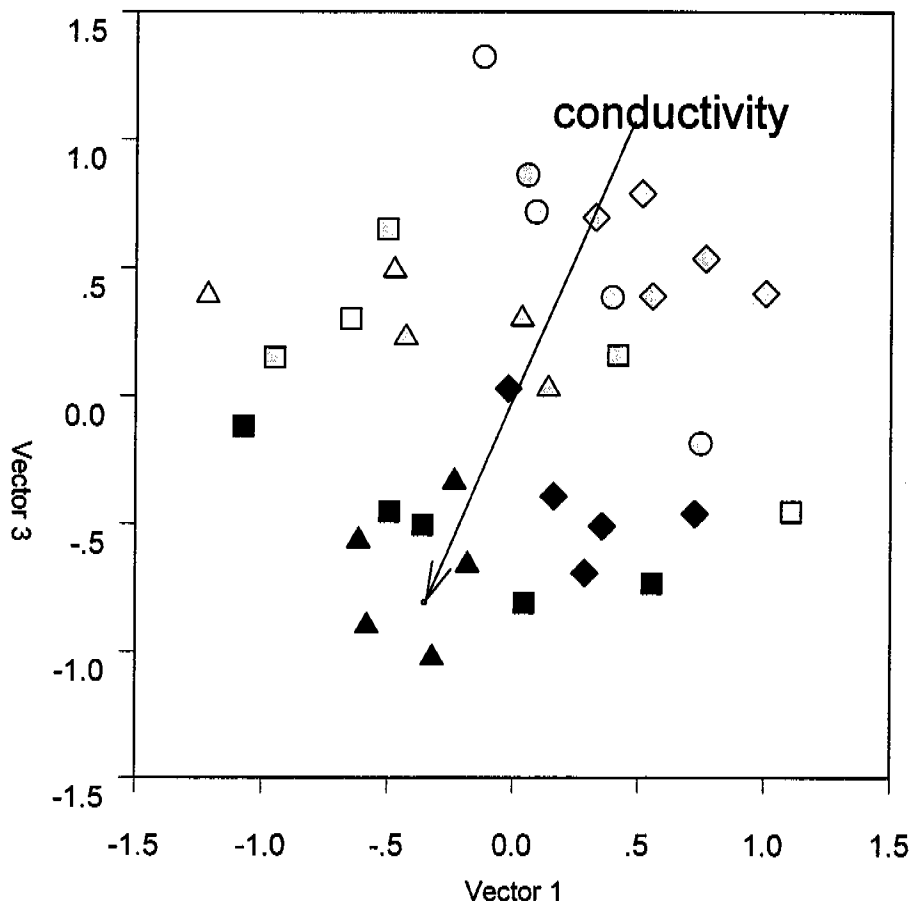
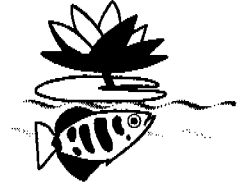
Total containment of mine waste waters

OR:

Partial compensating aspects of design and adoption of 'weight of evidence' approach to inference:

- Enhance the monitoring and assessment battery,
- Increase the number of control and test sites to establish a potential disturbance gradient.

- **Disturbance gradient derived from multivariate ordination of macroinvertebrate community data (ARR waterbodies)**



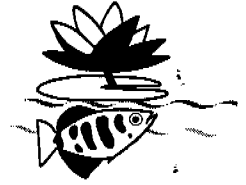
Waterbodies receiving
mine waters

- Coonjimba
- ▲ Djalkmara
- ◆ Retention Pond 1

Waterbodies not receiving
mine waters

- ◇ Buba
- Sandy
- Georgetown
- △ Town Lake

The environmental record at Ranger



- ◆ Effects of mine waste waters dispersed to Magela Creek from Ranger usually short-term and very localised.

- ◆ No effects observed off-site (creekside, and macroinvertebrate and fish community data).

- ◆ Since 1985, localised effects observed:

- Mixing zone during release of retention pond water 1985*

- Breeding response of mussels
- Fish avoidance behaviour

- Waterbodies, including billabongs, on mine lease 1995 (retention pond water releases)*

- Macroinvertebrate community structure and taxa richness altered.