Monitoring: An Essential Component of Environmental Management.[1]

Angas Hopkins
Principal Research Scientist
CALM Science and Information Division
and contactable at:
Western Australian Wildlife Research Centre
PO Box 51 Wanneroo W.A. 6065
Phone (09) 405 5100
Facs (09) 306 1641
email angash@wood.calm.wa.gov.au

An understanding of processes supporting natural and disturbed ecosystems is a prerequisite for sustainable management of those ecosystems and for the development of sound environmental policies. Well designed monitoring programs can provide much-needed information on both patterns and processes at relatively low cost. Monitoring can be good science and should be viewed as a worthwhile research activity. More importantly, it should be regarded as an integral part of management. It can also provide a useful focus for community involvement in management activities.

The rationale for monitoring

Monitoring has long been considered an integral part of rapid response systems such as financial systems and manufacturing plants. Compliance monitoring and reporting is now a fairly standard requirement of pollution licencing. In contrast, acceptance of monitoring as an integral part of living natural resource utilization and management has been relatively slow to develop (for some early examples, see Goodwin and Walker 1972; Grimsdell 1978; Gwynne and Craze 1975; Morrissey 1976; National Science Foundation 1977, 1978; Noble 1977; Norton-Griffiths 1973; Winbush and Costin 1979a, 1979b, 1979c). Furthermore, there is still considerable confusion as to what such monitoring might involve. It is useful, therefore, to begin this discussion with a definition of the term monitoring and a general outline of the way in which the concept might be applied to management of living natural resources (*sensu* IUCN 1980 and subsequent National and State Conservation Strategies).

Monitoring has been defined as "...the process of repetitive observations of one or more elements or indicators of the environment according to pre-arranged schedules in time and space in order to test postulates about man's impact on the environment..."(Bisset and Tomlinson 1981). This definition highlights two key features: repeated observations according to pre-arranged schedules and testing hypotheses about impacts. At the same time, the definition is excessively restrictive in that monitoring should be used to gather data on non-anthropogenic impacts particularly those associated with stochastic events such as drought, fire, flood and

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outbreaks of pests and diseases. Monitoring techniques can also be used to structure observations that are not immediately related to an hypothesis, including the collection of baseline data. It is worth noting that some very important insights into environmental processes have been gained from the analysis of sets of long-term data collected collected systematically but for other purposes: perhaps the best known example is the long-term atmosphere monitoring program at Cape Grim, the data from which are now used to show changes in atmospheric CO^2 levels.

Monitoring is not the same as long-term ecological research: the two activities are complementary but different. Monitoring need not be long-term - the time scale depends entirely on the hypothesis being tested. However, many monitoring projects will often be medium to long-term because of the very nature of the isssues being addressed. Monitoring as an activity is not necesarily confined to ecological issues although, in the context of this discussion, much of it will have an ecological orientation. A further important distinction is that monitoring often involves non-destructive sampling because of the need for continued sampling of the same place.

Long-term ecological research sites (LTERSs) are usually large and diverse whereas monitoring sites can be small but may be more numerous - there may be many (separate) monitoring sites at a single LTERS. LTER programs should include monitoring of a few key environmental parameters such as rainfall, water depth and quality, vegetation cover and so on, parameters that can be incorporated within the concept of a minimum standard installation. The other perspective is that the results of LTER programs are often very important in providing the basis for interpreting the results of monitoring programs.

Monitoring is central to living natural resource management for at least the following reasons (Hopkins 1988; Hopkins in press; Hopkins and Saunders 1987; Hopkins *et al.* 1987).

Firstly, the process of planning and management necessitates predicting the consequences of a range of options including the do-nothing option. For most areas, the knowledge that should form the basis for such predictions is lacking and it is unlikely to become available in the foreseeable future. It is generally not possible to postpone management until the research is done.

A solution to this dilemma is to incorporate some form of information gathering into on-going management. The suggested approach is to couch management decisions in the form of hypotheses, to implement the management decisions and then to test the hypotheses using monitoring procedures. This empirical approach to the study of process should lead to an incremental improvement in knowledge and understanding and, therefore, in subsequent planning and management. Figure 1 indicates how this form of experimental management (see Holling 1978) might operate.

Secondly, there is a need to establish procedures to evaluate whether management objectives are being met. For example, an agency charged with the responsibilty for conserving the State's flora and fauna will need to be able to demonstrate that the complete array of species ie. the biodiversity is being conserved. An agency responsible for management of a living, natural resource must be able to show that the rate of exploitation is sustainable. A third example is where resources are expended to rehabilitate a degraded area, then it is necessary to be able to report success or to justify a request for additional resources. These information needs can be met by establishing programs to monitor outcomes of management activities.

There will also be an increasing demand for monitoring-type data for State of Environment Reports and to meet other accountability requirements. In this context, it is worth noting that the recent ratification by Australia of the Convention on Biological Diversity imposes a duty to ensure that the biological diversity of the Nation is conserved, and that any utilisation of the biota is on a sustainable and equitable basis. This means that there will be continuing efforts to document the range of organisms including aspects of their genetics, and to document the assemblages of organisms (communities) and the ecosystem processes that support those assemblages. More particularly, it also imposes responsibilities to monitor the environment to ensure the persistence of biological diversity and to institute remedial action in the event that threats to persistence are perceived (see particularly Article 7 of the Convention, also Articles 8, 9, 10; ANZECC 1993).

Thirdly, there is a need to maintain an up-to-date knowledge of the distribution of the plant and animal species and their habitats throughout Australia. This can be achieved by establishing a network of biogeographic benchmark sites across the country coupled with a program for resurvey of those sites on a regular (if infrequent) basis. Monitoring of benchmark sites will also provide some insight into rates and directions of change. If a network of comparable sites is established throughout the State, the combined results will make it possible to distinguish general trends from localised fluctuations.

Setting objectives for monitoring

As with all scientific programs, it is important to have clearly stated objectives at the time of commencement. The framework of environmental monitoring developed by Wolfe and O'Connor (1986) and Wolfe *et al.*(1987) (both in Spellerberg 1991) provides as useful starting point for setting objectives for monitoring projects. .They have identified three general categories of environmental monitoring, each with a characteristic temporal and spatial scale: compliance monitoring to ensure that activities meet statutory requirerments, hyothesis testing (or model testing) to check the validity of assumptions and predictions (this would include the monitoring which is part of experimental management), and trend monitoring which may identify large-scale changes including those resulting from interactions of multiple factors. However, it is possible, and probably desirable, to design all individual monitoring projects to test hypotheses For monitoring projects, this can probably best be done through devising appropriate hypotheses to test. There are at least three advantages in adopting this approach. Firstly, it helps to link monitoring to actual management issues. Secondly, it simplifies the task of deciding on target organisms and/or environmental parameters to be monitored. Thirdly, it ensures that monitoring is accorded recognition as a legitimate scientific pursuit and is, therefore, given appropriate institutional support.

For compliance monitoring or meeting accountability requirements, an appropriate hypothesis would be one that relates back to the original management objective eg that there is no change to ambient levels of a pollutant. For experimental management, the hypothesis might be that the undertaking of the particular management action will not lead to any environmental degradation (say loss of topsoil or invasion by weed species). Where a resource is being utilized, such as in wildflower harvesting, the hypothesis might well be that the remaining, unharvested reproductive capacity is sufficient to maintain the population in perpetuity. For monitoring biogeographic benchmark sites, the appropriate hypothesis would be that there is no loss in diversity (species richness, equitability) within the native biota.

Designing individual monitoring projects

In order to develop any reasonable hypothesis to test using monitoring procedures, it is necessary to have some idea of what the likely impact or threat to the community or ecosystem might be. A provisional list of these, developed in the context of questions about the maintenance of biological diversity in the arid and semi-arid zones of Australia (Hopkins and McKenzie 1994), appears in Table 1.

Individual monitoring projects for testing hypotheses about impacts/threats will involve a variety of approaches and methodologies which, in each case, will reflect the nature of the specific problem. For example, if the hypothesis concerns erosion, the approach may well be to monitor the state of the soil crust and the A horizon using photography and measurements along fixed transects. If the hypothesis concerns effects of altered fire regimes on weed invasion, a direct sampling method would be used.

There will be a gradation of monitoring methods available for use at any particular site, and the choice of method or methods will depend on the objectives, logistic considerations including site access and funding.. For the example of monitoring biodiversity in the arid and semi-arid zone, some appropriate methods are indicated in Table 2. The simplest and most convenient of these is photography: it can give useful data over a long period provided there is adequate standardisation (eg. Noble 1977). Photographs are a very important tool for communicating the nature of changes that may occur over time. However, photographic monitoring has two principal disadvantages. It is often difficult to explain the changes that may be interpreted from photographs. Secondly, photography does not readily produce quantitative data suitable for incorporation into a computerised data base. This latter disadvantage may be remedied through the use of horizontal stereo-photography in conjunction with the Micro-photogrammetric System (MPS-2), the system used for the latest general forest inventory in Western Australia.

As a starting generalisation, the methods that would be used for monitoring a particular component of the environment at a particular site would be those that would be used to sample or survey that component at that site on a one-off basis, taking into account the need for standardisation. The methods outlined in Table 2 reflect this: many are the methods that have been developed for biogeographic survey for Western Australia (eg see McKenzie *et al.* 1987, 1989).

On-ground monitoring

Because of the need to ensure repeatability, the program for monitoring should centre around a system of fixed ground sites (permanently marked) that are sampled using standardised methods. For the biodiversity monitoring program, it is envisaged that the system would have two components: the biogeographic benchmark sites which would be sampled comprehensively, supplemented by a series of sites where only key elements of the environment relevant to the particular problem and hypothesis are sampled. The layout that is proposed to be used at each sample site is given in Figure 2 (from Hopkins *et al.* 1987). This involves the use of nested quadrats with quadrat size determined on the basis of size and density of the organisms or parameter to be monitored. For example, for soil organisms, a 1m x 1m may suffice. In contrast, during the biological survey of the Nullarbor region, 2 km x 2 km quadrats were used (McKenzie *et al.* 1987, 1989) while for survey of the more geologically complex eastern Goldfields, 0.25 km x 0.25 km quadrats were used (BSCWA 1984).

Minimum standard installation for on-ground monitoring

There is usually a minimum data set that is necessary to interpret results from any monitoring program. For example, monitoring biological diversity will need to be accompanied by monitoring of key environmental attributes and disturbance events. Stochastic events such as falls of rain and fires are particularly important triggers of processes in most environments; these kinds of events, therefore, must be recorded on a regular and continuing basis to permit interpretation of the biological monitoring data. Records of indicies such as greenness or photosynthetic activity derived from satellite imagery will be an important adjunct to traditional sources of data in providing some explanation of highly localised or patchy events at individual quadrats.

A minimum standard installation for a monitoring site should include rainfall and temperature data, and annual ground photography and satellite imaging.

Each site will also need to be permanently marked and comprehensively described at the time of establishment. The basic site description will include precise location information, altitude and other topographic data such as aspect and whether it is water and nutrient losing or gaining, details of substrate including geological relationships, description of the soil profile and salinity and other chemical attributes.

Remote sensing

Remote sensing including airborne methods such as aerial photography and videography, and satelite methods particularly multi-spectral scanning (MSS) and thematic mapping (TM) have potential for use in monitoring but this may be limited. The limitations arise on two fronts. Firstly, the objectives of most monitoring projects involves tracking species-scale phenomena; this requires species-scale rather than landscape-scale data. Secondly, there is a requirement to be able to implement remedial action promptly in the event that threats to the environment are perceived: experience to date has been that remote sensing has detected deteoration in quality of terrestrial environments at the point where it is (almost or actually) irreversible.

Satelite data have already found some uses in the arid and semi-arid zones of Australia (eg.Graetz and Pech 1987; Graetz *et al.* 1986). A promising technology is the use of airborne video scanners which can produce high precision (eg. 0.1m resolution) digital data of extensive areas at relatively low cost. It is highly probable that applications suitable for monitoring environmental processes will emerge in the present decade provided that appropriate questions are asked and research funds are made available.

Data management

A well designed record-keeping system is an essential component of any successful, long-term monitoring program (Hopkins in press). The data from the meteorological equipment, the information on disturbance events, the photographs, the biological monitoring data and the remotely-sensed data need to be gathered together and maintained in an accessible form, ready to be analysed. Ideally, they should be compiled in a Relational Data Base suitable for use with a Geographic Information System (GIS). This computerised data base should be designed to allow for ready analysis and display of results, and provision of observer prompts and feedback.

In addition, it is important to have a detailed record (archive) of all management decisions that may have some implications for the component of the environment being monitored, and the reasoning behind those decisions. This would include decisions to do.nothing. It is only by having access to this kind of detailed management information that results of monitoring programs can be unequivocably interpreted.

Systematic review and evaluation

To ensure that the monitoring program continues to be seen as relevant and useful, it should be designed to provide necessary and appropriate information to all end-users. Therefore, it is important to identify at the outset all the client groups, their specific information needs and the possible actions that they might take in response to adverse trends. For example, politicians and senior decision-makers in Government have the power to modify policies that impact on land-use; therefore it would be appropriate to provide regular State-wide summaries of the results of the monitoring program together with interpretations relating to land-use policy. Land managers, on the other hand, are interested in trends at a more local scale and can make more immediate but limited responses; for these users, results should be presented at least annually and in terms of land condition and potential productivity.

The cyclic process of planning and management is illustrated in Figure 1. This process provides for evaluation and subsequent review of policy and management strategies and plans.

Results of each monitoring project should be evaluated on an annual basis. The evaluation should take place following receipt of new data and should address the following questions:

i) Are the new observations reliable - have the data been correctly recorded and do they seem to make sense?

ii) Is the project continuing to provide information relevant to the objectives - should it be continued or discontinued?

iii) Are the results consistent or inconsistent with expectations - should there be a review of management policy, strategies or programs?

The responses to these three questions should be recorded on the files for each project and should also form part of the regular feedback to observers.

To ensure that the relevant results of the monitoring program are used in subsequent management decision-making, results of each project should be published on a 3-4 year interval. Project reports should be widely circulated. By bringing results to the attention of decision-makers and the public, it is expected that review of management policy, strategy and programs will become axiomatic.

In addition to the individual monitoring project reviews, there should be regular reviews of themes within the overall monitoring program. The timing of these thematic reviews should relate to reviews of relevant policy but it should not occur any less often than every 5 years.

Setting priorities

Despite the efficiency of the monitoring procedures, it would not be feasible to implement monitoring projects to evaluate every management action and to address every gap in knowledge immediately. It will be necessary, therefore, to establish priorities for monitoring.: this is a task that will best be done by environmental planners and managers in collaboration. Monitoring needs can be identified by both groups but only managers know the practical limits to what monitoring can be achieved. At the same time, planners generally have the broad perspective to enable them to rationalise monitoring needs between particular districts and regions. Some co-ordination is essential to minimise duplication in monitoring projects whilst ensuring that important issues are addressed.

Costs for on-ground monitoring

It is difficult to do more than indicate a ball-park figure for the cost of establishing and running a comprehensive program for on-ground monitoring program because each project is designed to test a particular, locally-relevant hypothesis. In addition, the actual monitoring will usually be integrated within normal management activities and so costs will be low and partly concealed.

Estimated set-up costs for a site to monitor impacts of grazing by sheep and cattle in the pastoral region of Western Australia are $ 700 - 1000 and annual monitoring costs are $ 5 - 700 (1994 dollars)(A. Holm, personal communication 1994). Costs for sites where information recorded includes more than soils and simple vegetation parameters may be as much as 20 - 50 % higher. For a system of 11,000 monitoring sites throughout the arid and semi-arid zones of Australia, the estimated costs are $ 9 - 12 M for setting-up and $ 6 - 7 M for annual monitoring (3 - 5 year rotation). Data management costs are additional.

These cost estimates are for a stand-alone monitoring system throughout that part of Australia most remote from scientific and technical support facilities They are, therefore, not to be regarded as representative estimates for the more general monitoring that might be proposed for metropolitan or near-metropolitan areas.

Is this cost justifiable? In making a case for the establishment of the Environmental Management and Assessment Program (EMAP) in the United States, it was estimated that annual expenditure on environmental regulatory programs (mainly various forms of compliance monitoring) in that country was in excess of $ 70 Billion. Yet, despite this level of expenditure and the massive volume of data collected, it was not possible to say whether or not the regulatory programs were effective in ensuring maintenance of the overall quality of the environment (US EPA 1990). EMAP is now in its developmental phase with over 200 scientists from a broad range of Government agencies, universities and research institutes and private organisations involved (Jones undated). It is anticipated that there will be a network of 12,500 new monitoring sites in addition to those already in place through existing programs. The literature suggests that the United States Government has accepted the need for a comprehensive and integrated, scientifically-based program for monitoring the state of living natural resources and has made the appropriate, substantial, financial commitment.

Is it possible to reduce the costs of on-ground monitoring? Firstly, certain costs may be reduced as a consequence of sampling design and the use of modelling techniques. For example, if sites are to be sampled on a regular, rotational basis, there is a choice between sampling all sites in a region in the same year or sampling a subset each year. The former sampling strategy is likely to be cheaper but it may not permit rigorous statistical analyses. The intensity of on-ground sampling may also be reduced through the application of techniques such as environmental domain analysis. Secondly, there is potential for rationalisation and cost-sharing through integration with other monitoring programs. For example, it might be possible to incorporate biodiversity issues within the existing State rangeland monitoring programs (WARMS see Holm *et al.* 1987) at little additional cost. And thirdly, there is potential for substituting remote sensing for some components of on-ground monitoring and thereby reducing field costs. This substitution is unlikely to be significant in the short-term, and in the medium to long-term it will depend on the identification of landscape-scale phenomena that are adequate and reliable indicators or surrogates of process at the species to communities/ ecosystem scale. For example, an uncoupling of the relationship between the vegetation greenness index and rainfall could trigger an alert of incipient land degradation and/or decline in biological diversity which could, in turn, lead to localised, supplementary, on-ground sampling.

Existing monitoring projects

Within Western Australia and Australia, a wide range of biophysical factors are monitored by many agencies and using different methods. Climate and weather monitoring is undertaken by the Bureau of Meteorology. Environmental agencies look at air and water quality parameters. The condition of vegetation on pastoral lands is monitored by managers using both fixed points with on-ground sampling methods and low level aerial photography, and attempts are being made to use multi-spectial scanning techniques (eg. Friedel and Shaw 1987 a,b; Graetz *et al.* 1986; Graetz and Pech 1987). Some of these agencies are using a common computerised data base management system, WARIS (Worldwide Application Resource Information System), which was developed by the Queensland Department of Primary Industries (see Walker *et al.* 1973).

At an even broader scale, global networks of environmental monitoring sites are currently being established in order to accumulate standardised observations on land, sea and air and to coordinate interpretation of the data (Dyer *et al.* 1988; Gwnynne 1987).

The Western Australian Department of Conservation and Land Management has developed a policy on monitoring entitled: *Reporting, Monitoring and Re-evaluation of Ecosystems and Ecosystem Management* (Policy No 28). The objectives of this Policy are:

*To study and record management decisions and their effects on CALM lands, and to incorporate the information so gained in subsequent development of policy and management plans.

*To maintain up-to-date records of distribution and status of the State's biota, and the management decisions that are made about that biota and about Departmental lands (and waters) and the consequences of those decisions.

*To provide a mechanism for systematically reviewing management policy and programs in the light of new information.
*To provide an on-going record system which will document changes in community species composition through natural ecological changes as well as management.

The policy acknowledges that present levels of knowledge about ecosystems and ecosystem processes are inadequate. It prescribes the establishment of a series of monitoring sites on Departmental lands (and waters) throughout the State and a program for systematic sampling of those sites. Management of Departmental lands will continue but the effects of management will be monitored. Results from the monitoring program will be assessed and used in making subsequent management decisions. In this way, the monitoring program will contribute to a gradual improvement in knowledge and in management.

Implementation of this policy is proceeding on a number of fronts. Firstly, a range of existing Departmental activities that fall within the concept of monitoring as described here are being reviewed to determine the how they can be better integrated. These activities include the regular sampling of forest inventory plots to gain information on tree growth rates, bimonthly reading of wetland depth gauges and sampling of water quality, monitoring populations of Noisy Scrub-birds at Two Peoples Bay Nature Reserve and several reintroduction sites through systematic recording of male territorial calls, and aerial survey of kangaroos. Secondly, a Monitoring Manual is being prepared. This will set out methods for sampling for particular components of the environment. And thirdly, CALM District and Regions are being encouraged to establish pilot projects so that they can become conversant with the concepts and methods involved in monitoring.

Benefits of the Monitoring Program

Monitoring can be an efficient and cost-effective means for gathering information about the resources being managed and the effectsof management actions on those resources. Through improving the publ;ic and scientific knowledge-base, it will.lead to gradual improvements in management.

The monitoring provides a framework whereby all management decisions and actions become accountable. This allows managers to identify closely with the work they are undertaking. Government Departments and private organisations will be able to show how they are achieving their objectives and, where the objectives aren't being achieved, how management policy, strategies and programs have been modified to improve the level of achievement.

With the concept of monitoring that is outlined here, much of the work will fall on the field managers. In trhis way it is hoped that monitoring will become an integral part of management. But the process of designing and implementing and analysing results from monitoring projects will also involve policy makers, planners and researchers. Monitoring can, therefore, become a focus for collaborative work within an organisation and between organisations that have common environmental goals.

As a further benefit, the monitoring program can provide a vehicle for public involvement in management. Local interest groups can be invited to participate in simple monitoring projects. They will learn more about the places and things being monitored and may well come to better understand the issues involved in environmental management programs.

Table 1. Impacts on and threats to biological diversity in the arid and semi-arid zones of Australia and proposed approaches to monitoring.

Impact/threat	Factor to be monitored	Monitoring method
Grazing and trampling by ungulates	cover/biomass of native vegetation	photograph, plant density, dimensions in belt transects, use Bitterlich gauge of spherical densiometer for cover estimates in quadrats, remote sensing
	intactness of soil crust and organic A horizon, geomorphological structures (including termite mounds), erosion and downstream sedimentation	photograph, Tongway method (shrublands), estimate along transect or in subquadrats, measure soil loss at fixed markers, sediment input into dams etc, remote sensing
	populations of palatable native plant species	census in fixed nested quadrats or along transects (also record reproductive output, seed bank size)
	populations of weeds and unpalatable species	photograph, census in fixed nested quadrats or along transects
	nutrients, nutrient cycles (loss through harvesting of livestock, erosion)	litter, soil and foliar samples coupled with biomass estimates, (record livestock offtake)
Grazing by native herbivores	cover/biomass of native vegetation	photograph, intercepts along line transect, use Bitterlich gauge or spherical densiometer for estimates in quadrats, remote sensing.
	populations of palatable native plant species	census in fixed nested quadrats or along transects (also record reproductive output, seed bank size)
	populations of weeds and unpalatable species	photograph, census in fixed nested quadrats or along transects
Altered fire regimes	availability of shelter, food resources for vertebrates and invertebrates	photograph, estimate cover and structure in quadrats or use intercepts along line transect,
	vegetation structure/physiognomy	photograph, describe in detail in quadrat using Bitterlich gauge or spherical densiometer for cover estimates, hypsometer for height estimates of trees
	population structures of native plant species	census in fixed nested quadrats or along transects, record reproductive output, seed bank size with seed traps, soil samples
	cover/biomass/populations of weed species	photograph, census in fixed nested quadrats or along transects, estimate biomass in subquadrats
Invasion by foxes and feral animals	in the case of herbivores, as for grazing and trampling by ungulates	see above
	predation on native animal species ie. populations of predator and prey species	estimate populations of predator and prey species using appropriate capture techniques, track/spoor counts, scat and gut content analyses
Harvesting of timber (*Callitris*, *Santalum* spp., and historical uses including fuel, pit props and fenceposts)	populations dynamics of harvested species	photograph, census in fixed nested quadrats or along transects, record reproductive output, germination and establishment
	availability of relevant shelter, food resources for vertebrates and invertebrates	photo, estimate cover and structure in quadrats or use intercepts along line transect

Exploration, mining and mineral processing	cover/biomass of native vegetation , intactness of soil crust, geomorphological structures, erosion and downstream sedimentation	photograph, plant density, dimensions in belt transects, use Bitterlich gauge of spherical densiometer for cover estimates in quadrats, estimate soil crust using Tongway method, measure sediment input into dams etc, remote sensing
	extent of spread of atmospheric pollutants (particularly SO_2) and effects on native plant species	photograph, soil, lichen and foliar samples, estimate specific effects along transect or in quadrats
	effects of solid and liquid tailings on native animal species	tissue analyses
	groundwater levels and quality, effects of changes on native vegetation	piezometer in bores, laboratory analyses of samples, estimate specific effects along transect or in quadrats
Visitor usage	cover/biomass of native vegetation , intactness of soil crust, geomorphological structures, erosion (trampling)	photograph, plant density, dimensions in belt transects, use Bitterlich gauge of spherical densiometer for cover estimates in quadrats, soil crusr in subquadrats with Tongway method, measure soil loss at fixed markers, remote sensing
	fire regimes	(see above)

Table 2. Proposed methods for survey and monitoring for components of biological diversity in the arid and semi-arid zones of Australia.

Component of the biota	Survey and monitoring method
Floristic assemblage	record within nested quadrats up to 400 m^2, occasionally up to 1000 m^2, with additional records of species in 0.25 - 4.0 km^2 vertebrate quadrat
Vegetation (physiognomy/ habitat)	photograph and describe in detail within 400 m^2 quadrat, occasionally up to 1000 m^2, with additional notes of unusual features in 0.25 - 4.0 km^2 vertebrate quadrat, record height and intercepts along diagonal line transect
Soil crust	photograph, record details along diagonal line transect through 400 m^2 quadrat.
Soil organisms	record details of geomorphological features such as termite mounds within 400 m^2 quadrat, sample using small pit traps in grid within quadrat.
Invertebrates	sample systematically using pit traps, light traps and foliar sweeping all habitats within 400 m^2 quadrat, sample other habitats occuring within 0.25 - 4.0 km^2 vertebrate quadrat including unusual habitats, record ant and termite fauna, land snails and/or other groups with reasonable taxonomy for use as indicators
Reptiles and amphibians	3 x sets of 6 pitfall traps with drift-fences within 0.25 - 4.0 km^2 quadrat, supplemented by opportunistic sampling and headtorching
Small mammals	3 x sets of 6 pitfall traps within 50 m drift-fences within 0.25 - 4.0 km^2 quadrat, supplemented by Elliott traps in moist habitats, opportunistic sampling, headtorching, predator stomach analyses
Large mammals	aerial survey supplemented with opportunistic observations within the 0.25 - 4.0 km^2 quadrat
Bats	record species using ultrasonic recording techniques supplemented by mist netting within vertebrate quadrat supplemented by records from caves, likely flyways and drinking sites
Birds	record during regular census times within 0.25 - 4.0 km^2 quadrat, with supplementary, opportunistic observations within the quadrat at other times