Options for long-term monitoring of arid and semi-arid terrestrial ecosystems in Australia[1].

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This paper presents options for monitoring biological diversity throughout the *c.*75% of the Australian continent which experiences a semi-arid to arid climate. It is prepared as the basis for discussion at a workshop at which it is planned to develop a comprehensive package of measures for monitoring biological diversity throughout the whole of Australia.

Approaches to monitoring at the species to communities/ecosystems scale are outlined. The estimated one-off cost of establishing a series of sites throughout the semi-arid to arid region is $ 35 M. A further $ 8 - 9 M will be required each year for on-going field monitoring. In addition, there will be significant annual data-management costs. Some cost reduction may be achieved through use of particular sampling methodologies, through integration with existing programs and through the use of remote sensing. Remote sensing will not replace the major on-ground sampling requirement.

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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 considerations of biological diversity.

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. It is, however, 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 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.

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.

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 Nation'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.

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 the Nation. This can be achieved by establishing a network of (biodiversity) 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 across the continent, the combined results will make it possible to distinguish general trends from localised fluctuations.

Biodiversity

Biological diversity refers to the variety of living organisms, the genetic information they contain and the communities of those organisms and the associated ecosystem processes. It is our living inheritance; it enriches our own lives and we have an obligation to ensure that future generations are able to enjoy it too.

Conservation of biological diversity is considered to be essential if humankind is to persist well into the future. Already we have glimpses of the ways in which naturally occuring organisms and biological/ecological processes are life-sustaining. In addition, the present biological diversity has the potential to provide solutions to the wide range of emerging environmental problems which are giving rise to the concerns for the future of the planet.

Whilst the inter-dependency between conservation of biological diversity and sustainable development has long been recognised by the environmental community (eg. IUCN 1980 and subsequent National and State Conservation Strategies), the issue received considerable prominence in the Brundtland Report (WCED 1987). That report identified the need for an environmental monitoring system to support improved decision-making about development generally. Special mention was made of monitoring biological diversity (in Spellerberg 1991, see also the discussion of international programs for monitoring discussed in that publication).

The Convention on Biological Diversity came into effect in Australia on 29 December 1993. The ratification of the Convention by Australia 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. 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).

The arid and semi-arid zones: the Great Australian Outback.

For the purposes of this workshop, Australia has been divided into a series of land-use zones. This paper is concerned with arid and semi-arid lands. However, the principles derived may well extend to other zones where environmental conditions do not permit cultivation on a sustainable basis because, for example, the soils are too poor and/or where similar land-uses take place.

The Atlas of Australian Resources (Plumb 1980) defines the arid and semi-arid zones as that area receiving less than 75 mm of mean wet season (?monthly) rainfall. Leeper (1970) provides an alternative definition as the area where the length of the growing period is less than 5 months. It includes almost 75% of the Australian continent - virtually all but the humid mountain and coastal areas. A map showing the extent of the zones is given in Figure 1.

Some additional areas of rangelands occur in the sub-humid zone and the monsoon zone ie. areas receiving less than 100 mm mean wet season (?monthly) rainfall (Plumb 1980), or areas with a growing period of 5 - 9 months (Leeper 1970). Excluded from consideration are areas which are used for intensive forms of agriculture such as those under irrigation and cultivation, or dryland cultivation, or grazing where the original native pasture species have been replaced.

Also excluded from consideration are aquatic systems. These will be dealt with elsewhere. However, it is worth noting that aquatic systems make a contribution to biodiversity of the semi-arid and arid zones beyond the mere addition of their specialised biotas - many are refugia and/or centres of nodes richness of the terrestrial biotas (Morton 1990). They are are particularly sensitive to the effects of mismanagement of the land and, for that reason, they could well be used as sites for monitoring land management generally (eg. Clark 1990).

The arid zone is an area of 270 M hectares in the central and central-western part of Australia. The rainfall is very low (growing period less than 1 month, Leeper

1970) and highly variable (annual rainfall below average for more than 50% of years for much of the zone, Friedel *et al.* 1990; see also Nicholls and Wong 1990; Pickup and Stafford Smith 1993); in effect the area is too dry to have a distinct, predictable, rainy period. Surface water is scarce. Dunefields cover 35% of the zone and the remainder has a varied landscape of generally low relief consisting of sand plains and calcareous plains, salt lakes, low rocky hills and gently undulating stony downs (Plumb 1980). Ranges of mountains occur around Tennant Creek and Alice Springs in particular (Taylor and Shurcliff 1983; Hopkins *et al.* 1983).

The dominant vegetation consists of hummock grasslands (spinifex, *Triodia* and *Plectrachne* species) with tussock grasslands (mainly Mitchell grass, *Astrebla* spp.) and shrublands (mainly saltbush, *Atriplex* spp. and other chenopods in the south, *Cassia*, *Acacia*, *Eremophila* in the north) (Beard 1990; Carnahan 1990).

About 40% of the zone is used for grazing; this is mostly non-dune country. Beef cattle predominate but sheep, which make up 15% of the livestock units, are run on the wetter fringes (Plumb 1980; Pickup and Stafford Smith 1993). The livestock are completely dependent on the sparce native vegetation so that the mean stocking rate is low (Plumb 1980).

The semi-arid zone is an area of approximately 290 M hectares surrounding the arid zone and extending almost to the coast (growing period 1 - 5 months, Leeper 1970). It is generally too dry to support stable agricultural systems such as crops and sown pastures but just wet enough to produce plant growth sufficient for the maintenance of the open-range pastoral industry based on sheep and cattle. Broad plains interspersed with low stony ridges predominate although there are important upland areas including the western parts of the Great Australian Divide in Queensland, the Flinders Ranges and parts of the Pilbara and the Kimberley (Plumb 1980; Hopkins *et al.* 1983). Surface water is scarce and ephemeral but much of the zone is underlain by the Great Artesian Basin and other smaller acquifers (Castles 1992).

Mallee open scrub and chenopodiaceous shrublands dominate in the extreme south, giving way northwards to low open woodlands/ tall shrublands (mulga, *Acacia aneura*) interspersed with areas of saltbush (*Atriplex* spp.). Mitchell grass areas extend in a broken arc from northern New South Wales through western Queensland to the Kimberley. Northwards of these grasslands, low open eucalypt or melaleuca woodlands extend into the Monsoon Zone. Where the soil is shallow, or deep and sandy, hummock grasslands (spinifex, *Triodia* and *Plectrachne* species) are common (Beard 1990; Carnahan 1990).

About 86% of the semi-arid zone is used for grazing livestock with beef cattle mainly in the north and sheep in the south (Plumb 1980; Pickup and Stafford Smith 1993). Problems of land degradation resulting from overgrazing are very common (Pickup and Stafford Smith 1993).

Objectives for monitoring

As with all scientific programs, it is important at the outset to have clearly stated objectives. Wolfe and O'Connor (1986) and Wolfe *et al.*(1987) (both in Spellerberg 1991) 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, and trend monitoring which may identify large-scale changes including those resulting from interactions of multiple factors. This provides a reasonable framework for setting objectives. However, it is possible, and probably desirable, to design all individual monitoring projects to test hypotheses. 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.

Two general classes of hypotheses for projects monitoring biological diversity may be distinguished:
(i) those related to the long-term persistence of the biota or a selected portion of the biota. This class may include hypotheses relating to effects of management where the chosen management activity is the do-nothing option, and
(ii) those dealing with particular impacts on, or threats to, the biota. This class will include hypotheses relating to management and (sustainability of) utilization.

On-ground monitoring for persistence of biological diversity

Notionally, monitoring the persistence of the biota as a whole necessitates repeated sampling of the whole assemblage of organisms, or at least a significant proportion of the assemblage, at selected sites. There are practical constraints to this approach, however. This comprehensive approach is best done as an extension of existing or planned biogeographic surveys. Surveys should be designed, and survey sites established, in such a way as to permit subsequent resampling and the collection of comparable, time-series data. The integrated survey-monitoring program should be viewed as long-term, with resampling scheduled on a 10 - 15 year frequency and requiring a minimum institutional commitment of 50 - 80 years.

Whilst it is legitimate to focus on vulnerable species or groups of species or life-forms in monitoring programs (eg. medium weight-range mammals, Burbidge and McKenzie 1989; palatable herbs and grasses, Friedel *et al.* 1988; Friedel and James in press), it is important not to neglect other components of the biota. The less conspicuous components of the environment might be equally important and/or useful as indicators of change. For example, small organisms with short generation-times and/or high metabolic rates tend to be sensitive to short-term changes, whereas species with storage effects (see Warner and Chesson 1985) and/or long-lived individuals may exhibit greater inertia (*sensu* Westman 1986).

The program for monitoring persistence of biological diversity should centre around a system of biogeographic benchmark sites, sites that are permanently marked and comprehensively sampled using standardised methods. This system of benchmark sites may be supplemented by a series of sites where only key components of the biota such as indicator species are sampled.

The system of benchmark sites should be designed to provide a comprehensive cover of all biogeographic regions throughout the semi-arid and arid zones. Sites should be located to provide a sample of patterns of variation in regional biological diversity (Austin 1991; Margules 1989) so the precise location of each one needs to be carefully considered in the light of available knowledge of patterns in the species composition, climatic gradients and patterns of surface stratigraphy, soils and geomorphology. Consideration should also be given to locating some sites on or close to nodes of richness, refugia and ecotones as these may provide early insight into rates and directions of change (cf. Morton 1990; Hopkins *et al.* 1987).

Density of sites should reflect the nature of the regional environmental gradients. For example, survey sites used for the biological survey of the the Nullarbor Region (McKenzie *et al.* 1989) where climatic, geological and topographic gradients are gentle were at a density of 1 per 4,000 km^2 whereas sites used for the biological survey of the eastern Goldfields of Western Australia (BSCWA 1984) where the geological and topographic gradients are steep and their patterns are complex were at about twice that density. For the whole of the arid and semi-arid zones, this translates to between 1400 and 2800 sites.

Sampling should be quadrat based (see Hopkins *et al.* 1987). For the Nullarbor survey, 2 km x 2 km quadrats were used (McKenzie *et al.* 1987, 1989) whereas for survey of the more geologically complex eastern Goldfields, 0.25 km x 0.25 km quadrats were used (BSCWA 1984). It will be necessary to sample between three to six times at approximately four to six-monthly intervals to obtain a reasonably complete picture of the range of organisms at any site (Fox 1990; McKenzie and Hall 1992; Wiens 1981). Additional sampling may also be necessary in order to pick up responses in the biota to particular rainfall events (see for example, Mott 1972; Wilcox 1963) or fires (see, for example, Boulton and Latz 1978).

A summary of proposed survey and monitoring methods is given in Table 1. This is drawn from practical experiences of survey and monitoring projects in the arid and semi-arid zones of Western Australia taking into account relevant published work from elsewhere in these zones (eg. Margules and Austin 1991).

On-ground monitoring of impacts and threats

In order to develop any reasonable hypothesis to test using monitoring procedures, it is necessary to have some idea of what the impact or threat might be. A provisional list of these appears in Table 2.

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. So, 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.

Suggested approaches to sampling components of the biota in order to monitor impacts/threats are given in Table 2. Specific methodologies should be adapted from those used at the biogeographic benchmark sites bearing in mind the desirability of standardisation.

The density of sites for monitoring impacts on and threats to biological diversity in the arid and semi-arid zones will be dependent on the nature of the anticipated impact or threat. The most extensive impacts are due to grazing and trampling by sheep and cattle; for this it is estimated that there should be a minimum of 1 site per 500 km^2. If all the arid and semi-arid zones were used for grazing, this would translate to a requirement for 11,000 monitoring sites.

Minimum standard installation for on-ground monitoring

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 the arid and semi-arid zones; 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 in the arid and semi-arid zones 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 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.

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 of biological diversity throughout the arid and semi-arid zones. Burbidge (1991) has reported the **total** cost of the Nullarbor survey as almost $ 1 M (1988 dollars). This translates to around $ 24 M for establishing the system of biodiversity benchmark sites and $ 2 - 2.5 M annually for monitoring on a 10 - 15 year resamplimg schedule (1994 dollars). Additional resources would be required for data management.

Costs associated with monitoring impacts and threats are even more difficult to estimate 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 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, 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.

If fully implemented, a program for on-ground monitoring of biological diversity throughout the arid and semi-arid zones involving these two complementary approaches will cost around $ 35 M for establishment of the network of sites and initial data gathering and a further $ 8 - 9 M each year for on-going field monitoring. In addition, there will be significant, annual data-management costs.

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. Most States and the Northern Territory either have rangeland monitoring programs in place or are planning to establish such programs (eg. Holm *et al.* 1987). These programs could be expanded to address biodiversity issues 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.

Remote sensing

So far in this paper, references to the use of remote sensing have suggested that the role of these technologies for monitoring biological diversity in the arid and semi-arid zones is limited. This is largely a consequence of two things. Firstly, the objective of the proposed monitoring program 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 biological diversity 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.

These concerns aside, we acknowledge that remote sensing has already found some uses in the arid and semi-arid zones of Australia (eg.Graetz and Pech 1987; Graetz *et al.* 1986)and that technologies and applications continue to develop. It is highly probable that applications suitable for monitoring aspects of biological diversity will emerge in the present decade provided that appropriate questions are asked and research funds are made available. The discussion above on costings and remote sensing is suggestive of our view of the direction research should take, and developments in relation to the National Drought Alert Strategic Information System (Brook *et al.* 1992) are indicative of the scope for this to occur.

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.

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 National and State-wide summaries of the results of the monitoring program together with interpretations relating to land-use policy. Rangeland 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 rangeland condition and potential productivity.

Logistic considerations

Significant aspects of any national program for monitoring biological diversity are matters covered by the Intergovernmental Agreement on the Environment (Heads of

Government 1992). Of particular relevance are Schedule 1, Data Collection and Handling, Schedule 6, Biological Diversity, and Schedule 9, Nature Conservation. Finalisation of arrangements for implementation will require discussions at a senior Government level. In the meantime, the following observations are pertinent.

The Commonwealth Government, as signatory to the Convention on Biological Diversity, is responsible for ensuring that any obligations that the Convention imposes are met. As noted above, the Convention requires signatory States to monitor biological diversity. Therefore, it is reasonable to suggest that the Commonwealth Government should meet the costs of the proposed monitoring program.

Under the Commonwealth of Australia Constitution Act 1901, powers over land ownership, planning, development and management including matters of environmental protection and nature conservation reside with the States. The States and the Territories have enacted legislation to cover to these areas of responsibility and have established Departments to administer the legislation (Bates 1992).

All States and the Northern Territory have existing programs and infrastructure which could be used to implement a monitoring program of the type outlined in this paper. It is suggested that the most cost-effective approach to establishing a program for monitoring biological diversity would be to use these existing State and Territory resources, supplemented as necessary, and with some national co-ordination and assistance with data management.

Lastly, substantial portions of the Australian arid and semi-arid zones are owned or subject to claim or are managed by Aboriginal people. These traditional owners and managers have much to contribute to present-day management, including monitoring, of the region: their insights may enhance monitoring programs by identifying key processes and they will certainly provide valuable logistic support. There is an imperitive, therefore, to consult with Aboriginal people in the design of monitoring programs for the arid and semi-arid zones, as indeed there should be to consult with all relevant groups.

Concluding comment

The arid and semi-arid zones of Australia was the repository of an important part of the typically Australian biota at the time of settlement. Some very conspicuous elements of that biota, namely the mid-weight range mammals, the Night parrot, and the Thick-billed grasswren, have disappeared from the area or have become very scarce (Recher and Lim 1990; Saunders and Curry 1990) and there may well be other elements, including species of plants and invertebrates, that have suffered similar fates. It would seem that the biota is sensitive to fairly subtle changes to the environment in ways that are not yet clearly understood (see Burbidge and McKenzie 1989 ; Morton and James 1988). The area also continues to support a variety of uses including extensive livestock production. There are questions about the sustainability of some of these uses, and an important subset of those questions is the extent to which they may, individually or collectively, contribute to further declines in the biota.

The establishment of a comprehensive program for monitoring in the arid and semi-arid zones is warranted on the basis of the importance of the biota and its sensitivity to environmental change. At the same time there is a need for programs to monitor sustainability of some of the uses of the area. The commitment of time and resources that would be required to implement all these monitoring programs, considered separately, is considerable. There is, however, scope for cost reduction by integrating the various programs, by adopting some agreed methodologies and standards and data-sharing procedures. High priority should be given to exploring ways of achieving integration.

There are many critical issues that will need to be resolved before a full-scale biodiversity monitoring program can be implemented throughout Australia. There are important questions about sampling design and methodologies, the use of remote sensing, data base design and data ownership, ensuring that the results are used effectively, to name a few. There are lessons to be learned from the experiences in other countries (see Spellergerg 1991); of these perhaps the most useful at this stage might be the planning process adopted in the development of EMAP (US EPA 1990).

Consideration should be given to the scope for integrating Australia's biodiversity monitoring program with Unesco's Man and Biosphere (MAB) program. One of the four primary goals of MAB's Biosphere Reserves program is "... to provide areas for ecological and environmental research and monitoring ..." (Davis 1983; Vinogradov and Wiersma 1987). One of Australia's existing arid zone Biosphere Reserves, the Unnamed Conservation Park in South Australia, has already been selected as a site for the Integrated Global Background Monitoring Network (Wiersma *et al.* 1987).

Australians have special responsibilities in relation to the monitoring and management of the arid and semi-arid zones. Firstly, the Great Outback is an important component of the Nation's landscape - important for developing and maintaining the Australian identity and sense of place, and important to share judiciously with visitors. Secondly, these zones are unique in not having been subjected to thousands of years of livestock grazing. We have the option of conserving their biodiversity in something like their original state (Friedel and James in press). Thirdly, arid and semi-arid lands contain some of the poorest nations of the world and large areas where productivity is declining rapidly through the combined pressures of rapidly increasing human and animal populations. Australia, in contrast, is a politically stable, affluent, developed country with good scientific facilities. We should aim to develop techniques for monitoring and for good management that are relevant to countries throughout the Indo-Pacific region, Australia's zone of scientific responsibility, and beyond, and then assist with implementation. Finally, and following on from the third point, we have an opportunity in the Australian arid and semi-arid zones to develop monitoring programs that recognise the special relationships between traditional people and their lands, that involve those people in the implementation, and thereby to set a precedent for the design of such programs world-wide.

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Table 1. 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

Table 2. 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)

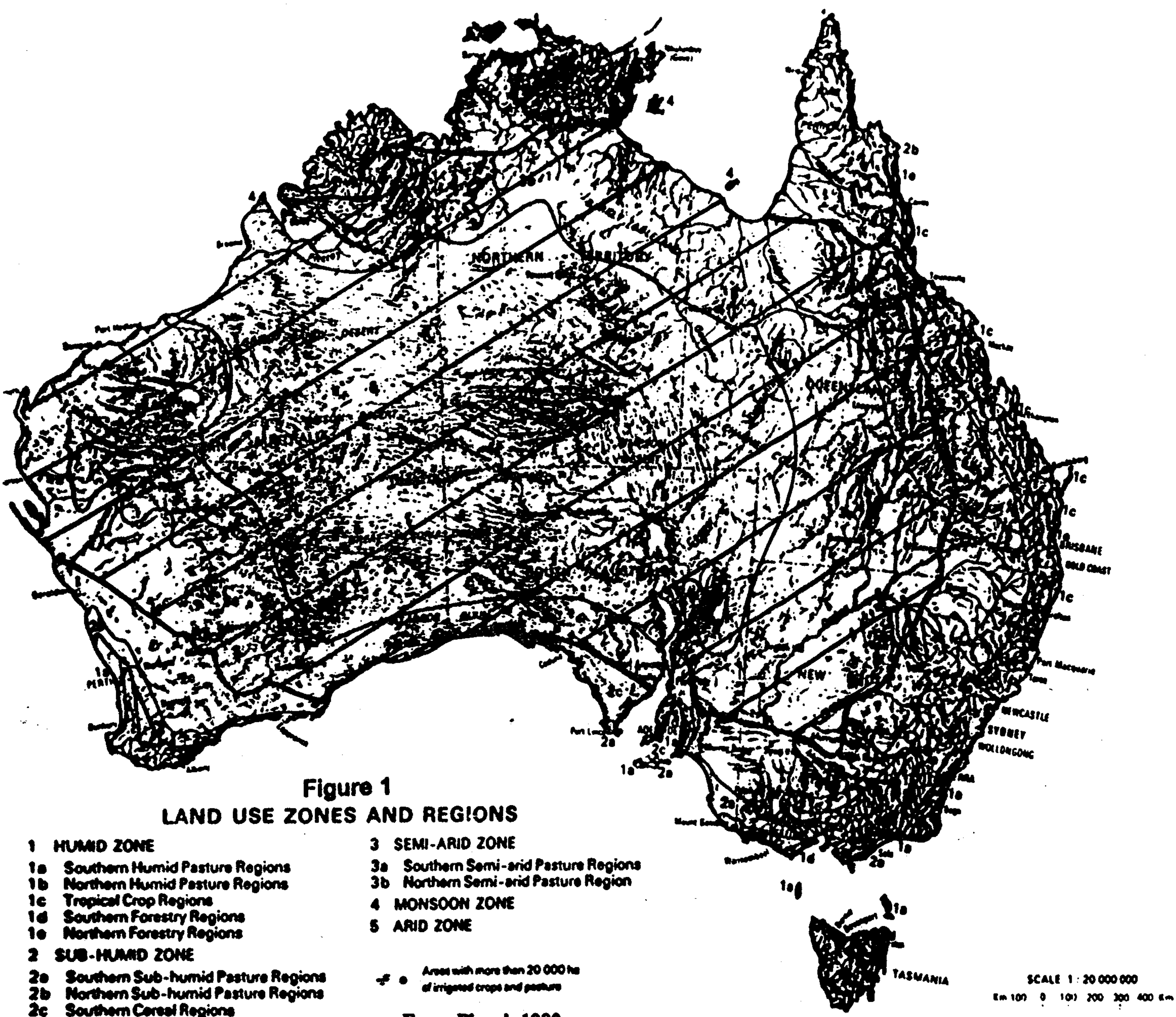

Figure 1

LAND USE ZONES AND REGIONS

1 HUMID ZONE

- **1a** Southern Humid Pasture Regions
- **1b** Northern Humid Pasture Regions
- **1c** Tropical Crop Regions
- **1d** Southern Forestry Regions
- **1e** Northern Forestry Regions

2 SUB-HUMID ZONE

- **2a** Southern Sub-humid Pasture Regions
- **2b** Northern Sub-humid Pasture Regions
- **2c** Southern Cereal Regions
- **2d** Northern Cereal Region

3 SEMI-ARID ZONE

- **3a** Southern Semi-arid Pasture Regions
- **3b** Northern Semi-arid Pasture Region

4 MONSOON ZONE

5 ARID ZONE

Areas with more than 20 000 ha of irrigated crops and pasture

From Plumb 1980