Environmental Indicators

For National State of the Environment Reporting

the land

Australia: State of the Environment
Environmental Indicator Report

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PREFACE

The Commonwealth State of the Environment Reporting system supports *the National Strategy for Ecologically Sustainable Development* and helps Australia meet its international obligations, such as those under *Agenda 21* and the OECD environmental performance reviews. The first independent and comprehensive assessment of Australia's environment, *Australia: State of the Environment 1996* was released by the Commonwealth Environment Minister in September of that year.

The next step in the evolution of the reporting system is to develop a set of environmental indicators that, properly monitored, will help us track the condition of Australia's environment and the human activities that affect it. To help develop these indicators, Environment Australia has commissioned reports recommending indicators for each of the seven major themes around which Commonwealth state of the environment reporting is based. The themes are:

- human settlements
- biodiversity
- the atmosphere
- the land
- inland waters
- estuaries and the sea
- natural and cultural heritage.

Clearly, none of these themes is independent of the others. The consultants worked together to promote consistent treatment of common issues. In many places issues relevant to more than one theme receive detailed treatment in one report, with cross-referencing to other reports.

Report authors were asked to recommend a comprehensive set of indicators, and were not to be constrained by current environmental monitoring. One consequence of this approach is that many recommendations will not be practical to implement in the short term. They are, however, a scientific basis for longer term planning of environmental monitoring and related activities.

These reports are advice to Environment Australia and have been peer reviewed to ensure scientific and technical credibility. They are not necessarily the views of the Commonwealth of Australia.

The advice embodied in these reports is being used to advance state of the environment reporting in Australia, and as an input to other initiatives, such as the National Land and Water Resources Audit and the Australian Local Government Assocation's Regional Environmental Strategies.

Summary

A key set of 29 key environmental indicators for the land is recommended for Australian state of the environment reporting at the national scale. Of these, 9 relate to accelerated erosion, 4 to physical change to natural habitats, 2 to hydrological imbalance, 3 to introduction of novel biota into habitats, 5 to nutrient and salt-cycling, and 6 to soil and land pollution. 33 supplementary indicators, which contribute to or help interpret the key indicators, are also identified. Monitoring strategies and approaches to interpreting and analysing each of the indicators are discussed, and possible sources of data are noted. Recommendations are also made for further development of environmental indicators for the land.

Aims of the study

- present a key set of indicators for land resources for national state of the environment reporting;
- ensure that the list of indicators adequately covers all major environmental themes and issues;
- examine each indicator in detail to ensure that it is rigorously defined and measurable and in an interpretive framework;
- identify suitable monitoring strategies for each indicator – including measurement techniques, appropriate temporal and spatial scales for measurement and reporting, data storage and presentation techniques, and appropriate geographical extent of monitoring;
- identify relevant data sources for each indicator, if these are available;
- define the baseline information that is needed to properly interpret the behaviour of the indicators.

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Executive Summary

Maintenance of ecosystem function is central to environmental integrity. Selection of indicators has therefore been based on their significance to this concept. In addition, reporting on a national scale requires an ecosystem, rather than a localised habitat, scale of monitoring and interpretation.

Ecosystem terrestrial functions conveniently divide into those which relate to geomorphological processes and those relating to biological processes and biogeochemical cycling. Biological processes are divided into those regulated by "producers" (chlorophyll-containing plants), "decomposers" (microfauna, bacteria and fungi) and "consumers" (invertebrate and vertebrate fauna).

Boundaries to earth processes are defined by the seaward edge of land, the solid geology of the earth's crust, and the atmospheric boundary layer. Other reports in this series deal with the indicators appropriate to human settlements, biodiversity, the atmosphere, inland waters, estuaries and the sea, and natural and cultural heritage; see p. 124 for a complete list of the reports. Some indicators that are appropriate to more than one theme, including this one, are treated in other reports; see Appendix 1.

Terrestrial processes may be altered by human actions, in which case an anthropogenic cause and effect may be distinguishable from the natural signature of the process. Indicators have been selected that can distinguish anthropogenic interventions from natural causes as unambiguously as possible. Some natural processes, such as erosion, are affected very significantly; this applies particularly across most land in sub-humid to arid regions.

Despite a very low overall population density, anthropogenic influences on terrestrial processes are found throughout the Australian continent because of widespread vegetation clearance, grazing, and subsequent disturbance to hydrological and nutrient cycles.

Six threatening processes have been used as the framework for choosing indicators. These are

- accelerated erosion;
- changes to natural habitats;
- hydrological disturbances;
- the introduction of exotic biota;
- disturbance of nutrient and salt cycling; and
- anthropogenic pollution.

The central role of vegetation is identified in many of the proposed indicators. Vegetation cover, extent, and condition are of critical importance in erosion control, nutrient cycling, habitat for biodiversity and maintenance of hydrological balance, and in providing the basis for our primary industries such as agriculture, forestry and horticulture. In addition, vegetation cover has a modifying influence on surface temperatures and local climate, as well as deep aesthetic appeal and value to tourism. Indicators that track all aspects of vegetative cover are central to the long-term sustainability of terrestrial ecosystems in Australia.

Indicators are described using a Report Card format in the text, with "key indicators" distinguished. These comprise the minimum set of indicators that, properly monitored, will provide rigorous data describing the major trends and impacts on the Australian environment. Indicators considered but rejected are listed in Appendix 1.

Indicators have been developed to reflect the anthropogenic pressure, the current condition, and the human response for each of these processes. One or more key indicators of Condition, Pressure, and Response have been identified for each process. These can be applied at a number of scales and to a number of land uses. Additional indicators have been proposed to supplement each key indicator, allowing a comprehensive interpretation across all land uses and jurisdictions.

A few proposed indicators are already operational for other purposes, but the majority, selected for the specific purposes of state of the environment reporting, will need further research and development before they can be used. In Table 1, indicators are identified by one asterisk where there is need for further research or by two asterisks where there is an urgent need for research, often because very little knowledge currently exists on the issue. (*) signifies that research is currently under way, but needs to be ongoing to ensure a worthwhile product is obtained.

Processes and biological pathways involved in environmental phenomena are complex, and uncertainties in our present knowledge about the relationships that societies have with their environment make it both inevitable and necessary for research to play a large part in this further development. A number of government-funded programs already support environmental research, which is spread across Commonwealth and State/Territory portfolios and agencies. Increasing commitment to the principles of ecologically sustainable development and international best practice requires that such programs work together more closely, and in partnership with the community and private sector. These opportunities should be seized upon in developing the ongoing research and monitoring framework necessary for such a complex and challenging task as reporting on the state of the environment.

Fewer than 10 indicators in the recommended list of 61 are sufficiently developed to be useable already, or without significant further research effort. Some of the most pressing research areas identified in the report are:

- the nature of the effects of more than one threatening process on environmental conditions;

- what the most sustainable trade-off responses are when several pressures affect various environmental domains;

- a suite of problems relating to the past and present use of agricultural chemicals, including detecting where they are used, what off-target organisms are affected, where they accumulate in the environment and in food chains, and the total chemical loading carried in different regions; and

- methodologies for extrapolating point-source data to various larger scales.

Most proposed indicators rely on being able to obtain data from government sources. Many traditional sources are now either being disbanded, cost-recovered between government agencies thus adding to total cost, or providing data of dubious and unreliable quality. Environmental monitoring and reporting is vitally dependent upon good, consistent, long-term record-keeping, and these trends are regarded as likely to jeopardise the ability to develop reliable and credible indicators in the national interest.

There are opportunities for harnessing the community monitoring activities of such programs as Landcare, Greening Australia and similar land-based actions more fully than is presently occurring, using the model developed for Waterwatch. This would entail Commonwealth assistance in setting up a similar coordinating mechanism, via the Internet, and providing consistent recording schedules. It would have great benefit for those indicators that depend on local knowledge and frequent observation — such as indicators of pests, weeds and other exotic species, and non-domestic vertebrate herbivore numbers — and in providing historical knowledge on past use of agricultural chemicals and checking ground-truthing reference points for erosion and vegetation cover.

Table 1

Summary list of the proposed indicators

Number	Name	C,P,R	Key national SoE indicator	Research and Development; * ,** or (*)
Issue 1	**Accelerated erosion and loss of surface soil**			
Pressure				
1.1	Change in total exposed soil surface contributing to erosion, as a percentage of land area per landcover region, stratified by major land use	P	Yes	*
1.1A	Percentage cultivated land area with exposed soils by catchment and agro-ecological region (AER)	P	No	-
1.1B	Area and percent of forests with significant soil erosion, by tenure and catchments	P	No	(*)
1.1C	Total area of open minesite bare ground, by catchment	P	No	(*)
1.1D	Area of unsealed roads and earthworks as a proportion of total land area, per catchment	P	No	*
1.2	Total grazing pressure relative to net primary productivity (biomass) by landcover regions and AERs	P	Yes	**
1.2A	Domestic vertebrate grazing pressure per landcover region, and AER	P	No	-
1.2B	Non-domestic vertebrate herbivores per landcover region and AER	P	No	(*)
1.3	Change in area that is impervious as a proportion of total area, by urban and rural catchments	P	Yes	*
Condition				
1.4	Surface soil loss index	C	Yes	*
1.5	Gullying index per major catchment	C	Yes	(*)
1.6	Change in dust storm index relative to number of high wind events by AERs and landcover regions	C	Yes	(*)
Response				
1.7	Percent, number and area affected of pastoral shires with stock at or below conservative stocking rates, by AER and landcover regions	R	Yes	*
1.7A	Area of pastoral properties reducing grazing damage by alternate use and feral animal control, by State and landcover region	R	No	*
1.7B	Percentage of shires destocking when feed reaches advised threshold, by AER and landcover region	R	No	-
1.8	Implementation of new drought policies	R	Yes	-
1.9	Percent of land managers using agreed Best Practice by land use and/or catchment	R	Yes	*(*)
1.9A	Percent cropped land with reduced tillage plus stubble retention, by AER	R	No	(*)
1.9B	Area of forested lands in which the legal framework encourages best practice codes of forest management, and the conservation of special environmental values	R	No	(*)
Issue 2	**Physical changes to natural habitats**			
Pressure				
2.1	Index of human accessibility related to landcover regions	P	Yes	(*)
2.2	Percent of each IBRA region lost to development relative to percent already affected by native vegetation loss	P	Yes	*
Condition				
2.3	Change in land use by catchments, AERs and landcover regions	C	Yes	(*)
2.4	Landcover change: proportion of each region covered by forest, wood, shrubs and grasses compared with 1990 baseline, by landcover and tenure	C	Yes	(*)
2.5	Extent of area by forest type, relative to total forest area, and location within catchments, by tenure	C	No	(*)

Table 1 (cont.) Summary list of the proposed indicators

Number	Name	C,P,R	Key national SoE indicator	Research and Development; * ,** or (*)
Response				
2.6	Fire control measure compared with natural fires, related to landcover regions	R	No	*
2.7	Rate of urban infill and increase in housing density relative to rate of urban expansion and rural subdivision into non-built-up areas	R	No	-
Issue 3	**Hydrological imbalance**			
Pressure				
3.1	Ratio of area of catchment under perennial: annual vegetation, as proportion of total catchment (report also by State)	P	Yes	*
3.2	Number of freely flowing bores per artesian basin (by State and AER) relative to numbers capped or regulated	P	No	(*)
Condition				
3.3	Percent area of land affected by dryland salinity, and acidity, by catchment and AER	C	No	(*)
3.4	Variation in plant water utilisation with landcover change	C	No	*
Response				
3.5	Index of measures to increase perennial vegetation cover, by area of catchment and AER affected	R	Yes	(*) *
Issue 4	**Introduction of novel biota into native habitats and communities**			
Pressure				
4.1	Rate of extension of exotic species into each IBRA, and of change in their abundance	P	Yes	*
4.1A	Number of reports of all, and of new, weeds, pests and diseases per AER and IBRA region	P	No	-
4.1B	Number of passenger and cargo entries per port or entry location by IBRA region	P	No	-
4.2	Impact of agriculture on conservation land, by AER and State/Territory	P	No	(*)
Condition				
4.3	Percent of total land area carrying different proportions of exotic families, estimated for each IBRA region	C	Yes	*
4.4	Weed infestation index: rate of spread x habitats affected	C	No	(*)
Response				
4.5	Effectiveness of reduction in damage caused by weeds, pests and diseases that are harmful at ecosystem scale, by IBRA regions	R	Yes	* *
Issue 5	**Nutrient and salt cycling**			
Pressure				
5.1	Total nutrient export Nitrogen, Phosphorus and Potassium from each AER and drainage basin	P	Yes	*
5.1A	Rates and distribution of Nitrogen, Phosphorus and Potassium accessions into each AER and drainage basin	P	Yes	(*)
5.1B	Sources of Phosphorus derived from land activities reaching rivers, by catchment	P	No	(*)
5.2	Terrestrial carbon (organic matter) loss rate by IBRA region	P	No	(*)
5.3	Change in area and location of salinised land, compared across regional catchments and AERs	P	No	*
Condition				
5.4	Net nutrient balance for major elements Nitrogen, Phosphorus and Potassium per year by land use mapped across IBRA regions and drainage basins	C	Yes	*

Table 1 (cont.) Summary list of the proposed indicators

Number	Name	C,P,R	Key national SoE indicator	Research and Development; * ,** or (*)
5.5	Rate of land carbon (organic matter) sequestration by AER and IBRA region	C	No	(*)
5.6	Change to net primary productivity by IBRA regions, grouped by catchments	C	Yes	(*)
Response				
5.7	Proportion of each forestry and farming system with stable nutrient balance by major catchment, AER	R	Yes	(*)
5.8	Estimated success of programs to reduce land carbon loss and increase sequestration, by landcover regions	R	No	(*)
5.9	Proportion of farmers using soil and plant tissue testing regularly, by industry and AER	R	No	(*)
5.10A	Percent intensive rural industries with effluent management cycling systems	R	No	*
5.10B	Percent urban settlements with and without tertiary wastewater treatment, by major catchment	R	No	-
Issue 6	**Soil and land pollution**			
Pressure				
6.1	Total immobile contaminant load on land area by catchment	P	Yes	*
6.2	Dollar value of pesticides sold per land use, by catchment	P	Yes	*
Condition				
6.3	Change in status of highly contaminated sites per catchment	C	Yes	(*)
6.4	Condition of environments surrounding high-radiation sites	C	No	-
6.5	Quality of mining operations relative to total mine sites, and regulation requirements, by drainage basin	C	No	(*)
6.6	Estimated area of pesticide application by catchment	C	Yes	* *
6.7	Rate of violations in residue levels (metals and organics) in harvested rural produce and foodstuffs	C	No	-
Response				
6.8	Reduction in emissions of land pollutants listed on the proposed National Pollutant Inventory, by drainage basin	R	Yes	-
6.9	Progress to a national set of baseline data on pesticide applications	R	No	*
6.10	Change in number of open landfill, industrial waste and orphan sites, by catchments and States/Territories	R	No	*
6.11	Implementation of integrated pest management (IPM) and agri-chemical risk reduction by rural industry	R	Yes	(*)

* = research undertaken, but supplementary research will be needed to provide information and analysis suited to state of the environment reporting needs.

** = little research available for current purposes, but the indicator is of acknowledged importance and research is urgently needed to provide an adequate basis for its development.

(*) = research is already being undertaken, but Environment Australia's requirements for this research need to be expressed and research support needs to continue for the indicator to become operational.

BACKGROUND

Commonwealth State of the Environment Reporting

In 1992, Australia's *National Strategy for Ecologically Sustainable Development* (Council of Australian Governments 1992) was endorsed by the Commonwealth, all State and Territory Governments and Local Government. The objectives of this strategy are:

- to enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations;
- to provide for equity within and between generations; and
- to protect biological diversity and maintain essential ecological processes and life-support systems.

The strategy called for the introduction of regular state of the environment reporting (SoE) at the national level to enhance the quality, accessibility and relevance of data relating to ecologically sustainable development.

The broad objectives of state of environment reporting for Australia are:

- to regularly provide the Australian public, managers and policy makers with accurate, timely and accessible information about the condition of, and prospects for, the Australian environment;
- to increase public understanding of the Australian environment, its conditions and prospects;
- to facilitate the development of, and review and report on, an agreed set of national environmental indicators;
- to provide an early warning of potential problems;
- to report on the effectiveness of policies and programs designed to respond to environmental change, including progress towards achieving environmental standards and targets;
- to contribute to the assessment of Australia's progress towards achieving ecological sustainability;
- to contribute to the assessment of Australia's progress in protecting ecosystems and maintaining ecological processes and systems;
- to create a mechanism for integrating environmental information with social and economic information, thus providing a basis for incorporating environmental considerations in the development of long-term, ecologically sustainable economic and social policies;
- to identify gaps in Australia's knowledge of environmental conditions and trends and recommend strategies for research and monitoring to fill these gaps;
- to help fulfil Australia's international environmental reporting obligations; and
- to help decision makers make informed judgments about the broad environmental consequences of social, economic and environmental policies and plans.

The first major product of this system was *Australia: State of the Environment 1996* (State of the Environment Advisory Council 1996), – an independent, nation-wide assessment of the status of Australia's environment, presented in seven major themes: human settlements; biodiversity; atmosphere; land; inland waters; estuaries and the sea; and natural and cultural heritage.

In *Australia: State of the Environment 1996,* each theme is presented in a chapter that follows the OECD (1993) Pressure-State-Response model (see also DEST 1994). The OECD P-S-R model describes, respectively, the anthropogenic pressures on the environment, conditions or states of valued elements of the environment, and human responses to changes in environmental pressures and conditions. In the land chapter of *Australia: State of the Environment 1996,* the pressures on the land were presented in detail, together with an account of the current condition of the land environment, and some responses to those pressures.

Australia: State of the Environment 1996 is the first stage of an ongoing evaluation of how Australia is managing its environment and meeting its international committments in relation to the environment. Subsequent state of the environment reports will assess how the environment, or elements of it, have changed over time, and the efficacy of the responses to the pressures on the environment. The next national SoE report is due in 2001, consistent with the regular reporting cycle of four to five years. In order to assess changes in the environment over time it is necessary to have indicators against which environmental performance may be reviewed. As pointed out in *Australia: State of the Environment 1996*:

> "In many important areas, Australia does not have the data, the analytical tools or the scientific understanding that would allow us to say whether current patterns of change to the natural environment are sustainable. We are effectively driving a car without an up-to-date map, so we cannot be sure where we are. Improving our view of the road ahead by enhancing the environmental data base is a very high priority. Our intended destination is a sustainable pattern of development, but it is not always clear which direction we need to take to get there."

The development of a nationally agreed set of indicators is the next stage in the state of the environment reporting process. Environmental indicators for the seven SoE themes were developed in parallel, with close consultation between the themes.

Environmental indicators

Environmental indicators are physical, chemical, biological or socio-economic measures that best represent the key elements of a complex ecosystem or environmental issue. An indicator is embedded in a well-developed interpretive framework and has meaning well beyond the measure it represents.

The set of key indicators must be the minimum set which, if properly monitored, will provide rigorous data describing the major trends in, and impacts on Australian ecosystems. It should include:

- indicators that describe the Condition of all important elements in each biological level in the main ecosystems;
- indicators of the extent of the major Pressures exerted on the elements; and
- indicators of Responses to either the Condition or changes in the Condition of the ecosystems and their elements.

The selection criteria for national environmental indicators are listed below (from DEST 1994); the set of key indicators should meet as many of these as possible.

Each indicator should:

- serve as a robust indicator of environmental change;
- reflect a fundamental or highly valued aspect of the environment;
- be either national in scope or applicable to regional environmental issues of national significance;
- provide an early warning of potential problems;
- be capable of being monitored to provide statistically verifiable and reproducible data that show trends over time and, preferably, apply to a broad range of environmental regions;
- be scientifically credible;
- be easy to understand;
- be monitored regularly with relative ease;
- be cost-effective;
- have relevance to policy and management needs;
- contribute to monitoring of progress towards implementing commitments in nationally significant environmental policies;
- where possible and appropriate, facilitate community involvement;
- contribute to the fulfilment of reporting obligations under international agreements;
- where possible and appropriate, use existing commercial and managerial indicators; and
- where possible and appropriate, be consistent and comparable with other countries' and State and Territory indicators.

In Australia, Aboriginal influence on grasslands and faunal populations has been widespread for at least 50 000 years, with recent reports from northern Australia possibly extending this period back to more than 100 000 years. Archaeological and palaeoecological evidence demonstrates that almost every part of the continent has been traversed or inhabited by Aborigines (Head 1989). European occupancy over much of the continent has had an impact for less than 200 years. In the period from first human occupancy until the eighteenth century, rates of change in ecosystems and their mode of functioning appear to have been relatively slow, with carnivores (including humans) and herbivores fluctuating in numbers that were restrained by the essentially arid nature of much of the interior and the modest fertility of nearly all terrestrial ecosystems. Thereafter, the speed of change resulting from the extraordinarily rapid spread of Europeans across the entire continent in a matter of a hundred years has been too great for the stability of the former state of ecosystems to be maintained, and almost all are in a transitional phase.

The 1996 baseline: our current state of knowledge and understanding

A map of the intensity of human occupancy (National Wilderness Inventory 1995) vividly demonstrates the areas that have been strongly altered by this recent colonisation. Almost all areas other than the great deserts and the most remote areas of the tropical north are laced with roads, trails, settlements and clearings, while the extent of widespread clearing and extensive alteration exceeds 80% of the land surface in much of the eastern and south-western corners of the continent, in rainfall zones greater than the 250 mm rainfall isohyet (Graetz *et al*. 1995). By 1996, the level of knowledge reported in the national State of the Environment Report was sufficient to make it possible to document the more visible symptoms of recent human occupancy and infer some of the changes that preceded these. It was not sufficient to allow a clear interpretation of many of these symptoms.

What we are now most concerned with is to learn more precisely how current human activities are affecting the ecosystem functioning of the supporting environments, what is being done about it, and whether these responses are ecologically effective. Those activities that we are more certain cause widespread environmental effects are either very visible (clearing vegetation, growing crops, building cities) or leave characteristic, unambiguous signatures (CFCs, localised radioactivity, high concentrations of nitrates in groundwater) which have become detectable as the result of rapid advances in analytical chemistry and physics over the past forty years.

One of the vexing problems confronting us in identifying clear indicators of such impacts is the fact that many human activities leave effects similar to those left by natural processes (algal blooms, turbidity in surface waters, acidification), or do not have an immediate, detectable effect (secondary salinity). Equally, many phenomena that are reported are not easily explicable and may have either natural or anthropogenic causes; for example, red tides, faunal epidemics, fluctuations in species numbers and fluctuations in seasonal conditions. To help us identify which processes are explicable, and whether their causes are natural, human or a combination of both, we require some model or framework from which to select measurable features, and hence develop relevant and practical indicators.

If we can identify such unambiguous indicators, we may then be in a position to validly relate human and natural causes to detectable environmental changes and to the societal responses these evoke using the types of relationships postulated in the Pressure–State–Response framework (Adriaanse 1993).

What are land resources?

Land resources are defined as those terrestrial features that exist above mean sea level. They include the landforms that compose landscape elements (plains, valleys, plateaux, mountains, peninsulas, islands and basins), the soils developed from the regolith, or weathered rock zone, together with the vegetational cover and faunal biomass (including human population) supported by this. They differ from inland water and marine resources in that human populations live on land, creating their own environments, modifying and constructing managed ecosystems, and domesticating many other species for their own continued survival and benefit.

From an economic or political viewpoint, land resources comprise a nation's mineral and fossil fuel deposits, harvestable natural and farmed timber, crops, animals and fish. These are normally considered the extent of the natural stocks that make up the resource wealth. Recently this view has been broadened to include the natural wealth that exists in a country's water and soil resources, biota and cultural features (Ahmad *et al*. 1989; Daly 1988; Lutz 1993; Serageldin and Steer 1995). The initial attempt by the World Bank to provide a country-scale audit on such a basis ranks Australia in the top two of 160 countries, along with Canada (World Bank 1997). However, such preliminary and crude attempts at assessment cannot yet tell us anything about the condition of those natural stocks. Some of the assessments undertaken in Australia by the now defunct Resource Assessment Commission to value natural resources have been used to weigh the relative value of mining and other developments in environmentally sensitive or heritage areas (Wilks 1990). In this report a broad view is taken, but the mineral and fossil fuel stocks, their condition and extent of exploitation are not included other than in terms of how their exploitation affects the surficial parts of terrestrial systems.

Many managed ecosystems have been established for a long time. Some of the oldest anthropogenic biomes are found among the grasslands of mesic climates, many of which have been substantially maintained and increased in area by human encouragement for periods of possibly 200 000 years in central Africa and western Asia, and up to 50 000 years in Australia, through various combinations of fire and herding of grazing animals. Agriculturally managed lands, progressively evolving into stable systems of domesticated plants and animals and later integrated into patchworks of repeat patterns of fields, paddies, orchards, settlements and woods, have dominated more-fertile floodplains and valleys in Asia, the Mediterranean basin and western Europe for between 2000 and 10 000 years. On this time scale, in contrast, Australia's managed land systems are actively changing very rapidly.

An ecosystem approach to indicator development for land resources

We must start with a few definitions. Terrestrial ecosystems are the focus of this report. They arise as the result of interactions between climate, topography, geology and biological organisms resulting in soil–vegetational associations. Other trophic levels — including faunal populations, food webs and keystone species — are here considered modulators acting on the particular ecosystem.

Earlier ecological attitudes considered ecosystems to have properties of quasi-equilibrium, where components show finely-tuned inter-dependencies and adaptations (Whittaker and Likens 1973; May 1973). Their characteristic signatures, reflected in their chemical and biological composition, were taken to be properties of particular component interactions (Whittaker 1975). When perturbation to a system occurred, a period of transition was identified, followed by a new set of state variables. Geochronology gives us many examples of such state–transition–new state phases in the geological history of the planet. The greatest is the evolution of terrestrial life forms that changed the composition of the atmosphere. The Archean Era, when the atmosphere contained high levels of carbon dioxide, was dominated by marine life. Then in the Proterozoic Era green land plants started to consume carbon dioxide and oxygen increased in such proportions that new life forms, specifically adapted to oxygen respiration, arose (Margulis and Sagan 1986; White 1986). More recently, however, the temporal variation view of terrestrial ecosystems has been modified. It is considered that most ecosystems are inherently non-equilibrial, and do not progress in a gradual and orderly manner from pioneer to climax vegetation assemblages; rather, they fluctuate between states of punctuated equilibria. This view accounts for the sudden and catastrophic effects that periodically disrupt gradual ecosystem processes, "resetting" ecosystem sequences and interactions between component functions. Resilience, or the ability of the system to recover, is thus the most significant attribute of ecosystem sustainability (Holling 1986).

While this view is intellectually appealing, it poses problems for the development of indicators able to provide early warning of problems and detect change through trend analysis. If sudden collapses and unpredictable fluctuations are part of the normal pattern of non-equilibrating systems, then attempts to forecast future ecosystem behaviour from indicators that provide monotonic trends will be doomed to failure. A distinction may be needed between those processes that are dominated by physico-chemical reactions and those that are mediated principally by biological components.

Essential land ecosystem functions

Tansley (1935) coined the word ecosystem to refer to the combined plant and animal communities plus their physical environment, where the upper and lower physical boundaries are the boundary layer of the troposphere and the solid geology from which soil is derived. The essential processes that are universal through all ecosystems occur through three functional groups of living organisms; these are the primary producers, the consumers and the reducers.

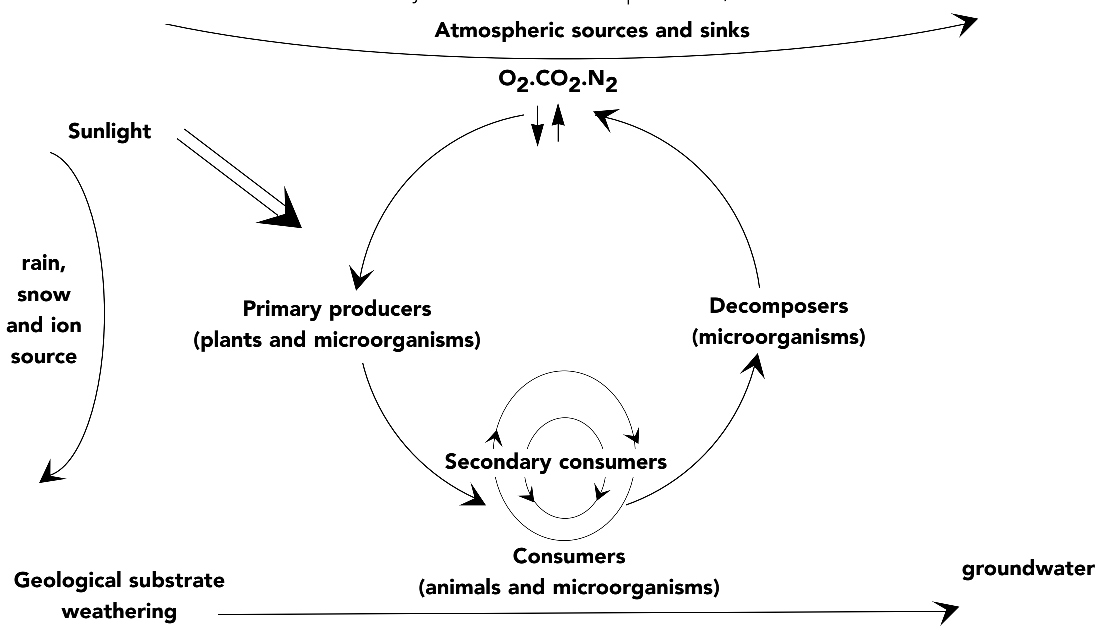
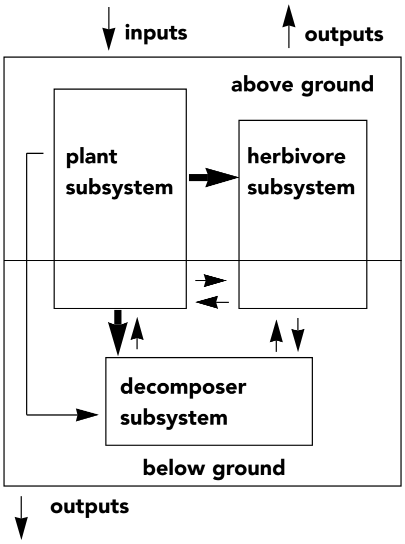


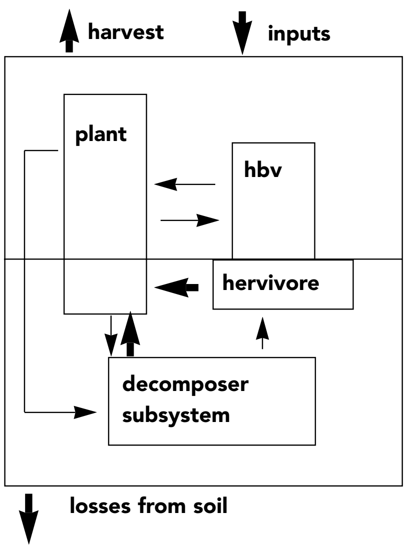
Figure 1. Simplified system to describe the flow of energy, carbon and nutrients in terrestrial ecosystems.

Plant material, synthesised from carbon dioxide with the help of solar energy, is consumed by animals and mineralised by micro-organisms. The key role of heterotrophic micro-organisms is clearly seen. Micro-organisms are extremely versatile, occur everywhere, and do not require plant or animal life for existence, whereas the reverse is true. They are principally found in soil — particularly in the topsoil where carbon accessions are more abundant — and their activity is controlled principally by water availability. Without them, all life as we know it would cease.

Ecosystem function is thus first and foremost characterised by the ability of soils to break down plant and animal remains, and liberate carbon dioxide, nutrients and water for plant functions. More than 90% of the essential microbiological functions occur in the surface five to fifteen centimetres of the soil, so that loss of this small mass of topsoil represents a much greater loss of ecosystem function than subsequent loss of the much larger mass of soil which constitutes the rooting volume for most plants. It is for this reason that the effect of erosion is only weakly indicated by measuring the mass of soil lost per unit time. Loss of surface cover (standing leaf and stem protection, fallen and dead leaf, bark, wood and debris, and the near surface root mass) is not merely a convenient surrogate by which to estimate erosion; its prevention is a critical factor in preventing erosion.



A NATURAL ECOSYSTEM



AN INTENSIVE AGRI-SYSTEM

Figure 2. Influence of plant diversity on ecosystem function with natural and intensive agricultural systems. (after Swift and Anderson 1994.) Thickness of arrows denotes the relative size of the exchange in terms of the control of ecosystem function. Note: carnivores are not included in their schemes.

Table 3 (see next section, "Indicators of ecosystem stability, instability and resilience") identifies biological processes and principal characteristics of the producer, decomposer and consumer groups of organisms, and describes in general terms the changes that occur in managed ecosystems that rely on a selected few domesticated species. Swift and Anderson (1994) have shown that the size of the three groups, in terms of energy, matter and numbers of interactions, also changes, as described in Figure 2.

Swift and Anderson note that the main difference between the natural and intensive agricultural systems lies in the level of plant control of the decomposer system. The decomposer system (within the soil) is very resilient in itself and will continue to function even under circumstances of stress when many species are eliminated because of the high levels of functional substitution and redundancy in soil micro-flora. However, lack of plant control will lead to an uncoupling, in space and time, between the nutrient availability produced by decomposers and the plant demand — which is why many agricultural systems are leaky with respect to nutrients and water. They point to the imbalance in C:N ratios in agricultural systems (typically about 10:1, rather than the >20:1 ratios found in natural systems), which does not allow for sufficient immobilisation of nitrogen by micro-flora.

A model framework for state of the environment indicators of land resources

Indicators of land resource condition need to be able to distinguish, in an unambiguous and cost-effective manner, between natural and anthropogenic causes of environmental change. Where natural processes operate in a chaotic, non-systematic fashion or on very long time scales, differentiation may not be possible unless a characteristic anthropogenic signature is detectable. The model shown in Figure 3 of the processes and variables operating in the environment provides a convenient framework against which to test the value of each proposed indicator from this perspective.

Terrestrial ecosystems form as the result of interactions between climate, geology and landmass.

Both chemical and microbial transformation processes are involved in the elemental cycles that are responsible for such ecosystems. The boundary conditions for a general model of these processes in terrestrial environments occur where exports or imports to and from the system are not balanced by reverse flows.

Geomorphic processes shape the landforms, and their activity forms the baseline measure of environmental condition from which anthropogenic influences should be assessed. A core geo-indicator checklist that measures gradual and catastrophic changes that occur in time-steps of less than 100 years at scales of 0.1–100 km has been developed by Berger and Iams (1995).

The phenomena and processes selected are indicators of:

- wind and water erosion;
- sedimentation and particulate deposition;
- chemical solution, dissolution and precipitation;
- volcanism and seismic activity;
- physical weathering and paedogenesis;
- wave action and coast formation; and.
- glaciation.

These have been used to provide a checklist in developing Table 2 (see next section), relevant to Australian conditions and any anthropogenic pressures associated with these processes.

Figure 3. Boundary conditions for earth processes.

Atmospheric Circulation *photo-oxidation, radiation, precipitation, aerial deposition*		
Fauna *ingestion, metabolism, excretion, respiration*		
Vegetation *photosynthesis, respiration, elemental extraction–deposition, combustion(fire)*		
Soil *microbial interactions, respiration, oxidation–reduction, solution–deposition, volatilisation, leaching*		
Terrestrial Landforms *erosion, deposition (slope, marine and fluvial geomorphic processes), evaporation, seismic deformation*		
[Marine]	Seaward Drainage	Inland Drainage
Regolith *chemical solution–deposition, leaching, mineral transformation*		
Groundwater *oxidation–reduction, hydrostatic pressure change, chemical solution–deposition*		
[Solid Geology, Volcanism]		

Life functions depend on, and interact with, solar radiation and atmospheric gases. The most critical elemental cycles are those of carbon, nitrogen, phosphorus, sulphur and water. Chlorophyll-containing organisms (mainly higher plants on land) photosynthesise carbon, hydrogen and oxygen in the presence of sunlight to produce plant tissue. Other important transformations occur through the mediation of soil biota. Without soil biota there would be no steady nutrient cycling as we know it, as wastes and residues from macro-fauna and flora would decay at much slower rates. Soil biological activity is responsible for cellulolytic decomposition, the mineralisation of plant-essential nutrients, and the ceaseless transformation reactions between organic and inorganic pools of nitrogen, sulphur, phosphorus and other plant-essential nutrients.

While micro-organisms are found adapted to every known suite of environmental conditions (including total anoxia, saturated salt solutions, extremes of temperature, high pressure and high radiation), the presence of comprehensive functional groups of micro-organisms capable of all essential chemical transformations can be a valuable indicator of ecosystem integrity. These functional groups include:

- oxidative–reductive cellulolytic decomposers;
- nitrogen transformers (nitrification, nitrogen-fixing, denitrification);
- phosphorus and sulphur transformers; and
- carbon synthesisers.

Indicators of Ecosystem Stability, Instability and Resilience

Current hypotheses and explanations

Evolutionary ecology should predispose us to consider ecosystem change inevitable and desirable, but public anxiety focuses on the possibility that the whole life-support system of the biosphere may be dangerously perturbed by our activities. On time scales relevant to human life spans this appears unlikely, as it would need some cosmic event that altered the atmospheric composition or solar energy received, or the earth's orbit. However, looking over the next one hundred years, and the scale of Australia, there is real concern that loss of landscape diversity may alter ecosystem functions (that is, the transfer of carbon, water and nutrients) permanently and adversely.

This is rather different from the more frequently expressed concern about loss of species diversity through habitat destruction, or loss of genetic diversity through fragmentation of populations, which occur at smaller scales of tens of square kilometres — rather than the hundreds and thousands of square kilometres implied by this report's concern with landscape function. Small-scale habitat fragmentation that most affects species-level biodiversity is dealt with in the biodiversity indicators report (Saunders *et al* 1998).

We still do not know, however, exactly how and why any change in biodiversity may alter the effective functioning of ecosystems, because we know little about the self-assembly and organisation of species in communities and the effects of different types of stressor on the resilience of these systems (Schulze and Mooney 1994). Intuitively, many feel that complex systems are more stable, and that complexity equals species diversity — a hypothesis developed by Elton (1958). Later ecologists have considered that stability equates with the resilience of the system — that is, the capacity to return to the original state after stress is removed (Conway 1981).

May's work (1973) demonstrating mathematically that the more complex the system the greater the amplitude in species number — whereby any initial instability tends to resonate, rather than be dampened down, over time — provided a counter viewpoint on the relationship between diversity and stability. Cases have also been observed where a few keystone species can exert a disproportionate degree of control over an ecosystem (eg. herbivore mammals or their predators, nitrifying micro-organisms, flammable tree species), and play a much greater role in preserving or altering ecosystem function than the general majority of species. Only recently, in experiments that deliberately altered species diversity while maintaining other conditions the same, has there been any evidence to support Elton's hypothesis. Tilman *et al*. (1996) have reported a case where, in a well-replicated experiment, grassland ecosystem productivity was reduced where altering species richness altered plant productivity and soil nitrogen utilisation. Their work may be viewed as corroborating the model of Swift and Anderson — that nutrient leaching losses (principally nitrate) are reduced where plant diversity increases because of greater nutrient capture and immobilisation in diverse communities with different morphologies and patterns of demand.

We may summarise some of the more established principles of ecosystem stability and diversity as follows:

- Many local diversity levels are the function of local immigration or extinction (as occurs in islands, or island-like isolated communities).
- The presence of trees and structured vegetation increases diversity through modification of heat and water clines.
- Contemporary earth is passing through a series of Ice Ages — which has raised extinction rates, with long-lived species extinction rates rising differentially at high latitudes.
- Moderate physical disturbance (eg. seasonal droughts, tropical storms) appears to increase diversity.
- Low-productivity environments are often more biologically diverse than high-productivity environments (eg. the south-western corner of Australia — and equatorial rainforests, with the highest speciation values in the world, have some of the most nutritionally poor soils).
- Destruction of specialised habitat is the principal cause of anthropogenic species extinction.

- The size of undisturbed fragments is most closely related to the preservation or eventual decline of species; the smaller they are, the greater the rate of loss.

- The more fragmented a habitat is already, the greater the number of extinctions will eventually be (Tilman *et al*. 1994).

For the purposes of this report, therefore, we identify those factors that are primary causes of change to ecosystem function (carbon, water and nutrient transfer). These are summarised below.

Primary causes of change to ecosystem function

- Human population density, technology level and activities.

- Frequency, size and severity of disturbances (fire, flood, hurricanes, grazing, clearing, volcanic dusts).

- Habitat fragmentation or extension by any of the above.

All of which may lead to:

- Change or shift in the relative size of energy, element and nutrient pools and water cycles.

Distinguishing natural causes and human interventions

Tables 2 and 3 show the features that result from natural and anthropogenic forms of environmental processes in Australia. In some cases these are clearly distinguishable, but in others no distinctive characteristic or signature is immediately recognisable (either by visual change or by measurable chemical, biological or physical response). Erosion, for example, is a natural process that shapes all terrain, is the cause of sedimentary rocks, and proceeds inevitably in all environments. Accelerated erosion, on the other hand, is the product of human interventions that remove vegetational protection from the earth's surface. It is the largest, best known and probably least quantified form of land degradation in Australia. The reasons for the lack of quantification are that it is difficult to distinguish from natural erosion, deposition also occurs at the same time from both natural and induced erosion, and detailed case studies that measure both the scale and the amount of erosion are costly, frequently requiring specialised tracer methodologies, and therefore rare.

Table 2

Comparison of geomorphic processes with analogous human interventions and their resultant features.

Geomorphic process	Resultant features	Human interventions	Resultant features
1. Wind erosion–deposition • in arid regions • along coasts • after fires and drought	• wind-pruned vegetation • dunes & dune-fields • deflation pans • stone deserts & rock fretting • dust storms	• clearing vegetation • cultivations and burning • overgrazing by stock	• trapped deposits in fences, roads • wind-scars in crops & fields • deposition features downwind on bare ground • bare ground
2. Water erosion–deposition • all regions except glacial • land dissection • sedimentary deposits & rocks	• valley floors & slopes • lake & coastal sediments • river channels & beds • alluvial plains, terraces, fans	• clearing vegetation • cultivations and burning • overgrazing by stock	• steep-sided gullies • rapid headward gully extension • estuarine sediment plumes • bare ground • increased suspended solids & turbidity • loss of A horizons from soil profiles
3. Chemical weathering • all regions except glacial • rock decomposition • solution–deposition processes	• karst limestone features • rock-joint enlarging • silcrete–calcrete layers • primary salt lake deposits • desert varnishes	• clearing vegetation • draining and flooding • annual for perennial species • altered hydrological regime	• secondary salinity features • rapidly acidified soils & water • high metals, N,P,S salts in groundwaters • changes to hydrological regime
4. Mechanical weathering • thermal freeze–thaw • wetting–drying (link to 2 & 3)	• polygonal ground • exfoliation features • precipitates & gases	• surface soil manipulation • coverings (mulches) • clearing of residues	• alterations to thermal regime • changes to wetting–drying cycles • resultant variations to plant growth
5. Fluvial processes • action of rivers & streams	• flood-plain formation • channel migration, inception • meanders, ox-bows, gorges • slope retreat	• dams, weirs, levees, locks • canals, diversions, drains	• sediment distribution changes • landscape changes to hydrological regime • changes to flow regime
6. Fire • from lightening strikes • mainly tropical–subtropical • dry-season incidence	• fire-adapted species • extensive grassy savannas • infrequent, extensive scars	• fire to stimulate grasslands • arson • controlled burning • greater than summer incidence	• grasslands beyond climatic range • distribution beyond tropics • frequent, localised, close to roads, houses
7. Wave action • all coasts • wind and current influenced	• beach formation • coastal features; spits, bays, • wave-cut platforms, tied islands, • lagoons, off-shore bars	• groynes, moles, harbours, • excavations, especially round • estuaries & bays with cities	• changes to coastal features • altered sediment distribution • earthworks and structures
8. Glaciation • in mountains • in glacial regions • glaciations	• corries, hanging valleys, • moraines, erratics, eskers • changes in sea level • soil re-formation	NOT APPLICABLE	NOT APPLICABLE
9. Volcanism and seismicity • edges of tectonic plates • active mountain-building zones • major fault-lines	• volcanoes, rift valleys, • faults, uplift blocks • ash deposits, soil formation • lava & mud flows, hot springs	NOT APPLICABLE	NOT APPLICABLE

Table 3

Comparison of biological processes with analogous human interventions and their resultant features.

Biological process	Resultant features	Human intervention	Resultant features
10. Carbon cycling • assimilation by plants • biomass decomposition • food chain sequences • respiration • volcanic emissions • carbonate sedimentation • lightening/photolysis • coal, oil deposition	• organic biomass–plants • soil organic matter • floral & faunal communities • stable atmospheric composition • fluctuating atmospheric composition • carbonate rocks and soils • trace gas changes • coal, oil, gas deposits • high CO_2 in soils	• fossil fuel burning • vegetation planting & clearing • animal herding & harvesting • firing vegetation • ploughing, seeding etc. • landfill operations • manufacturing	• fluctuating atmospheric composition • changes in soil organic matter • savanna grasslands • fields, crops, large human populations changes to greenhouse gases • plastics, pesticides, C-based chemicals • waste dumps • change in species distribution • forms of acid rain, acid *waters*
11. Nitrogen cycling • fixation by algae • plant uptake of nitrate etc. • leaching through soil • adsorption on clays • nitrification–denitrification • biomass decomposition • food chain sequences • volcanic emissions • rock formation	• organic biomass–plants • soil organic matter • floral & faunal communities • sediments and rocks • stable atmospheric composition • trace gas changes • fluctuations in N-oxides	• vegetation planting & clearing • animal herding & harvesting • firing vegetation • ploughing, seeding etc. • landfill operations • manufacturing processes • culturing bacteria for N-cycling • fertiliser application	• fluctuations in N-oxides • changes in soil organic matter • nitrate leaching • N-oxide fluctuations • greenhouse gas changes • rapid increases in cereal food production • forms of acid rain • groundwater contamination • changes in species distribution
12. Essential element cycling* • microbial transformations • plant uptake • biomass decomposition • food-chain sequences • rock & orebody weathering • inorganic–organic forms • volcanic emissions • geological time-scales *(Ca,K,P,S,Fe,Mg,Mn,Zn,Cu, Co,Se,Mo,B)	• metal ions throughout food chain • natural variation in concentration • locally adapted organisms present • soil acidification by plants • resorting of elements vertically in soils • geological space–time deposition gradients. • biological origin of Ca, P, S deposits	• vegetation planting & clearing • animal herding & harvesting • firing vegetation • fertiliser application • manufacturing processes • mining, metals dispersion • landfill & waste disposals	• biotic toxicities & deficiencies • increases in food production • water contamination (blooms) • shifts in soil functional flora • atmospheric & water pollution • new food chain pathways for metals • waste dumps • altered ratios of soil metal ions
13. Producers • chlorophyll-containing plants • photosynthesis • 3 pathways (C3,C4,CAM) • leaf area dominated	• LAIs 1–8 across most lands • seasonal new leaf production • adaptations to drought & fire • wide range of habitat adaptations • wide range of defences to predation • high degree of endemism	• domestication of plants • specific organs selected • trees for timber, fruits, nuts • grass species favoured • monocultures selected • synchronised ripening	• larger fruiting organs • totally exotic species • fruits, seeds harvested & removed • escapees form weeds • more annuals than perennials • managed landscapes
14. Reducers • bacteria, fungi, soil biota • faster in wet, warm conditions • slower in cold or dry conditions • soil mesofauna predate	• ubiquitous in all environments • adaptations to all complex molecules • abundance limited by C (or S) source • fungi more in wood, bacteria in protein	• reduced C substrate • reduction in saprophytes • N and P flora inoculated • fertilised farm soils	• microbial biomass responses • shift in functional groups • rhizosphere pops. increase • more bacteria : fungi
15. Consumers • humans at top of chain • few other carnivores • herbivores ubiquitous	• hunter-gatherer for +50 000 yrs • low population densities? • migratory habit, related to vegetation • native vertebrates adapted	• exotic herbivores introduced • rapid spread, few predators • permanent clearing of veg. • annual export of plant matter • permanent human colonies	• increased population densities • humans the major carnivorous predator • increased total herbivore load • reduced carbon store • urban environments around coasts

Clear and unambiguous distinction between the natural and anthropogenic pressures that are occurring in the same ecosystem can be obtained where adjacent areas are under different forms of land use — particularly where one of these is a non-disturbed form (conservation reserve) and the other significantly disturbed (farmed or grazed). The effects of logging, grazing or farming in the managed area can be assessed through comparisons of net biomass production, erosion and cycling of nutrients. Paired catchments are particularly valuable for this type of study, as in the classic studies of Likens *et al*. (1970) on the forested catchments of New Hampshire. However, true comparability is difficult to obtain, especially where the conservation area is an island surrounded by a virtual ocean of farmland or where the differentiation in land use has occurred because of an inherent difference in topography or soils. Non-disturbed ecosystems are notoriously under-represented in the lower-lying, more fertile agricultural farmlands of southern and eastern Australia, with conservation reserves averaging less than 1% of total farmland area in the IBRA biogeographical regions inventory (State of the Environment Advisory Council 1996).

Alternatively, comparisons can be made where linear physical or administrative boundaries separate otherwise comparable environments associated with different land uses. Distinctive examples in Australia at the scale required for national reporting occur either side of some State boundaries where clearing and tenure conditions have varied, either side of the animal-proof fences separating pastoral and untenanted rangelands, and either side of rivers where irrigation is practised on one side and not the other. There are some rather speculative, but interesting, examples where even rainfall is considered to differ on the two sides of pastoral fencelines because stock grazing has had such a major effect on cover as to alter land surface temperature (Lyons *et al*. 1993).

Direct monitoring of pressures and their impact has become institutionalised either where the issue is localised, the land value or industry impact is high, or a threat to human health is readily perceived. Monitoring is then a part of regulatory or statutory requirements — as is the case, for example, with nuclear reactors, petrochemical industries and wastewater disposals. Hence monitoring of pressures arising from introduced biota affecting agriculture, such as pests and weeds, and of pressures from manufacturing, defence and industrial activity such as radioactive wastes, effluent entering water supplies and chemical residues in food is more institutionalised than monitoring of pressures that result in accelerated erosion, changes to natural habitats or hydrological disturbance.

Interrelations between disturbance, spatial scale and time

Spatial

Conveniently, the national scale of reporting for Australia is the continent, with a spatial scale dimension of 6 x 10^6 km^2. Within-continental regions (as distinct from global or supra-national regional scales) may align with major catchments, climate-based biological zones or land-use regions, depending on the aspect of the terrestrial system being considered. Australia has 245 major catchments recognised by hydrologists, 10 major climatic regions conventionally recognised (AUSLIG 1983), and 11 major agro-ecological regions made up of 46 constituent agricultural–climate–terrain associations (SCARM 1993). These are the scales at which reporting is required.

Monitoring and measurements of terrestrial systems taken at finer resolutions must therefore be capable of aggregation or extrapolated integration to coarser spatial scales for reporting at the national level. Effective utilisation of process-based environmental science, based on what are effectively point-source measurements, constitutes a severe challenge. Two approaches are commonly used to overcome this difficulty. One involves developing a mathematical model in two dimensions that provides spatial boundary conditions to the legitimate extrapolation of the point-source data. The other is to use a combination of remotely sensed and ground-truthed data, with the remotely sensed data capable of comprehensive coverage of spectral-emitting phenomena and the ground-truthing capable of measuring quantitatively both those and other non-spectral phenomena in finer detail. Both approaches are required in estimating mass balances and fluxes of components in and out of a defined region, as envisaged in the ecosystem model described here.

Temporal

Environmental reporting is expected to be conducted on a regular basis, every 4 to 5 years. Ephemeral phenomena that leave no cumulative or permanent trace (eg. grasshopper swarms, or a single abnormally hot or cold season) will not be useful indicators of terrestrial change, even though they may be highly notable at the time. Very slowly acting changes or perturbations, on the other hand, may give rise to profound long-term change that may pass unnoticed for decades unless actively looked for — where a model predicts their existence, and an analytical method is sufficiently sensitive to detect them. Anthropogenically derived organic compounds such as pesticides and poly-aromatic hydrocarbons (PAHs) may persist in altered chemical form and in such small amounts that they are not detectable with contemporaneous methods of analysis, only being recognised as a problem to later generations when they accumulate in certain retentive environments or are exposed by a new method of detection.

Many anthropogenic changes to land condition are observable within a year or less, but others may take up to 100 years to express themselves — if they perturb the hydrological cycle, or have a small, cumulative effect on the chemical composition of a large land or water mass. Ideally, therefore, indicators will be based on measurable phenomena and processes that are sufficiently scientifically authenticated to allow natural causes to be separated from anthropogenic (if possible, through the characteristic and unambiguous nature of the anthropogenic signature) and have a sufficient signal-to-noise ratio for any trend to be detected within one to three decades.

Reporting framework and regionalisations used

Because the way we manage our land resources has impacts on other parts of the environment such as biodiversity and hydrological cycles, and on primary industries, different reporting stratifications are needed to address these.

In this report four regionalisations are used:

1. Catchments: There are 12 Major Drainage Divisions (MDDs) recognised in Australia by the Australian Water Resources Advisory Council, and these are subdivided into 21 when mapped on a continental scale by AUSLIG. As reporting units they have merit, but they are too large to be satisfactory monitoring units. They are composed of some 245 river basins or catchments that constitute the scientific and local monitoring scale, although institutionally they are organised into 77 water planning regions. The drainage basins and their eight groundwater counterparts may provide the principal reporting framework for the Inland Waters Indicators Report, but monitored information will be collected on a catchment basis. This regionalisation is used for indicators relating to hydrological disturbance and pollution, where pressure and response indicators should be viewed within a catchment context above all others.

2. Agro-ecological regions, as agreed by the Standing Committee on Agriculture and Natural Resources and used by the National Collaborative Project on Indicators of Sustainable Agriculture (NCPISA) project (SCARM 1993): This regionalisation is based on an alignment of Statistical Local Areas (or shires) with topographic features following early work of Laut *et al.* (1980), and is used for indicators relating to soil loss, nutrient and salt cycling and introduction of novel biota where agricultural practices can have most effect. A map of the spatial relationships between the Major Drainage Divisions and Agro-ecological regions for Australia has been produced by the National Resources Information Centre (NRIC) for NCPISA. Table 4 gives the proportion of each drainage basin overlain by agricultural land.

Table 4

Proportion of Major Drainage Divisions overlain by agricultural lands.

Basin	Percent	Basin	Percent	Basin	Percent
North-east coast	87	S. Australian Gulf	88	Gulf of Carpentaria	85
South-east coast	65	South-west coast	73	Lake Eyre Basin	85
Tasmanian	40	Indian Ocean	81	Lake Bancannia	94
Murray–Darling	92	Timor Sea (NW)	60	Western Plateau	32

3. Interim Biogeographic Regionalisation for Australia (Thackway and Creswell 1995): This total ecosystem classification based on "natural regions" combines biogeographical, environmental and vegetational regionalisations. In its most disaggregated form, it comprises 80 regions. After extensive consultation with all jurisdictions it has been adopted by the ANZECC Task Force on Biodiversity, and is used here for the indicators relating to changes to natural habitat and introduction of novel biota.

4. Vegetation structural categories of Specht (1970), referred to as the "landcover regionalisation": This classification was adopted by Carnahan for the Atlas of Australian Vegetation (AUSLIG 1990), and by Graetz *et al*. (1995) for reporting on landcover disturbance across Australia. It takes remotely sensed current information as its basis, and is used here for indicators relating to changes to erosion and loss of topsoil, and physical changes to natural habitats. In the form used by Graetz *et al.*, there are 34 categories stratified into two major zones across the continent — the Intensive Landuse Zone (ILZ) and the Extensive Landuse Zone (ELZ).

Biogeographical regionalisations are generally based on floristic assemblages and vegetation patterns first systematically developed by Specht (1970) and then adopted by Carnahan (AUSLIG 1990), Thackway and Creswell (1995) and Graetz *et al*. (1995) using digital Landsat imagery, and then matched to biophysical regions. They have different degrees of value for our present purposes. Those classifications based on vegetation type — using structural forms of height, spacing and density — are more suited to the continental-scale and ecosystem-function aspects of this study. A very detailed recent classification by Specht *et al*. (1995) based on endemic floristic composition, especially taking account of understorey flora and the endangered status of native species, does not use the altered floristic composition of much of the agricultural, peri-urban and urban environments, and is not suited to the reporting scale of this study. Those regionalisations that do take the altered state into consideration have been used as a baseline for measures of cover change and the extent of further plant alterations (tree planting, changes to crop and pasture distributions, extent and composition of exotics, and ratios of these to natives).

Many impacts resulting from human occupancy stem from how land is used. Land tenures are, in themselves, an indicator of the terms and conditions under which land is used by people, but also demonstrate their limitations. Many forms of "pastoral leasehold" tenure exist in Australia, each with different sets of conditions which lead to a range of anticipated and unexpected responses. A simplified classification recognised in the AUSLIG mapping categories distinguishes eight types of tenure across Australia.

Administrative boundaries and jurisdictions also influence the ways in which land is used and managed. Characteristic straight-line vegetational features which are so clearly identified on the remotely sensed mosaics of the vegetation of Australia follow State and property boundaries and reflect differences in past political decisions and attitudes to clearing. Thackway and Creswell (1992) used this approach to demonstrate the relative proportions of major vegetational communities represented in eight land tenure categories by six major land uses.

Land Ecosystems in the Australian Socio-Political Context

Population: settlement distribution and legal framework

Less than 200 years of European occupancy has been sufficient to establish some rural land uses and practices — such as static pastoralism — as traditional and normal through a combination of economic, social and political expectations. Other practices, such as native vegetation clearing, have now been reassessed and, considered unsustainable, are being abandoned. Cultural and political norms are likely to continue to change over the next hundred years, with rates of change in land use and demographic distribution even faster than in the past.

The minimum period for profitable return on investment means a period of at least 20–40 years is needed for an activity to establish. By then, additional investment, the influx of people, and the establishment of support services and infrastructure make it too difficult to change land use in any radical fashion. Unprofitable land uses may be masked by government interventions (subsidies) where the initial reason for the development was political, not economic (eg. soldier settlement schemes compared with gold mining). Changes to land use have normally occurred thereafter only through competition for land and market forces, or exhaustion of the resource on which the use depended.

Established land uses are supported by tenure arrangements that give particular rights, responsibilities and privileges to the occupants. While Australia has inherited a British legal framework, some Common Law features of land use that prevail in the United Kingdom have not been maintained, and legal features that were inherited from the colonial past have been retained. This is particularly striking with respect to leasehold lands, retained by the Crown, and publicly owned. Tenure conditions therefore form an important indicator of anthropogenic pressures on land resources. Changes to these tenure and title arrangements are indicators of human responses to land condition, although they may also be viewed as socio-political and economic pressures on the environment. Constitutional responsibility for land resources is split between Commonwealth and State powers. Since Federation (1901), the Constitution has confirmed the rights of States and Territories to manage natural resources within their jurisdictions. This has presented a number of problems, particularly for systemic aspects such as integrated catchment management and control of weeds, pests and diseases across administrative boundaries.

Effects of populations: settlement metabolic flows and total land use impact

Australian populations are low by world standards. European settlement has concentrated strongly in coastal areas, especially at estuarine mouths of flooded river systems of the eastern and southern seaboards, and more than 80% of the population lives on 1% of the land area. The following three categories of human settlement have been used by demographers, based on population density and services; their impacts on the environment are discussed in Chapter 3 of *Australia: State of the Environment 1996*. Urban settlements now functionally include many surrounding small settlements. Rural regions are defined as those with cleared agricultural areas. Remote regions are those whose populations live outside these regions (mainly in semi-arid and arid rangelands). Indicators for the direct impact of people on the environment have been proposed in *Australia: State of the Environment 1996*, pages 3-4, 3-5. Resource flow indicators reflecting the consumption of resource inputs (water, energy, food, forest products and land) are valuable, as is the use of an extended metabolism model to compare inputs with outputs of waste, as net metabolic flows (energy, water, food minus wastes) per capita, for urban, rural and remote settlements.

It must also be strongly emphasised, however, that very substantial changes to ecosystems have occurred in parts of Australia even with low population numbers and direct resource consumption through the impact of domesticated, feral and pest species associated with rural and remote populations, and through uncontrolled clearing for agriculture and forestry and construction of exploratory and communication tracks and roads. Indicators developed for land resources must be able to detect the impact that even low human populations can have over enormous areas through the indirect effects of those species that trail in man's wake and ecological processes thus disrupted.

Land tenure and titles, by land use

The effect of land tenure conditions on land resources strongly influences their environmental state, but terms and conditions are very variable among States and Territories, even for the same category of title. This issue is of such general importance that it should be further researched for Environment Australia's future needs in environmental reporting, and custodial responsibilities.

Categories of land used for mapping and reporting purposes in this report are:

1. Vacant Crown land.

2. Perpetual pastoral leases.

3. Freeholds: rural, urban, industrial, forestry, mining.

4. Limited-term pastoral, mining and other leases.

5. Aboriginal land titles.

6. Defence lands.

7. Nature reserves, conservation lands.

8. Reserved Crown land.

9. Multiple purpose public land (see Commonwealth, State and Territory gazettals on publicly acquired lands).

Those conditions which affect the environment most closely are the prescribed and proscribed uses and activities described in lease agreements. These may be separately negotiated in some instances almost on a case by case basis, but in general a hierarchy of values has been arrived at which places economic returns highest in priority.

Land value, natural resource value and environmental value

Valuations of land resources may be derived from estimation of the asset's income-generating ability, the land value in the marketplace (generally set by location, tenure conditions and recent sales), or the estimated value for government revenues and collateral insurance. Several research projects are currently attempting to develop assessment protocols for land value related to land condition and risk of land degradation (eg; CSIRO, CRC for Soil and Land Management, PM's Rural Financial Summit 1996 and Rural Adjustment Scheme Review DPIE 1997). Resource valuation is a well-developed discipline, but environmental valuation is in its infancy, with a few research projects (eg. sponsored by the Land and Water Resources Research and Development Corporation) and papers in journals such as *Ecological Economics.*

A number of resource inventories are institutionalised by government. These include regular inventories on mineral and petroleum deposits (AGSO and BRS), and annual reports on crops and other forms of agricultural production, domestic animal stocks, forestry plantations and fisheries (ABARE). Inventories of forest resources are of more recent origin, the National Forest Inventory having been established only in 1989, and Comprehensive Regional Assessments of forest resources are only being initiated now (eg. Malefant and Davey 1996). Historical progress in legislation, inventories, monitoring and assessment itself provides a reflection of community responses to the environment. Earlier twentieth century legislation and inventorial activities concentrated on commercial aspects of productivity and safeguarding agricultural production above all else. The current holistic approach embodied in Commonwealth, State and Territory actions — such as the New South Wales Integrated Catchment Management plans and the Comprehensive Regional Assessments of Forests — marks, in itself, a more inclusive attitude towards the utilisation of natural resources.

A number of proposals for other government-sponsored inventories, such as the National Rangeland Monitoring Strategy and the Land Resources Assessment Group's Soil Reference Sites, have been under consideration by SCARM. These may be reappraised in the light of the Land and Water Resources Audit's activities *(Natural Heritage Act 1996)*, but have lacked adequate funding to date.

Community-based data for national indicators

Some community-based programs are very successful in contributing to our knowledge of the environment, and many of these are catalogued in Alexandra *et al*. (1996). Some of the best-known operating nationally are Waterwatch, which now has the facility for entries to be logged onto an Internet web site, and the National Bird Census, providing information to the Atlas of Australian Birds. Programs such as Saltwatch, which operates in some States including Victoria, monitor specific issues such as stream salinity in late autumn.

Unfortunately, the opportunity for including many of the local land-based monitoring activities in national land indicators appears small at this stage. The most promising areas, where monitoring at local scale could be most valuable, would be in detecting and identifying new weeds and pests. Current monitoring of both floral and faunal pest species by under-resourced government agencies is acknowledged to be deficient in coverage and often inaccurate.

To date, however, no coordinating mechanism has been established to gather the information that is collected in a consistent and standardised format. Some monitoring projects are short-lived, or lack the funds necessary to record and collate data across jurisdictions. Even where there are national programs, as for example the National Landcare Program, collation and analysis of data contributed from individual projects has been of low priority, or an afterthought, contributing to problems of data quality and gaps. For this reason, none of the proposed indicators relies on community-based data gathering activities, although in several instances the quality of the indicator and its interpretation could be greatly improved if locally collected data were available.

Indicators of Human Impacts on Ecosystem Function

This section is arranged according to the processes that affect ecosystems, and the threatening, anthropogenic forms of these processes as they influence ecosystem function, as described in Tables 2 and 3. The processes that are threatening to ecosystem function are summarised under six headings in Table 5. Pressure, Condition and Response indicators for land resources have been developed for each of these.

Indicators have been selected according to the criteria developed from DEST (1994). (See p.9).

Appendix 1 gives a full list of proposed indicators for land from a range of international, national and other activities (OECD 1993; Pieri *et al*. 1995; Canadian Forest Service 1995; State and Territory proposed indicators, 1995–96; State of the Environment Workshop on land indicators, 1996 (unpublished)) that were considered for inclusion, against the above criteria, and the reasons for exclusion in the cases where these were not finally selected.

Table 5

Threatening processes to ecosystem function and their anthropogenic causes

1. Accelerated erosion, loss of surface soil:
- overgrazing and ground-cover loss
- bare soil exposure during crop production
- entrainment of nutrients and organic compounds with clay colloids in concentrated run-off
- land clearing and bare land exposure
- resulting in disruption of the organic matter part of the C, N and nutrient cycles, reduction in primary and secondary productivity, and external (other sector) costs.
2. Changes to natural habitats
- population expansion and technology advance giving rise to:
- deliberate clearing of vegetation for urban development, agriculture, plantations
- fragmentation of vegetational communities from road and rail, farming and peri-urban expansion
- chemical pollution of groundwaters, soils, surface waters and atmosphere
- drainage and loss of wetlands
- reducing the capacity of natural habitats to grow, reproduce, and complete food chains. Frequently these activities also affect natural selection and survival at or below species level.
3. Hydrological disturbance:
- vegetation change, reducing transpiration and increasing groundwater accession
- diversions and regulation of river flow, surface drainage from infrastructure earthworks, roads etc.
- reduced rainfall from desertification?
- sealing of land surfaces under buildings, roads and other impermeable surfaces
- excessive application of irrigation water
- groundwater pumping
- giving alterations of the distribution of water in the landscape, the dispersion and concentration of associated salts and nutrients, changes to land use and land values, and high preventative and rehabilitation expenditures

Table 5 (cont.) Threatening processes to ecosystem function and their anthropogenic causes

4. Introduced, exotic biota:
- widespread use of exotic, domesticated plant and animal species for agriculture and forestry
- migration of people between geographic regions
- import and export of animal and plant products with associated pests and diseases
- resulting in shifts in food webs, changes to vegetational communities and habitats, relative abundance of species, species and sub species creation and extinction, changes to land use and land values.
5. Nutrient and salt cycling changes:
- cultivation, harvesting and removal of plants and animals (agriculture and forestry)
- additions of fertilisers, lime, gypsum, organic materials
- clearing of vegetation and alteration of hydrological balance (see item 3 above)
- loss of ground cover leading to accelerated erosion and loss of topsoil (see item 1 above)
- localised concentrations from processing and industrial activities
- mobilisation and precipitation of metal salts through changes to soil wetness (see item 3)
- resulting in habitat alteration, adaptive change in fauna and flora, changes to land use and land values, net benefits to agriculture and forestry, net losses to other sectors and environment.
6. Anthropogenic pollution:
- storage and concentration of radioactive nucleotides (dumps, obsolete plant, fall-out)
- dumping of non-biodegradable metal, plastic, poly-aromatic hydrocarbon wastes
- prolonged and repeated use of agri-chemicals at high dose rates
- nil or low-grade treatment of bio-solids, animal wastes, industrial and domestic wastes
- resulting in concentrations of toxic levels of metals, nutrients, and derived organic chemicals that produce mutation and pathology in higher organisms. Long-term costs incurred by society through waste of materials, and in health, safety and ecosystem disruption.

Most of the major pressures affecting Australian land resources stem from the impact of either human settlement or unconstrained use of resources for primary production. Their effects are now quite well established, and have been documented in Woods (1983), Commonwealth of Australia (1993), Resource Assessment Commission report (1995), Tothill and Gillies (1992) and Hamblin and Williams (1995).

Although most pressures on Australian land resources are agreed upon, and their quantitative effects have been studied in specific cases, there is much less agreement on what are the most appropriate and relevant indicators. Rural and community organisations have focused on indicators that are appropriate at the local scale, with a strong focus on agriculturally relevant indicators or on a few readily identified features of soil and water quality (eg. earthworms, frogs, salinity). While being very valuable in influencing community awareness, these indicators do not scale up readily to regional or national needs.

Rationale for the selection of Indicators of Environmental Condition, Anthropogenic Pressure and Societal Response on Terrestrial Ecosystem Function

The Pressure–State–Response (PSR) scheme adopted for environmental reporting by some UN agencies and OECD countries does not suit all environments or member countries' stages of development and technology. Developing countries, and those in the semi-arid tropical and subtropical zones, frequently have greater problems of resource degradation than waste management and pollution; that is, their problems are those of source rather than sink. Australia's current environmental status, summarised in the *Australia: State of the Environment 1996,* falls into this category.

The PSR model is therefore now being used in a modified form within the State of the Environment Unit of Environment Australia, with condition of the environment receiving more attention, and the relationship between anthropogenic pressures and societal responses more clearly articulated. The original framework (Adriaanse 1993) implied strong causal relationships exist between pressure, state and response, but this is certainly not the case. Even in well-studied natural sciences there are substantial areas of uncertainty, particularly in the newer disciplines of ecological and biogeochemical phenomena. Relationships between many societal actions and reactions are not well understood, especially in this century when technological change and social mobility have been powerful drivers of the social norms (Bourke and Butler 1995; Burdge and Vanclay 1995).

The ecological consequences of human activities are also only partially understood (Treweek 1995); in many cases, it is a case of being wise after the event. This has led to advocacy of the "precautionary principle" as one of the principal tenets of Ecologically Sustainable Development (Commonwealth of Australia 1993). Pressure indicators have been selected where the ecological consequences of current actions are supported by scientific studies and well-tested hypotheses.

In this report we have therefore confined ourselves to focusing on those threatening processes which are well-known to have environmental impact, and in which changes to human behaviour will produce a desired effect.

Selection of response indicators has been based on the need for desired behaviour that may require attitudinal and legislative changes as precursors, but which do not, in themselves, give rise to changes on the ground. The existence of a piece of legislation does not necessarily mean that it is effective; implementation requires personnel and the machinery of government. Many country and provincial environmental reports that have been published over the past few years have been criticised for being deficient in their response sections. Work by the ANZECC task force on identifying a common set of indicators has also demonstrated that response indicators are the most problematic. On reason is that many desired goals may be best measured by the absence of an adverse effect; for example, the effectiveness of Australia's quarantine provisions is measured by the low number or absence of outbreaks of disease or pests. Another is that many required responses are political, requiring the overturning of past legislation. This is particularly contentious in the case of land and inland water resources, where alterations of tenure or changes to rural assistance schemes or to water rights are charged with political tension and involve significant financial penalties to vested interests.

Issue 1: Accelerated erosion and loss of surface soil

Indicators of Anthropogenic Pressure

1.1. Key Indicator: Change in total exposed soil surface contributing to erosion, as a percentage of land area per landcover region, stratified by major land use

Description

The change from one reporting period to the next in exposed soil surfaces contributing to erosion — including all surfaces that have less than full plant or ground surface cover, where there is a leaf area index of less than three. The composite key indicator is compiled from a number of components that separately measure the total catchment area with bare soil identified from remote-sensed imagery (excluding rock outcrops) composed of: 1. area of cultivated land with exposed soil (4.1.1.A); 2. area of eroding forest land (4.1.1.B); 3. area of exposed mine sites (1.1C); and 4. area of unsealed roads and earthworks as a proportion of total land area, per catchment (1.1D) — divided by the total area of the landcover region in each major land use class.

Rationale

Ideally, erosion should be monitored directly using sediment traps, and partitioning erosion by process (sheet, rill, gully, wind). This is not feasible in Australia, where the land area is too vast and the climate too variable for comprehensive ground-monitoring. Catchment sediment monitoring is progressively becoming established in the southern and eastern parts of the continent, but is very sparse in the centre, north and west. Remote sensing methods are being attempted for some districts, but are still not operational in most. We are therefore forced to accept a surrogate indicator that will provide information on the likelihood of erosion, and its anticipated provenance.

Erosion by wind and water is dominated by processes that operate on bare soil surfaces. Soil forms the source of the material being eroded in most Australian landscapes. This is the most important indicator of pressure relating to accelerated erosion, providing the information on the potential source of transported material. Bare features that do not contribute material to erosion, such as rock outcrops, sealed man-made surfaces and gibber (rock-covered) desert plains, would be subtracted from the total area of the landcover region being assessed. Indicator 1.3 (Proportion of catchment that is impervious) deals with those areas that contribute run-off separately. The land use stratification will then assist the interpretation as to whether erosion is solely natural, or a combination of natural and anthropogenic.

Monitoring design

To distinguish effects of natural and accelerated erosion, the monitoring design must include a time-series of areal change on adjacent (preferably paired) localities in the same climatic zone but under different land uses. Tenure categories provide the context for identifying study locations, with the control treatment being located on uncleared vacant Crown land, national park or reserve, or unoccupied Defence lands. Localities need to be of sufficient size for erosion processes to operate, and in particular to provide for sufficient fetch for wind erosion processes in the direction of prevailing and dominant winds, and for overland flow distances of up to several kilometres from watersheds. The size of bare ground areas under each land use selected should be measured regularly, preferably at the end of the dry season when potential erodibility is highest. Remote-sensed NOAA and Landsat data can be used to define the best time for interrogating the data, as well as providing some of the needed data sets. Time-series of at least ten years (southern half of the continent) and twenty years (north and central) are needed for any trend analysis to be undertaken.

Data sources

Remote sensing data sources: NOAA–AVHRR data and Landsat data. These provide the regular, operational framework for identification of the major areas of green cover (NDVI — from Environment Australia and DOLA), and the closer-scale reference sites via Landsat. Because of the difficulty in distinguishing woody perennial (non-chlorophyll biomass) from bare surfaces, remote-sensed data must be supplemented by ground-truthing. Specific erosion sites exist in some catchments, principally in south-eastern Australia, but these are not distributed in a representative framework for sampling across all climate zones. A planned set of soil and land reference sites under the Australian Collaborative Land Evaluation Program (ACLEP) (McKenzie *et al*. 1995) will monitor landform, soil and regolith, and will provide valuable information on erodibility factors in future. The largest network of monitoring sites regularly visited currently is that in the pastoral rangelands, where pasture condition is monitored in a program conducted by State and Territory primary industry and conservation agencies in collaboration with leaseholders (Table 6). These sites are important to indicators of vegetation type and condition, as well as to erosion.

Table 6

Site numbers and parameters of State/Territory rangeland monitoring schemes.

Number of sites	WA	NSW	QLD	NT	SA	Vic
1996	800	340	400	40	3000	20
1998	1700	340	800	200	5000	20
Summarised parameters:						
• GPS located	Yes	Yes	Yes	Yes	Yes	Yes
• ground-truth for satellite analysis	Yes	Yes	Yes	Yes	Yes	Yes
• season rating	NOAA	Yes	Yes	Yes	Yes	
• land unit	Yes	Yes	Yes	Yes	Yes	Yes
• soil surface	Yes	Yes	Yes	Yes	Yes	Yes
• grazing condition		Yes	Yes	Yes	Yes	Yes
• original vegetation	land use	land use	Yes	land use	land use	Yes
• woody cover	belt survey	belt survey	belt survey	belt survey	quadrat	
• herbaceous cover method	quadrat	quadrat	quadrat	quadrat	quadrat	quadrat
• frequency of observation	3–6 years	1 year	3–5 years	2–5 years	2–7 years	0.5–1 year

Prepared for NCPISA project by Alec Holm, AWA., July 1996.

The National Rangeland Monitoring Program, overseen by a sub-committee of the Sustainable Land and Water Resources Management Committee of ARMCANZ, manages this program, and reports to its own agencies. National reporting has been restricted because of the need for additional funding to support the extra data manipulation (see Agenda paper Item 10, SCARM, Meeting 3, Melbourne November 1996). The Tongway (1994) system of landscape recording and interpretation is used for reporting surface condition.

Forest lands: Because of the rapid changes in information acquisition in forests through the combined activities of the Comprehensive Regional Assessments (CRAs) and the Montreal Process, the most topical sources of information will be via Roger Hnatuik (Bureau of Resource Sciences) and Ian Noble (Research School of Biological Sciences, Australian National University) and contributions to the CRAs. Additional valuable data sources on erosion in forested regions that are contributing to the Montreal Process indicators (see Indicator 1.1B etc.) are provided by the CRC for Catchment Hydrology, CSIRO's Division of Forestry and Forest Products, and State agencies such as Tasmanian Forestry.

Agricultural and urban lands: These are not covered by any regular monitoring system, but frequent research studies are conducted in the grain-growing regions, with historical data sets listed through conferences on soil conservation. A full assessment of bare soil environments would require a comprehensive monitoring system to be set in place, using existing catchment monitoring studies. One possible future sources of inventoried site information will be custodians of data from the Land and Water Audit.

Areas of catchments: The classification being undertaken by the Australian Heritage Commission for the protection and management of wild rivers provides the best and most accessible information on watershed boundaries and areas.

Analysis and interpretation

Values for each sub-indicator described in the key indicator will be expressed as a proportion of the total land area per catchment, with an associated erosivity factor (from soil type and climate erosion models) — eg. 1. wind erosion, McTainsh *et al*. 1(1990), Shao *et al*. (in press); and 2. water erosion, revised forms of the Universal Soil Loss Equation such as RUSLE (Renard *et al*. 1997), or water erosion in the cropping zone by AGNPS (Kinell *et al*. 1997) or PERFECT (Littleboy *et al*. 1988). A stratification by land use, monitoring design using paired localities, and use of the sub-indicators is necessary to identify the proportion of erosion that is anthropogenic in origin. An assessment would be made of the extent of the bare ground capable of erosion, and the change in this since the last reporting time. The reasons for these areas and changes would be diagnosed from the comparisons between land uses within climatic zones, and whether these have an anthropogenic component related to particular activities (such as earthworks construction or overgrazing).

Reporting scale

National and catchment maps, showing five-yearly (or annually computed) change. Minimum scale will be determined by cost of the Landsat fields required to complement ground sites.

Output/reporting

Maps showing location and increases and decreases in bare area per landcover region. Tabular matrices of area by land uses and change in extent per year. If possible, a risk assessment rating (using the climate–soil type–erosivity potential) by land use and catchment. Risk rating maps are prepared for particular clients and groups of stakeholders, not as a part of institutional requirements.

Linkages to other indicators

Component pressure indicators 1.1A to D contribute to this indicator, and condition and response indicators 1.4, 1.7 and 1.8 to 1.10 should be used in association with this indicator.

1.1A. Percentage cultivated land area with exposed soils by catchment and by agro-ecological region (AER)

Description

The amount of cultivated land that is not covered by stubble, debris, crop or other plant material during some part of the year, especially during non-cropping seasons.

Rationale

This indicator supplements key indicator 1.1, giving greater interpretive value to the key indicator by partitioning the effects of bare ground between different land uses. Stubble retention and reduced tillage systems have been commercially available and adopted by parts of the cropping industry for more than a decade (Cornish and Pratley 1987), so that documenting the extent of cropped lands not adopting such systems provides reasonable evidence for avoidable anthropogenic accelerated erosion.

Monitoring design

A proposed design could include transects at right angles to rainfall isohyets, and directions of dominant wind, over a distance of 200–500 km, taken from Landsat imagery — with ground-truthed spot checks along the same transect lines. Transect lines to be of a frequency that covers all major crop systems in AERs 3–8. Extent to be estimated from ratio of bare to covered paddocks and total area of cropped land (ABARE crop forecast statistics, produced annually).

Data sources

Occurrence and distribution to be obtained from remotely sensed data (Landsat TM) at resolution of 30 m^2 reported at 1 km^2, and computed as proportion of standard area of catchments and AERs. Minimum data sets needed: wet and dry seasons annually. Wind-scar and surface wash patterns from Landsat data provide conclusive evidence of local features, but are not suited to national-scale reporting (see Wallace and Campbell 1998). Crop forecasts and cropped land statistics from ABARE and Australian Bureau of Statistics (ABS).

Reporting scale

TM measured areas along transects using various scales from 1 to 25 hectares, scaled up by statistics of cropping areas and added to provide a component to the national-scale reporting of key indicator 1.1.

Output/reporting

As for Key Indicator 1.1.

Linkages to other indicators

Links to 1.1, 1.1B, 1.1.C and 1.1.D, and to the condition and response indicators 1.4 to 1.7 and 1.8 to 1.10.

1.1B. Area and percent of forests with significant soil erosion, by tenure and catchments

Description

Area of forested lands (using the Montreal Process definition of forests to include closed and open canopies (greater than 50%) and woodlands (canopies of 20–50%) subject to significant erosion, as proportion of total land area under forest, stratified by tenure and catchment. Significant erosion in this context means erosion that leaves clearly identifiable erosion features (rills and gullies) and deposits (infills, accumulations of transported material).

Rationale

This indicator is that proposed as Indicator 4.1a in the Montreal Process (Canadian Forest Service 1995) list under Criterion 4, Section 3.4 Conservation and Maintenance of Soil and Water Resources — "Area and percent forest land with significant soil erosion". The subsequent Montreal Process Indicator 4.1b, "Area and percent of forest land (including plantations) managed primarily for protective functions, eg. watersheds, flood protection, avalanche protection, riparian zones", would provide a set of data towards the development of this indicator. The indicator is proposed because of the need to bring the Montreal Process indicators and State of the Environment indicators together in the future, but it should be recognised that at present the chances of obtaining field data on the two proposed indicators are low for many Australian forests, particularly the 70% of forest area that is in private ownership.

Monitoring design

Sampling of each forest land cover type (closed forests, open and thinned forests) using the baseline data and sampling pattern established by Graetz *et al.* (1995), with Landsat TM data within these authors' Intensive Landuse Zone (ILZ). A repeat sampling sequence will be needed, if possible on an annual basis, or on a 2–3 year basis, to provide estimates of regeneration rates from bare ground where trees are clearfelled for production. Local studies carried out by forestry commissions, universities and water boards will be needed to provide ground-truthing for actual erosion rates.

Data sources

Principal sources will be archived and current Landsat TM data sets via the Regional Comprehensive Assessments and Environment Australia's Biodiversity Group. Ground-study reference sites, especially those which measure erosion, should be catalogued and geocoded for integration with this activity. State and Territory government agencies are able to provide information for the portions of forests in their care, but it should be noted that the First Approximation Report on the Montreal Process (Commonwealth of Australia 1997) noted that no systematic broad-scale collection of data has yet occurred for this indicator.

Analysis and interpretation

It is proposed that areas of exposed forest soil be tabulated and mapped in terms of length of time land remains bare of cover. Good forest practice will leave sufficient trash debris from felling operations for this to be a negligible amount (Victorian Natural Resources and Environment 1996). Percent exposed soil should be cross-referenced to tenure type and catchment, to identify types of managers complying with or ignoring good practice, and which drainage systems are most likely to be affected by accelerated erosion.

Reporting scale

Regional Forest Assessment areas and major catchments. Total values across all jurisdictions then provide an area value to the key indicator; this should be small relative to other causes of exposed soil.

Output/reporting

Regional tables, and summary maps showing forest types (landcover regions) most affected.

Linkages to other indicators

Links to the other erosion indicators 1.1, 1.7 and 1.8, and to Key general response Indicator 4.7.

1.1C. Total area of open minesite bare ground, by catchment

Description

Areal extent of open mine sites, quarries and associated earthworks by catchments, providing a measure of the potential for water erosion from exposed mine sites.

Rationale

This indicator provides interpretative information for the volume of soil that could be contributing to soil suspended sediment and dust from mining activities. Although mine sites only occupy a small area of land, the total land disturbance is so great that they can easily form focal points for accelerated erosion. The extent to which erosion then occurs depends upon location within the terrain of the catchment, mine design and control measures (such as rehabilitation of used areas, settling ponds).

Monitoring design

Baseline maps of catchments with locations of open mine sites would be compiled, and the changes over time recorded relative to the erosivity of the exposed materials, using a sheet and rill erosion model such as Rosewell (1997) in conjunction with the revised universal soil loss equation (Renard *et al*. 1997). A 5-year time interval should be sufficient for this indicator.

Data sources

Locations of mine sites can be obtained from the Commonwealth and State/Territory agencies' listings found in the Register of Australian Mining Reports (the 1996/97 report is the 17th annual edition) used in conjunction with a geocoded location analysis across a continental coverage erosion model of rainfall intensity, soil type and slope. The Centre for Minesite Rehabilitation (University of Queensland) and CRCs in the mining and engineering sectors hold a range of data sources on exposed minesite condition, and the extent of the influence of different types of exposed regolith on erosivity.

Analysis and interpretation

The areal extent and location of open mine sites must be evaluated in conjunction with the erosivity prediction maps. This analysis provides an estimate of the relative volume and extent of erosion that may be derived from mine sites, compared with other human activities.

Reporting scale

Can be aggregated upwards from LGAs and small catchments to regional catchments, and a national value for total area of land contributing should be computed for feeding into Indicator 1.1.

Output/reporting

As part of Indicator 1.1, and independently as maps per catchment showing location of mine sites with the potential to contribute to water erosion.

Linkages to other indicators

Links to Indicator 1.1 and to condition and response indicators of accelerated erosion.

1.1D. Area of unsealed roads and earthworks as a proportion of total land area, per catchment

Description

This indicator gives the proportion of exposed surface contributing to eroded materials coming from unstable earthworks, principally unsealed roads and adjacent verges — as a percentage of total exposed land area.

Rationale

Because of the highly dispersive and erodable nature of many subsoils in Australia — where over one-third of the soils are sodic (Naidu, Sumner and Rengasamy 1995) — waterborne and wind-transported materials derived from this source are expected to be of significant quantity. The contribution of sediments and dust from these sources is nearly always ignored in estimates of anthropogenic erosion. However, as the majority of road length in many rural, and all remote, LGAs is unsealed, it is probable that this source of materials is far greater than that coming from such isolated activities as mining and forestry.

Monitoring design

A baseline measurement exercise would be required that would measure all unsealed road lengths. Repeat updates would be made on a 5-year time scale, except in localised areas of rapid change detectable from reconnaissance appraisal of aerial photography comparisons. Analysis would involve computing the potential of unsealed roads as sources of accelerated erosion relative to the main soil groups' erosivity (climate and slope) using an appropriate model, and checking against rates of regrading and other activities of main roads departments.

Data sources

Data from State and Territory main roads departments and local governments on total lengths and widths of roads, with supplementary aerial photographic coverage or Landsat TM data for recent road works depending on resolution and dates of coverage available. Location of roads across major soil groups of differing erosivities could be GIS-interpolated using national coverage of sodic soils, and erosivity maps (State of the Environment Advisory Council, 1996) Local measurements, if available, could be used on selected locations to test the hypothesis that erosion is dependent on soil dispersivity and infiltration rate.

Analysis and interpretation

The contribution likely from this source to be compared with that coming from other anthropogenic sources, both in terms of areal extent and with respect to erosion potential maps (regional and continental scales).

Reporting scale

Possible from LGA to national scale, but of most significance at regional catchment (or major catchment) scale. At the regional scale, it will provide valuable information for water boards on the relative contributions of roads and farming activities to sediment contamination in water supplies.

Output/reporting

Tables of surface areas of potentially erodable roadworks, stratified by erosivity class per major catchment or catchment.

Linkages to other indicators

Forms one of the component indicators to Key Indicator 1.1 and linked to related condition and response indicators of accelerated erosion.

1.2. Key Indicator: Total grazing pressure relative to net primary productivity (biomass) by landcover regions and AERs

Description

Total grazing pressure includes grazing and browsing by all domestic stock, all vertebrate pests and native herbivores, and a general estimate of the invertebrate load, per landcover region. Net primary productivity is compiled separately from Indicator 5.6 (Change to net primary productivity by IBRA regions, grouped by catchments). Grazing pressure by vertebrates is compiled from adding Indicators 1.2A and 1.2B with the invertebrate load estimate. Stratifications proposed are landcover regions and agro-ecological regions.

Rationale

Grazing is the single greatest pressure on the 66% of the land area used for pastoral activities and farmed livestock production. The effects of overgrazing have been extensively documented in the rangelands (Tothill and Gillies 1992; Wilcox and Cunningham 1994; Wilson and Hodgkinson 1991), and in agricultural regions where excessive stocking rates on pastures can readily cause accelerated erosion as well as deterioration of remnant native vegetation. In many arid regions, ecologists consider that the recorded domestic stocking density contributes roughly half the total grazing pressure. Watering points installed by pastoralists have increased the total vertebrate populations including kangaroos, while invertebrates such as termites have an unusually large effect in these environments and may account for half the total carbon cycling.

As total grazing pressure has little meaning unless related to the biomass production capacity in each environment, the net primary productivity — calculated from the potential biomass production capable of being produced under the prevailing radiation, temperature and rainfall conditions — is proposed as a minimum reference point against which to evaluate total herbivore pressure. Ground-truthing and remote-sensed estimates of the actual standing biomass in any one reporting period are considered in Indicator 5.6.

Monitoring design

A combination of direct and indirect measurement will be needed to compile this indicator. Actual and estimated numbers per unit area can be derived from various statistical sources. Direct evidence on effects of domestic, feral and kangaroo vertebrate grazing pressures, and invertebrate grazing pressures, will ideally come from the baseline relationships between grazing and erosion — such as described for north-eastern pastoral regions by McKeon *et al.* (1990) — derived from long-term comparisons, using exclusion experiments, made by CSIRO and the Universities of Adelaide, New England, New South Wales and Queensland. Relationships between total animal biomass levels, loss of surface cover and erosion potential from different vegetation assemblages could be developed from this information to assist management over a range of environments and land uses. Estimates of total grazing pressure should ideally cover the range of seasonal conditions from wetter to drier than long-term average, or every three years as a minimum.

Data sources

There are many concerns over the accuracy and availability of data for feral and native vertebrates; see Indicator 1.2B. Modelling of net primary productivity (kg/m2/year) at landcover and IBRA region scale for Australia has been published by groups from various universities and CSIRO and for Environment Australia. The information sources used for indicators 1.2A and 1.2B are reported under those headings. The Native Grassland, Rangeland and Ecology Societies of Australia have all compiled from time to time the locations of domestic grazing effects study sites.

Analysis and interpretation

Base maps of net primary productivity (see Indicator 5.6) would be used, against which values for total grazing pressure would be mapped across landcover regions. Regions where total herbivore grazing exceeded estimated safe levels should be compared with the total area of bare ground provided by Indicator 1.1. The full range of values for "total grazing pressure", and its two sub-components, may be capable of being regressed against Indicators 1.1 and 1.7 — ie. "surface soil loss index" — across all landcover regions. Relationships between these might be capable of further refinement for future predictive estimates of safe and harmful levels of grazing pressure to minimise accelerated erosion.

Reporting scale

A stratification of 34 landcover regions and 11 AERs, rather than catchments, has been proposed because of the close relationship between animal distributions, vegetation and agricultural activities, and the lack of a relationship between vegetation classes and watersheds. However, the impacts of effects of overgrazing through accelerated erosion are found in sediment transport through catchments and dust storms across all regionalisations. As other erosion pressure indicators are reported on a drainage-basin regionalisation, this should provide sufficient cross-referencing. Reporting of stock and vertebrate pests can be taken down to Statistical Local Area (SLA) scale and finer stratification of IBRA regions if needed.

Output/reporting

Maps of total grazing pressure relative to baseline values of net primary productivity per landcover region. Total grazing pressure has traditionally been described by dry sheep equivalents (DSEs), but equivalents used for kangaroos and other native and feral vertebrates defined through the State and Territories grazing density guidelines (see Indicator 1.7), per km^2, are subject to wide inaccuracies. For example, the figure for rabbits varies from 8 to 16 per DSE in different publications. Alternative measures based on estimated biomass consumption per unit bodyweight have more validity, but are not available everywhere. As non-domestic animal numbers fluctuate sometimes over orders of magnitude with seasons, the monitoring period must be defined in terms of the types of seasons experienced, not just numbers of years.

Linkages to other indicators

As described — links directly to pressure Indicator 1.1 and condition Indicator 1.7. It can be used to interpret condition Indicator 2.2 ("IBRA regions affected by habitat alteration and loss").

1.2A. Domestic vertebrate grazing pressure per landcover region, and AER

Description

Estimated total number of domestic herbivores per unit area averaged over the monitoring interval, and expressed as a standard animal equivalent — often reported as Dry Sheep Equivalents (DSEs) as sheep are the most numerous of the domestic species regularly reported on in agricultural statistics.

Rationale

Domestic herbivores are predominantly sheep and cattle that are farmed for commercial purposes. The very much smaller numbers of commercially farmed and harvested horses, camels, goats and deer reported in agricultural stock statistics have only localised effects in most regions, although their numbers may be significant in some catchments (such as the estimated 60 000 horses in the Adelaide Hills, and the formerly high numbers of buffalo in the Northern Territory). Numbers of domestic stock, reported through Agricultural Census and industry records, can fluctuate significantly both nationally and regionally depending on prices received and seasonal conditions; nationally, sheep numbers for example have varied between 130 and 180 million over the past decade, primarily because of fluctuations in the market price for wool and, to a lesser extent, for sheep meats.

Monitoring design

Primary statistics are obtained from the census collection districts across all jurisdictions, providing data for all farms contributing to the Economic Value of Agricultural Output (EVAO) calculations in the year of collection. Statistics would require differentiation of animals receiving supplementary feedstuffs from those wholly dependent on natural grazing. Other crop and feed questions in the "AgStats" can provide some of this information.

Data sources

Historically, domestic stock numbers have been reported annually through the Agricultural Census and ABARE Agricultural (AEGIS) Surveys, but the variation in the EVAO (the cut-off value for what constitutes a farm) from year to year means that not all properties are recorded in the Census. This may lead to underestimates of the real stocking rates in impoverished regions, such as those suffering from drought, and on many family pastoral properties which have had negative incomes for long periods. Supplementary ABARE statistics — which draw on a percentage of all farms in the broadacre, dairy and pastoral regions — have been increased recently to accommodate the needs of reporting within the AER regionalisation framework. In future, this source of information will be severely curtailed by the reductions in the frequency of the full census to once every three or five years and in its comprehensiveness. In addition, there are known inaccuracies, omissions and misrepresentations in the ABS data. Because of these limitations, additional on-ground validation is strongly recommended.

Analysis and interpretation

Statistics on animal numbers require conversion to feed intake values by grazing. A number of very well substantiated animal grazing models — such as the GRAZPLAN suite of models (Donnelly *et al*. 1997), GRASP (McKeon *et al*. 1990) etc. — provide algorithms for different environments in temperate to tropical and native to improved pasture situations. However, the total grazing pressure of domestic livestock, expressed as biomass consumption patterns, is not produced as a routine output by any agency or industry body, and would need to be modelled for particular regions.

Reporting scale

From landcover and AER regional scales to national.

Output/reporting

Annual graphs and tabular data by AERs, with maps of animal number distributions on a three to five year cycle. Animal distribution maps with continental coverage were last produced by BRS in 1990.

Linkages to other indicators

This is a sub-indicator feeding directly into Indicator 1.2, and the information gathered on standing animal biomass and modelled vegetational biomass consumption will contribute to the nutrient and carbon indicators 5.1A and B to 5.6. Data for Indicator 5.6 are also required for the development of Indicator 1.2 and its sub-components.

1.2B. Non-domestic vertebrate herbivores per landcover region and AER

Description

All vertebrate grazers/browsers not counted in domestic stock numbers — including all kangaroo species and feral goats, donkeys, pigs, camels, horses, rabbits and mice — by landcover region and AER, where possible. Invertebrate grazers (including locusts, psyllids and other plague-like pests, as well as other background grazers such as snails, beetles and termites) will have to be estimated from any published records, because their specific effects cannot be estimated with any confidence at the scales required. NOTE: there are severe constraints to primary data for this indicator (see below), but it has great significance for both the land and biodiversity, and requires consideration for funding support for monitoring.

Rationale

The total pressure on native rangelands is often double or treble that due to the domestic stock, and normally fluctuates much more widely with season. While many landholders are very conscious of a particular "pest", such as rabbits, the difficulties of estimating total grazing pressure exerted mean that this part of the grazing pressure is seldom taken into account in setting realistic stocking rates. Increased access to water, particularly through provision of bores and drinking troughs, has expanded the total vertebrate populations in many areas of the rangelands, while improved pastures on the margins of the rangelands offer a more continuous source of feed and water to breeding populations than occurs naturally. Monitoring programs being established by industry bodies, such as the Meat Research Corporation's Northern Australia Program No.3 and Southern Grazing Systems Program, have as one of their prime aims to train farmers and pastoralists to assess their real pasture condition better, and estimate its carrying capacity realistically. Better estimates of non-domestic animals will assist such community- and industry-based programs.

Monitoring design

While this indicator is very much needed, it presents significant design problems in implementation. Use would need to be made of existing monitoring strategies, together with numbers reported by State and Territory vertebrate pest control officers — including trapped and surveyed numbers, statistics from culling and pest control killings, road deaths, and population modelling related to seasonal conditions. There are well-recognised limitations to the validity of results obtained from such data as road-kills and sightings (distributional inaccuracies, preferential species selectivity etc.). Aerial counts of large vertebrates have also been used routinely in some environments, but are of limited value in well-vegetated and cloudy regions. Rabbit numbers are currently monitored nationally for control by rabbit calicivirus by a State–Commonwealth program which identifies the location of all deliberate releases and known escape points, and samples within these areas.

Data sources

Vertebrate herbivores described as "vertebrate pests" — including feral goats, pigs, camels, donkeys, horses, rabbits, buffalo and grey and red kangaroo — have been reported through the Vertebrate Pest Program (now ceased) through the Bureau of Resource Sciences in the past. National collation of this information, which is derived from State and Territory monitoring programs, may now be in jeopardy. The distributions of native and introduced vertebrate species have historically been collated by ANCA (now the Biodiversity Group, Environment Australia). Because there are many criticisms of the ways in which such data are obtained, and so many missing data, variations in methodology and other limitations, severe reliability constraints must be placed on any reporting that uses existing data sets. Nevertheless, this is a much-needed indicator and should be supported by additional funding either at agency or community level.

Analysis and interpretation

The main difficulty with this indicator will be with primary data reliability and availability. A number of data sources will be required to supplement government agency reports, because of the fluctuating location and distribution of animals dependent on local conditions. Crosschecks with the "vegetation stress index" developed using the Normalised Difference Vegetation Index (NDVI) may assist in identifying false positives (eg. if animal numbers are reported high because of road kill figures but NDVI values in the area are very low, meaning little green feed, the likelihood is that kills are not representative of regional densities). Error terms will be needed throughout.

Reporting scale

Local conditions are highly significant, and the richness of data sourced from local studies will be of great benefit to improving the accuracy and utility of this indicator. Compared with the community activities of Waterwatch, Frog Watch etc., there is little marshalling of support for the monitoring of numbers of vertebrate pests, yet their effect on native vegetation and biodiversity is pronounced. Regional-scale reporting is therefore a primary aim, with national figures aggregated only to fulfil reporting requirements.

Output/reporting

Text and maps at regional scale on a 5-year basis, with maps of domestic and non-domestic grazers developed for the same regionalisations, presented together or as overlays in a GIS. Reliability maps would be required, both for numbers of non-domestic herbivores and as graphed relationships between expected grazing pressure and proportional reduction in biomass.

Linkages to other indicators

Forms a part of the combined Indicator 1.2, and contributes to 4.1, 4.3 and 4.5 (Issue 4: Introduction of novel biota into native habitats and communities).

1.3. Key Indicator: Change in area that is impervious as a proportion of total area, by urban and rural catchments

Description

The change in total area of sealed surfaces and naturally impervious land (rock outcrops) that shed water to other parts of a catchment, with negligible infiltration, as a proportion of total catchment area per reporting period. Defined catchments are the same as those used in the Inland Waters Report (Fairweather and Napier 1998). A sealed surface is defined as one which is essentially impermeable under all rainfall intensities; it does not include natural conditions such as non-wetting soils or dispersive sodic soils where infiltration rates are slow (< 1 mm per hour) but the majority of low-intensity rainfall events (<10 mm per day) do not result in significant runoff. Unit hydrograph values are essential to determine the cut-off point in some catchments at the which land areas are considered essentially impervious (see further under Linkages).

Rationale

The proportion of the surface area of catchments that is sealed provides an estimate of the runoff potential. Actual runoff and erosion may be less because of within-catchment infiltration and evaporation, but increases in runoff occur when sealed surfaces are artificially increased, or develop as the result of a sequence in semi-arid regions of loss of cover from severe overgrazing, trampling and clay sealing. Increased sealing is a process of particular significance in coastal catchments where much urban expansion is occurring. Up to 40% of some catchments are estimated to be impervious and contributing to stormwater volumes (State of the Environment Advisory Council 1996). For this reason, catchments should be reported as either dominantly urban (and linked to the report on human settlements (Newton *et al.* in prep.))

or dominantly rural (and linked particularly to the report on inland waters (Fairweather and Napier 1998)). Major catchments that straddle both (eg. the Swan–Avon in WA and the Hawkesbury–Nepean in NSW) may be reported twice.

Monitoring design

A baseline value of total area sealed and naturally impervious that is as comprehensive as possible across all scales and jurisdictions is required, but thereafter regular updating would be more effective if done as nested sampling across those catchments known to be changing rapidly as a result of demographic variation, see the human settlements indicators report (Newton *et al*. in prep.), with detailed quantification restricted to catchments (mostly coastal) where urban expansion and infill are measurable on a three to five year timescale. Total area affected in many inland catchments will be small, and may be insignificant as a proportion of the total catchment size.

Data sources

Data sources are primarily current cadastral maps and planning proposals with aerial photo and Landsat MSS data on areas occupied by housing and built structures, supplemented by local planning authority reports to State Governments, possibly also with details from metropolitan and rural water authorities for interpretation and area estimation. The most difficult information to obtain reliably is the areas of grazed rangelands that have become bare scald areas effectively impervious to most rain events. Some of the Rangeland Monitoring Program sampling sites may be able to provide data for this aspect.

Analysis and interpretation

This indicator will rely heavily on the scale and accuracy of catchment boundary base maps, river flow monitoring (by unit hydrograph) and local rainfall statistics. For current metropolitan areas there are abundant detailed analyses that can be drawn on to estimate the effect on urban stormwater and its disposal of increasing the area of sealed surfaces, but in peri-urban and inter-urban developments — such as typify parts of the New South Wales and Queensland coasts — existing analyses may be sparse, with few estimates done on a routine basis. Identification of gaps in the capacity of local governments and water boards to estimate this indicator will provide an important message to government on monitoring needs.

Reporting scale

Local concentrations of population require that this indicator is reported at local scale for specific catchments. The total impact on coastal catchments should be reported relative to Interim Marine and Coastal Regionalisation for Australia (IMCRA) regions, and that on inland catchments relative to inland drainage basins. Regional summaries to basin scale are the most practical upper limit to aggregation.

Output/reporting

On a three to five year timescale, with tabular information on areas covered and text on estimates of effects on stormwater, runoff and erosion.

Linkages to other indicators

This indicator relates to the inland waters indicators (Fairweather and Napier 1998) under the issue heading Water Quantity, and to the estuaries and the sea indicators (Ward *et al*. 1998) under Class 6 Integrated Management Indicators 6.1, 6.2 and 6.3 (coastal development, coastal catchment management and coastal discharges). Indicators of urban expansion developed through the human settlements report (Newton *et al*. 1998) may access the same data sources. It should be linked to the indicators of river quantity by river hydrograph monitoring, and storm and flood modelling and management indicators.

Issue 1: Accelerated erosion and loss of surface soil

Indicators of Condition: Combined wind and water erosion

1.4. Key Indicator: Surface soil loss index

Description

Loss of organically-rich A horizon from soil profiles, scaled (and therefore presented as an index) across all Soil Orders capable of being reported by existing methodologies and with existing data availability, stratified by land use, and reported by IBRA at five-year time periods, or per measuring period. Soil organic matter is used as the bio-indicator of biologically active topsoil.

Rationale

This is a critically important indicator. The most important ecosystem functions affected by erosion are plant nutrient supply, nutrient (especially carbon and nitrogen) cycling and sequestration, and waste material decomposition. Reduction in nutrient supply directly reduces primary productivity and thus the vegetation cover, which in turn affects habitats, climatic conditions and erosion control. Direct surface soil loss is difficult to assess at the continental and regional scales required for national reporting. Localised studies may not be representative of large areas, and therefore a combination of sub-indicators of comprehensive assessment and site-specific rate studies is required. The information developed is relevant to international policy formulation, having importance to the total carbon loss and sequestration calculations used in the Intergovernmental Panel on Climate Change's reporting on greenhouse gas emissions, and to Australia's status on net emissions. Modern soil classification systems recognise a separate and distinctive anthropogenic form of surface soil in agricultural regions that has been disturbed, inverted and reformed from cultivation. However, a total lack of surface soil — distinguished by the absence of organically stained dark materials, with no light, finely particulate, organic debris and very low level of soil fauna and microbial activity — is the most telling evidence of gross ecosystem deterioration.

Large-scale changes that result from combined wind and water erosion in overgrazed regions may result in substantial loss of primary biomass productivity across ecosystems, and can be detected spatially where comparisons are made between different land uses across the same known broad soil type — eg. each side of administrative or physical boundary lines and fences, which are visually distinctive and where differences of tenure condition, clearing etc. are known to occur. Examples include the north–south boundary between Victoria and South Australia, and the various dog-proof and rabbit-proof fencelines. Improvements through regrowth of land cover should also be able to be recorded.

Monitoring design

1. A network of soil and land reference sites that are representative of soil and land types in each region has been proposed through ACLEP for regional scales of 1:100 000 to 1:250 000, but as yet this does not exist. Also, the design does not contain paired site comparisons. Examination of paired soil sites that have developed within the same soil series but been subjected to different land practices provides the most reliable form of evidence of changes to soil condition and properties. The baseline continental map of soil carbon being compiled by BRS uses data of varying quality from some 10 000 sites. While most are not now retrievable, some are geo-referenced and will be available as future potential sites for revisiting. Measurements should include the existence or lack of complete A horizons, supplemented by contextual descriptions of the state of the surface soil and surrounding land condition — so that colour hues of soil surface can be calibrated against actual soil organic matter contents and type for each major soil series. A set of look-up tables will need to be developed that relate actual soil organic matter levels to colour values. End-members of long-term agronomic, grazing and fertiliser experiments located in the agricultural ILZ do provide some of the required paired site comparisons, and are documented and of known history and location (Martin *et al.* 1995), but they do not cover all great soil groups or agro-ecological regions.

2. Using remote sensing, specifically Landsat TM scenes, compare the dominant soil colour values at fixed locations over time to detect possible changes in surface condition. Selected transects would be located for examination from archived historical and current fields of view, across regions that are exposed to different land tenures and land use. Those regions of Australia that are unsuited to the method would be masked out. This method may not detect surface changes in already dark-hued soils, and in areas with dense top-storey canopy cover. However, it has particular appeal for semi-arid and arid areas of light soil hues, where remoteness and the difficulty of other

forms of evaluation result in sparse or no data collection. Measurements in this type of area are being made by the Department of Land Administration of WA (DOLA), and have been used in association with rainfall statistics to investigate the extent of desertification which may have resulted in changes to rainfall distribution in WA (Lyons *et al*. 1993). Interrogation of the archived Landsat TM data from the Biodiversity Group's landcover disturbance survey (Graetz *et al*. 1995) would help to prioritise the ranking of those soil–vegetation associations that have already been identified as being vulnerable to further cover loss and land degradation.

3. Baseline estimates of the soil organic matter contents (and equivalent colour values) that should occur under each IBRA vegetation type, modelled and calculated from existing carbon models (obtained from Indicator 5.5). Comparisons would then be made of the expected and observed soil surface colours (equivalent to or a surrogate for the soil organic-rich topsoil). The methodology follows one developed for catchment regions (Regional Council zones) in New Zealand described by Sparling (1996).

Data sources

1. Recent exercises by CSIRO and BRS in mapping soil carbon for Australia from known archived information and transect monitoring would form a primary data source. Computed projected soil carbon changes from the pre-European era to the next 50 years by IBRA regions (eg. Grace and Post 1996) would provide the initial baseline for assessment of reported management-induced changes. Long-term sites have recently been audited for their scientific value, as described in Martin *et al*. (1995), and a national subset has been identified that may be used for benchmarking studies on changes to soil properties, including details of surface soil organic matter, soil structure and soil fauna. Other historic sites and soil property data sets that can be included have been described; types of survey design, statistical analysis and limitations to the use of historical data are discussed in McKenzie *et al*. (1995).

A computer-based directory to data sets held by government agencies containing meta-data for some 3170 surveys has recently been compiled by the BRS (Barson and Shelley 1996), covering surveys dating from 1888 to today. The number of records per State and Territory varies from 1740 for WA to 95 and 45 for SA and the ACT respectively. These surveys provide generalised land system information, but would not provide detail on soil organic matter at a consistent scale across all regions. The majority are spatially referenced, and meta-data including spatial coverage and currency, quality and availability of information are recorded for each and accessible through the web site http://www.nric.gov.au/nric/data/lrs_search.html. Soil carbon data lodged with CSIRO have been used to provide a best-available soil carbon map of Australia for 1996. This would provide the first estimate for future comparisons.

2. Existing archived Landsat TM data, current coverages along the same transect sampling lines, and subsequent regular re-sampling along the same transect lines using Landsat or equivalent remotely sensed coverage.

3. Soil carbon models, such as CENTURY (Parton *et al*. 1986) and SOCRATES (Grace *et al*. 1996), as adapted to the estimates for soil carbon sequestration by IBRA region, as described above.

Analysis and interpretation

Using the soil surface maps calculated from carbon models, compare with regional transect values of increases in albedo or decreases in the measured Ao and A1 horizons compared with reference (undisturbed) sites, plotted as fractional losses of colour value or scaled organic matter content (matched to colour value via look-up tables). Point values of surface soil loss or decline in colour value would require extrapolation via a kriging, or other, scaling technique to provide a spatial coverage across the relevant land use by soil series extent, matching against land-use change over time. It should be noted that historical land use changes (eg. past clearing and land degrading practices) that have now ceased, but are still causing losses of surface soil, cannot be distinguished from recent clearing or further loss of surface soil by this means. It is important from the point of view of ecosystem function, however, to know whether surface soil loss is still occurring from past actions even where these are no longer being practised.

Reporting scale

Continental, at the scale of the soil map of Australia (CSIRO) 1:1 million, digitised, and regionally at the scale of landcover regions and catchments; where paired reference sites and soil cover maps (NSCP–NLP project 1988–98) exist, at the scales of those maps, generally between 1:100 000 and 1:250 000. Such maps are available for much of the continent from the Land Systems Surveys carried out over the past fifteen years as a result of the National Soil Conservation Program and its successor, the National Landcare Program.

Output/reporting

Maps and accompanying text showing the deviation from expected rate of change in soil surface colour and depth over time, with undisturbed nature reserves, forest areas and native remnants providing the ground-truthed validation of expected values. Transect graphs across the continent at tropical, sub-tropical and temperate latitudes comparing disturbed and undisturbed values would be readily understood.

Reporting scale

Large regional scales, 1:100 000 to 250 000, and continental (but with masking out of areas where the method is not applicable). Forms the coarse grid framework for the finer ground-truthing and verification that it is anticipated will be available if the ACLEP Reference Sites come into operation.

Linkages to other indicators

Requires Indicator 5.5 to provide the modelled soil carbon reference baselines. Closely linked to other carbon loss and sequestration indicators (5.2 and 5.8), and useful for interpreting changes in Indicator 5.6 (Change to net primary productivity by IBRA regions, grouped by catchments).

Water erosion

1.5. Key Indicator: Gullying index per major catchment

Description

Gullying index (G.I.) would be a composite indicator. Lengths of current steep-sided gullies L_c now actively deepening and extending headward would be subtracted from total (historical) lengths of steep-sided gullies L_t (i.e. anthropogenically caused gullies) per catchment. This indicator has greater relevance to some regions of the continent, where relative relief is greater, than to others.

e.g.: $G.I. = L_t - L_c$

Ideally, the gullying per catchment should be scaled (0 to 10) to represent the difference in erosivity between soft sedimentary and massive, unfaulted granitic rocks. A surrogate scaling ratio may be available from continental erosivity modelling exercises (see under Rationale).

Rationale

Accelerated gully erosion was estimated to be a significant contributor to total erosion in *Australia: State of the Environment 1996*, pp. 7-15 to 7-17. Natural erosion varies, however, with the degree of dissection that occurs in rocks of different degrees of hardness and fracturing, with soil types of differing degrees of dispersion, and with present and recent past climatic conditions operating. Any indicator of anthropogenic water erosion must be able to distinguish accelerated from natural erosion. Although special tracer studies provide quantitative evidence of differentiated erosion between surface and subsoil (Olley *et al.* 1995), and have been used to study gullying rate and sediment yield in the Murrumbidgee catchment, the method is too costly for routine monitoring in all regions. The other two major forms of water erosion over land, sheet and rill erosion, have been estimated for the continent using modelling approaches such as Rosewell (1997), based on the Revised Universal Soil Loss Equation (Renard *et al.* 1997), and are treated as separate component indicators (1.1 and 1.6).

Monitoring design

A dissection ratio for each major catchment based on available geological and topographic mapping classifications could be used to identify regions in which to sample, using a nested design to identify “hot spots” or catchments likely to contain active gullying. Transects would be chosen to intersect the headward extents of drainage lines below watersheds, and aerial photo and Landsat coverages regularly examined and measured for headward extension. Stereo-pair examination of gully slope steepness and depositional features would provide corroborating evidence of current activity. Work of this type is conducted by the Department of Lands Administration, WA, for the Pilbara and Kimberley river estuaries during 1995–96, where coastal catchments provide evidence of episodic sediment plumes. Such rare and episodic evidence of active erosion is not monitored in all jurisdictions.

Data sources

Air photo coverages from departments of lands and conservation, and Landsat TM 30 m^2 coverages from the Australian Centre for Remote Sensine (ACRES) (although this source of Landsat images will change in the future) for general terrain coverage, with ideal coverage taken during low-cloud, dry season conditions when terrain features show most clearly. Supplementary information gained from high-resolution air photos selected from routine State and Commonwealth agency repeat coverages. Local evidence of gullying may be confirmed from Landcare and other community group activities that are the subject of rehabilitation projects and granting schemes under the Natural Heritage Trust.

Analysis and interpretation

Rates of gullying by catchment location, derived from analysis of headward extensions across transect boundaries in the headwaters of catchments, should be cross-checked with land use indicators (e.g. Indicator 2.3), records of rainfall over the monitoring period and vegetation cover index (derived from NDVI). Those areas identified as having significant gullying indices should then be classified according to the likely causes of gully extension. The causes most likely to operate are loss of ground cover (from drought, overgrazing, fire or a combination of the above) followed by high-intensity rains above the infiltration rates of bare soils. Rainfall rates are generally only available at the scales needed on a daily basis, rather than via tipping-bucket instantaneous measurement. Daily rates below 10 mm/day would be excluded from the analysis in most instances.

Reporting scale

By catchment and aggregated to drainage basin or AER, with national figures being expressed as the percentage of catchments affected.

Output/reporting

Mapped regions of greatest extension, with tabular length ratios on a five-year reporting basis.

Linkages to other indicators

Links to Land Resources Indicators 1.1 (and sub-indicators), 1.2 and 5.1B "Sources of phosphorus derived from land activities reaching rivers, by catchment", and is a context indicator for Inland Waters indicators of water quantity (flow data).

Wind erosion

1.6. Key Indicator: Change in dust storm index relative to number of high wind events by AERs and landcover regions

Description

Change in the frequency of values for a dust storm "index" that combines the records of three different types of dust events: severe dust storms (SD), moderate dust storms (MD) and local dust events (LDE), compared with the level of dust storm predicted from values derived from the "effective moisture model (E_m)" of Burgess *et al*. (1989). This model describes the climatic parameters controlling wind erosion. The index values are related to each other by the maximum visibility thresholds for each type of event (Bureau of Meteorology definitions) as developed for the National Project on Indicators for Sustainable Agriculture (McTainsh pers. comm.). The dust storm index (DSI) then is:

DSI = (5 x SD) + MD + LDE/20

SD = weather codes 33, 34, 35 and 98; MD = weather codes 09, 30, 31 and 32; and LDE = weather codes 07 and 08 of the 1982 Bureau of Meteorology classification.

The wind erosivity (E_w) index (McTainsh *et al*. 1990) is predicted for an area, and where the DSI exceeds this value enhanced erosion has occurred; this may be attributed to anthropogenic activities in a region where comparisons between land uses are possible.

Rationale

This indicator has been developed for the NCPISA Indicators of Sustainable Agriculture project, to monitor the off-site environmental impact of agriculture. In that form the effect on down-wind populations and atmospheric quality will be measured, using historical meteorological records of visibility as a surrogate for dust flux and a climate–terrain model to partition components due to natural and anthropogenic dust. Estimates of topsoil loss in semi-arid and arid regions might also be made with this approach if meteorological observations are available and spatial resolution problems can be solved (McTainsh *et al*. 1990). A short research project is being undertaken by G. McTainsh to compute values for this indicator for the NCPISA project and test its value for state of the environment reporting on a regular basis.

Monitoring design

Using the 152 meteorological stations with historical records of at least 40 years (most have records for more than 100 years) that record daily wind run and/or wind velocity as well as other basic meteorological data, together with modelled wind energy, evaporation and vegetation cover to predict erosivity, record the dust storm indices for locations downwind of different land uses that exceed the predicted E_w index. Achieve as comprehensive a coverage as possible. There are limitations because of the low spatial resolution of stations in the arid areas, where dust event frequencies are highest. Limitations in the primary data sets are being investigated by the Bureau of Meteorology to determine data reliability.

Data sources

Primary data sources are the Bureau of Meteorology — with data pre-processed to a common format of daily dust and wind data for the stations and other climate variables (evaporation, temperature, rainfall) required for computing wind erosivity — and further processed meteorological data held by the Centre for Land Conservation, Griffith University. Vegetation cover data for the past 15–20 years can be obtained from remote-sensed coverages, but there are no regular historical sets of variations of vegetation cover for earlier years. NDVI coverage with supplemental Landsat interpretation is now available for present and future updating. Land uses will be derived from the same sources as used in Indicator 2.3 "Change in land use by catchments".

Analysis and interpretation

Changes in DSI over time will be computed for individual stations and interpolated isolines by regressional statistics. Interpolation algorithms and confidence limits provide cutoffs to regional analysis. Wind erosion factor analysis is able to assist in locating the source of dust, with information from vegetation cover, land use and tenure indicators being used to assist interpretation of the reasons for deviations of E_w from predicted. Wind erosion is not a significant form of total erosion in areas of greater than about 600 mm rainfall. The extent to which anthropogenic accelerated erosion can be detected is only partially assured at present, and the current research project will assist in establishing the validity of the method.

Reporting scale

National and regional mapping over scales of 1: 250 000 to 1:2 million, with associated maps of relative reliability, and local to regional remote sensing and ground-truthing of supplemental information on bare ground (Indicator 1.1 and supplemental indicators).

Output/reporting

Maps of dust storm totals, and wind erosion factors and resultant dust storm and erosivity, with text and graphic information on regions of high dust source and deposition.

Linkages to other indicators

Pressure and condition indicators of bare ground, land use and total erosion, and response indicators on all practices that increase or decrease bare ground, particularly in relation to lower rainfall (<600 mm) environments.

Issue1: Accelerated erosion and loss of surface soil: Indicators of Appropriate Response

1.7. Key Indicator: Percent, number and area affected of pastoral shires with stock at or below conservative stocking rates, by AER and landcover regions

Description

This is a key indicator for Issues 1 and 2. Conservative stocking rates are defined as those that do not cause extensive damage or loss of cover during low-feed conditions, when compared with non-grazed areas. Recommended stocking rates — provided by the Departments of Agriculture in WA and NSW, Agriculture and Fisheries NT and Primary Industries Queensland and SA — calculated on the basis of animal intake, palatable species and biomass production capacity, may be indicative of carrying capacity for good to moderate seasons. These can only be used if heavily qualified with reference to the conditions pertaining in particular regions over the preceding three to five seasons. The number of complying shires, as a proportion of all shires, that are managing their domestic stock at or below these rates is evidence of good management practice. The areas of land affected are also needed for comparisons between regions to be valid.

Rationale

Pastoral leases cover 31% of Australia, and grazing is the principal activity over twice that area; it is the principal land use across nearly half the IBRA regions. In recent surveys, e.g. Tothill and Gillies 1992 and LWRRDC 1994, the majority of pastoral properties in the northern beef pastoral industry had stocking levels above recommended stocking rates — in many cases associated with vegetation and soils described as degraded (Graetz *et al*. 1995). Tothill and Gillies, for example, estimate there are some 22 million hectares of Mitchell grass pastures that safely carry 1.7 million beef equivalents in Queensland because more than two-thirds of the area is in excellent (A) condition, but of the 17 million hectares of mulga lands more than 5 million are in severely degraded condition despite low cattle numbers (only 500 000 beef equivalents in 1992–93). Brigalow and *Aristida–Bothriochloa* communities in Queensland are everywhere heavily overstocked, whereas ribbon grass country in WA and NT is mainly in good condition and conservatively stocked.

In many pastoral regions, the primary cause of overstocking is too small a property size for the lower terms of trade experienced now compared with those during the period of property boundary establishment. When considering the most appropriate response indicator, however, monitoring expansion in property size presents even greater problems in data access than grazing pressure measurement. Domestic stocking rates are able to be obtained reasonably reliably and frequently, and increases in cattle numbers are known to have been greater in Queensland and NT over the past 25 years than in other areas. Improvements in terms of reduction in cattle and sheep equivalents would be registered as positive responses to the impact of overgrazing on erosion and biodiversity in those AERs and landcover regions that are documented.

Data sources

Estimates taken for land conservation purposes from surveys undertaken by Tothill and Gillies (1992), Wilcox and Cunningham (1994) and the National Rangeland Monitoring Program's operations in all rangelands in 1994–96 (see Indicator 1.1) would provide baseline values, with supplemental information on rangeland vegetation stress index being supplied from the NCPISA attribute "Vegetation stress index" (SCARM 1998). Cattle and sheep numbers would be derived from the agricultural statistical returns (ABS) used in Indicator 1.2A, minus the numbers of feral and native herbivores (Indicator 1.2B); Environment Australia and the Bureau of Resource Sciences hold historical data sets on vertebrate pest numbers and distributions.

Analysis and interpretation

Estimates of total grazing pressure and conservative stocking rates have replaced the earlier "recommended stocking rates" provided by agricultural agencies. They are calculated from potentials set by models of growth of rangeland native pastures under different climatic and grazing regimes, in which animal intake requirement, net biomass production per season, and ratios of edible to non-palatable species are the main inputs (e.g. McKeon *et al*. 1990; Freidel 1990; Bastin 1989), and form the basis for the recommended rates and guidelines increasingly provided by State and Territory agencies. Feral and native herbivores are often as great in number as domestic stock; they represent an added burden that was not allowed for in most recommended rates. Values for beef and sheep equivalents described in recommended stocking rates can therefore exceed safe limits in poor seasons. Stocking rates must be adjusted to seasonal conditions. Potential stocking rates so set are calculated routinely by model outputs, and evaluated for spatial applicability using remote-sensed information (Clewett *et al*. 1991). Although stock numbers are collected at property scale, these data are not released by the ABS below collection district scale for confidentiality reasons, and the response is set at shire level because of this. The data do, however, allow comparisons to be made on the effectiveness of rural policies aimed at good pastoral management as implemented by individual managers (these are frequently very clear-cut).

Reporting scale

The National Rangeland Monitoring Strategy Program proposed by the Sustainable Land and Water Resources Management Committee (meeting 3, November 1996) would form the most effective institutional method for reporting this indicator nationally, with summaries for each State and Territory, AER and Extensive Landcover Zone region .

Output/reporting

Annually by shire, aggregated to landcover region and AER (where boundaries are aligned to SLAs) in graph form to show the percentage of shires with stocking rates at or below recommended levels, plotted against potential rates set by season. Maps of AERs and States of the same, in summarised form.

Linkages to other indicators

This indicator should be assessed in conjunction with condition indicators dealing with vegetation condition and clearing in biodiversity and the land. The NCPISA indicator "Rangeland condition" can contribute annual values of remote-sensed information on vegetation stress index towards interpreting this indicator.

The following sub-indicators will be required for analysis of this key indicator.

1.7A. Area of pastoral properties reducing grazing damage by alternate use and feral animal control, by State and landcover region

Description

Pastoral properties that have diversified into other occupations such as eco-tourism, servicing recreation and mining, become non-pastoral Aboriginal lands, or acquired conservation status and have thus reduced overall grazing by feral pest control and destocking procedures.

Rationale

With declining terms of trade, and continued difficulties in managing cumulative land degradation from past practices on low or nil disposable income, some pastoralists have converted their operations to forms of eco-tourism, conservation parks, or other occupations that cause less pressure to lands already biologically degraded or eroded. A significant number of Aboriginal land holdings have been taken up on previous pastoral properties, some of which continue to be run as commercial animal production holdings while others still contain some stock but are not engaged in active operations. Properties in some districts — such as the Murchison–Gascoigne and the south-western Mulga lands (Queensland) — are currently in the process of changing their primary function. This trend is expected to continue into the future (Rural Adjustment Scheme Review (DPIE 1997), Draft National Rangeland Strategy (ANZECC and ARMCANZ 1996)). Monitoring of this process provides valuable information for assessing the effectiveness of current policy settings at State, Territory and national level, by such inquiries as the Inquiry into Ecologically Sustainable Land Management (Industry Commission 1997). Where the management of land has included closing down surplus watering points, removing fences, utilising fire for weed control, culling or eliminating large vertebrates and ripping warrens, dramatic improvements in vegetation cover and species diversity can occur (e.g. in parts of the Kimberley Ranges, WA).

Monitoring design

Survey of selected pastoral properties designated by tenure and lease agreements classified by primary and subsidiary activity to provide a foundation database, which can then be assessed periodically by State and landcover region stratifications for changes in types of commercial and non-commercial activities per property, compared with pastoralism alone. Ranking of activity related to land condition would be ground-truthed by spot sampling across different IBRA regions.

Data sources

Unpublished information from relevant State, Territory and Commonwealth departments (e.g. ATSIC, Agriculture WA, Agriculture and Fisheries NT, Department of Natural Resources Queensland and their NSW and SA equivalents) — supplemented in some cases by ABS returns, in particular demographic census data on occupations and agricultural statistics on number of farm establishments (although the EVAO cut-off threshold confuses these statistics). Pastoralists engaged in Landcare and industry monitoring schemes may be an additional information source, through special surveys.

Analysis and interpretation

Information on change in land use — principal and subsidiary occupations — requires verification by remote-sensed scenes selected across the sample of properties and checking against stock numbers and sales. Information on destocking of vertebrate herbivores also requires data from pastoral and rural lands protection boards on rates of removal of vertebrate pests and culling of kangaroos. The final output, in many cases, would be an estimate only. Any analysis should consider what influence State or Territory legislation and tenure conditions may have, by comparing "paired" properties either side of borders within the same biophysical regions.

Reporting scale

As for Indicator 1.8.

Output/reporting

As for Indicator 1.8.

Linkages to other indicators

This indicator should be used in conjunction with 1.8 to interpret data on changes in domestic stock numbers for reasons other than the normal influences (market price and climatic condition). The information will become more valuable with time if a monotonic trend continues, rather than showing short-term response to price and climate.

1.7.B. Percentage of shires destocking when feed reaches advised threshold, by AER and landcover region

Description

Number of drought-affected shires (defined as having less than the lowest decile rainfall for an agreed number of months, compared with the full range from long-term records) that have taken action to destock relative to the total number of pastoral shires per AER or landcover region, in a reporting period.

Rationale

From the 1989–96 severe drought period in north-eastern Australia, advisory services to pastoral and agricultural activities have been able to provide timely, media-accessed information on linked range seasonal grazing (vegetation) conditions and weather forecasting. Advances in weather prediction with the Southern Oscillation Index (SOI) have been particularly useful in the eastern half of the continent, and combined long-term monitoring, vegetation growth modelling and seasonal forecasting have improved predictions sufficiently everywhere to provide reliable advice to farmers and graziers. Stock owners should be able to take advantage of this service sufficiently in advance of acute feed scarcity to diminish the adverse effects of severe grazing pressure that were previously common during drought. The proportion of shires (surrogate and aggregate of properties per shire) complying with such advice will demonstrate the effectiveness of both advances in information and producers' ability to adopt advice.

Monitoring design

Random survey technique across all pastoral regions experiencing drought as identified by the Bureau of Meteorology and departments of primary industries, using agreed Exceptional Circumstances criteria.

Data sources

Information on drought conditions from State and Commonwealth offices of the Bureau of Meteorology, plus regional pasture and animal condition bulletins issued by agriculture and primary industries agencies, and NDVI comparative values (Environment Australia). Destocking movements from rural press figures (sales, transport movements) and stock trucking company phone surveys, and from rural stock agents and pastoral companies.

Analysis and interpretation

A non-parametric statistical analysis of relative numbers of stock movements out of drought-stricken districts compared with numbers moving in non-drought periods.

Reporting scale

Regional aggregation of shire values, to State, AER and landcover scales. A national value would only be valuable as a time-series to track overall progress in sustainable land management (say a twenty-year period).

Output/reporting

As for 1.7 and 1.7A.

Linkages to other indicators

As for 1.7 and 1 7A.

1.8. Key Indicator: Implementation of new drought policies

Description

The extent to which revised drought policies proposed in 1989 — under which self-help through advisory services, property management planning and increased weather and vegetation condition forecasting replace financial drought assistance schemes — are implemented across all States and Territories,.

Rationale

In 1989 new proposals for drought management were introduced by the Commonwealth Government, and white papers circulated (DPIE 1989). These proposals recognised drought as a normal feature of Australian climate and not a natural disaster, with reductions in rural assistance through traditional drought declarations and its replacement with a range of support services including improved seasonal climate forecasting, advice on pasture and cropping conditions and appropriate management, increased advice on property management planning and special training schemes. The proposed legislation became coincident with a long period of drought in north-eastern Australia; exceptional circumstances were invoked and legislative reform halted. More recent developments, including Property Management Planning and the Mid-Term Review (DPIE 1997) of the Rural Adjustment Scheme, have now provided an integrated framework in which to progress the change towards self-reliance, training and improved information sources for pastoralists and farmers.

Monitoring design

Independent surveys conducted for Environment Australia on the status of the draft national drought policy proposals and associated laws, policies and programs within each affected Commonwealth and State agency; monitoring the policies and strategies of the National Farmers' Federation and Ministerial Council committees such as SCARM and SRLWMC over time; tracking any changes to the 1989 drought policy proposals and assessment of actual implementation rate in each jurisdiction.

Data sources

ABS and ABARE surveys of pastoral practices; documentation of progress through Ministerial Council agenda items, government discussion papers and community consultations; Commonwealth, State and Territory Government legislation; and Research and Development Corporation reports. This indicator will require independent surveys to be undertaken in order to satisfy concerns as to the credibility of findings.

Analysis and interpretation

Number of properties per rural lands or catchment management board, by State and Territory, that use 1 to *n* practices (e.g. destocking, use of weather and pasture forecasts, production of emergency feed, re-fencing and stock movements, monitoring of pasture condition etc.) compared across jurisdictions, using a time chart and relative progress (none to complete) for separate regions, and a national overview. The results should be considered a surrogate to tracking progress in attitudes and behavioural change among both rural government agencies and land managers. Attitudinal change is shown in progress in policies and legislation. Implementation progress may be tracked by documenting the take-up of policies on sample properties in each State/Territory and redundancy of previous legislation (drought declarations, separation of exceptional circumstances from DPIE to Department of Social Services subsidies to interest rates).

Reporting scale

National, State and Territory.

Output/reporting

Regular text report.

Linkages to other indicators

Links with progress on other government policies and strategies for environmental management such as the Strategy for Ecologically Sustainable Development, the National Rangeland Strategy and the National Strategy on Biodiversity (the latter is being used as a framework for the biodiversity indicators report (Saunders *et al.* 1998)).

1.9. Key Indicator: Percent of land managers using agreed Best Practice by land use and/or catchment

Description

Numbers of land managers (both private and public, corporate and single) that use an agreed group or "basket" of best (or more sustainable) practices, as a proportion of all land managers of that category. Categories are designated land uses described in Indicator 2.3. Where land use is not defined, tenure will be used as a surrogate.

Rationale

This indicator is needed in response to each Threatening Process (Table 6). Rural, mining and manufacturing industry peak bodies, statutory marketing authorities, research and development organisations and government bodies have all expressed strong support for improving adherence to international Best Practice in recent years, including adoption of environmental assurance schemes such as ISO 14000 standards (by the National Farmers' Federation (1994), Outlook Conferences (1993–97) and Environment Management Industries Association of Australia reports). Disposal of wastes has increasingly come under the scrutiny of State and Commonwealth environment protection authorities. Progress in achieving these management practices provides the best indication of resource and environmental protection over all land uses.

In relation to control of erosion, rural producers are guided by the list (Table 2.3) in SCA (1991) of more sustainable practices and Property Management Planning guidelines endorsed by the Sustainable Land and Water Resources Management Committee of SCARM. A study undertaken in 1997 for NCPISA assessed the number of farmers using such practices as re-fencing by soil type, changing production systems to take account of land capability, financial planning to allow for adoption of sustainable technologies such as changing irrigation methods and trash-handling seeding equipment, stratified by agro-ecological regions (SCARM 1998).

Data sources

Information sources are poorly collated nationally, and are not reliable. In-depth surveys, such as special surveys undertaken by ABARE on Landcare activities (Mues *et al.* 1994), provide the most reliable information, but cost a substantial amount each time they are conducted. Sub-indicators 1.9A and 1.9B should improve the reliability of this indicator, but this is an important indicator for which it is likely that separately funded studies will be required to obtain the necessary data across different sectors and regions.

For agreed practices: ISO 14000 operation manuals, industry environmental practice codes (manufacturing, mining and forestry) and rural industry guidelines provided to marketing and producer organisations, but excluding product quality assurance schemes that do not relate to environmental management.

For numbers of landholders operating according to agreed practices: Local and State government annual reports on their own land management practices (introduction of new State and Commonwealth legislation that seeks to control threatening processes as a surrogate), rural producer surveys conducted by ABARE and some ABS agricultural statistics on farm practices (e.g. tree planting, fencing and crop management, and some aspects of pasture management; information for such aspects as erosion control has only been collected very recently and is very difficult to use).

For industrial and commercial operators: Compliance and infringement data may be available in some cases through EPAs, but most relate to waste disposal only. Surveys conducted by industry bodies such as the Environmental Management Industries Association of Australia of their own members. The Department of Industry, Science and Tourism (DIST) may be able to supply company-by-location details for industry awards for best practice.

For forestry and mining: Commission and company guidelines and reports list harvesting and open-site restoration measures undertaken. More details of these are listed in Indicators 1.9B, 2.4 and 6.6, but independent spot sampling surveys may be required to ensure the credibility of results.

Analysis and interpretation

Although the indicator is expressed as a percentage, it may be difficult to quantify as other than crude estimates. Nevertheless, this is a very important indicator to strive to obtain because it represents the effort in all parts of the community to manage land resources more sustainably.

Reporting scale

National by land uses; regional at State and Territory level (because of differences in State-level legislation affecting tenure and practices); and by landcover region. This indicator should be reported on at three to five year intervals.

Output/reporting

Tables, and maps using a land use or land tenure cover, as the base framework. Note: wherever tenure is used instead of actual land use there is a danger of misinterpretation, as legal and Australian Surveying and Land Information Group (AUSLIG) conventions for legend titling of tenures are commonly read by non-specialists to mean something other than what they mean in law (e.g. "private, public, fee simple, alienated, unalienated" as descriptive adjectives).

Linkages to other indicators

This response indicator should be used in conjunction with sub-indicators 1.9A and 1.9B to interpret pressure and condition indicators of accelerated erosion, and is linked to biodiversity and inland waters indicators of responses to erosion threats.

1.9A Percent cropped land with reduced tillage plus stubble retention, by AER

Description

The area of cropping land that is cultivated and sown to field crops under systems of minimum tillage — using herbicides instead of cultivation for weed control, with stubble or other residues (such as cane trash) retained after harvest until the next crop, or pasture, germinates — as a proportion of all cropped land.

Rationale

Significant reduction in erosion from farm lands has been repeatedly demonstrated in all environments, but particularly of water erosion from summer-dominated rainfall regions and wind erosion from Mediterranean climates and mallee lands in Australia (Cornish and Pratley 1987). Systems of reduced cultivation, which do not rely on repeated, severe mechanical disruption of bare soil to obtain weed control and seed beds, have been developed and adapted to nearly all soil–climate combinations for Australian crop lands. A greater degree of control of erosion, together with increased water-use efficiency through infiltration, is achieved when trash and stubbles are retained — not burnt or ploughed in. This combination of practices is recommended by all State agricultural and soil conservation agencies to minimise soil losses from cropping, and the degree of adoption of the more sustainable practice is monitored by this indicator.

Data sources

Area of cropped land is estimated annually by ABARE from field surveys (although they do not survey sugar cane, cotton or rice) and others for crop forecasting purposes, and additional remote-sensed Landsat TM data can be used to detect areas of opportunity cropping beyond the normal confines of the cropping belt. Collection of data on the proportion of land left exposed, sown with minimum tillage, or with stubbles retained is restricted to field surveys undertaken for special research purposes, and to occasional questions in the ABS agricultural statistics. Historically, estimates of fallow land were reported in the agricultural statistics, but this has been discontinued. A number of States request particular questions (at their expense) in the Agricultural Census, but these are not comprehensive across all jurisdictions. Improvements in questions posed through the Agricultural Census would be a valuable outcome of work to develop indicators of land resource use in Australia.

Analysis and interpretation

Summation of areas sown to minimum tillage with and without stubble and trash retention as a proportion of total cropped area would be made across SLAs per year. Error terms could occur in delayed planting or non-planting after working up, and in stubble/trash figures, and are difficult to estimate other than by taking separate surveys of farm responses or ground-truthing from road transect surveys across AERs. Checks will also be needed to assess those situations in which cultivation has been used as an exceptional measure to control mouse plagues, and other weed or pest outbreaks.

Reporting scale

As for 1.9.

Output/reporting

As for 1.9.

Linkages to other indicators

Should be used in conjunction with pressure Indicator 1.1A and condition Indicator 1.4, and to support the interpretation of 1.9. The NCPISA project is using a selection of practices in its "Implementation" attribute that include stubble retention (in some States), and experience with this project should assist further development of this indicator.

1.9B. Area of forested lands in which the legal framework encourages best practice codes of forest management, and the conservation of special environmental values

Description

This indicator combines Montreal Process Indicator 7.1D with part of Indicator 7.1E. Under Criterion 7, Legal, institutional and economic framework for forest conservation and sustainable management, Indicator 7.1D reads "Extent to which the legal framework encourages best practice codes for forest management, and 7.1E reads "Extent to which the legal framework provides for the management of forests to conserve special environmental, cultural, social and/or scientific values." The 1997 First Approximation Report (Commonwealth of Australia 1997) describes 7.1A as the legislative and administrative framework used in the Commonwealth, States and Territories, for both native and plantation forests and woodlands, to encourage best practice in management and use. The area of each Forest Region is designated by tenure, government agreements and biological attributes. Best practice is not described, but refers to codes of practice extant on dedicated public forested lands, and also applying in Tasmania and Victoria to private land used for timber production. There are minimum controls in some other States. Because Indicator 7.1E includes issues that are not part of Environment Australia's responsibility, the proposed indicator concentrates solely on the special environmental values. No details are proposed as yet.

Note: "The area of forest lands, both public and private, harvested for timber according to internationally agreed guidelines, to preserve forests from erosion and lasting loss of native tree vegetation" would be the ideal indicator, but information would be very difficult to obtain.

Rationale

This indicator will chart the voluntary compliance of the timber industry in following practices that are both environmentally acceptable and increasingly demanded for international trade in wood and wood products. The Montreal Process indicators have been selected because Comprehensive Regional Assessments (CRAs) of forest lands in Australia will provide much of this information in the future, although the first set will not be complete until about 1999 (Tasmania, Gippsland and Central Highlands only were complete in 1997) and will probably not be able to provide information about much privately owned forest and woodland.

In the form described by the Montreal Process, this indicator and its pressure equivalent (see Indicator 1.1B) are difficult to implement because of scarcity of data, particularly on privately owned forest land. In the assessments, detailed questions are asked about legislative frameworks for forest management, codes of practice etc., which requires intense involvement with all State forest and conservation agencies in supplying a larger range of information on forest stocks and condition than before, although information on forests under private title or effective ownership is less accessible. Reporting internationally through the Montreal Process, and state of the environment reporting, will increasingly require this type of information at the national level.

Monitoring design

The proposals for the CRAs and Montreal Process provide the framework under which changes to the legal framework at State/Territory and Commonwealth level need to be tracked. Consultation and repeated surveys with State forest and conservation agencies, forest industry associations and community groups within each Forest Region will provide the survey data to show the observance or otherwise of existing legislation. Information is more difficult to obtain from the nearly 70% of forests that are under private ownership or title; in these areas, a variety of methods has to be used including air-photo interpretation, road surveys, examination of production statistics etc.

Data sources

Primary sources are with State/Territory forestry commissions. Gazetted laws and programs, published Codes of Forest Practice (e.g. Victorian Department of Natural Resources and Environment 1996), with meta-databases and mapped summaries, are held by BRS, NRIC, and other parts of DPIE and Environment Australia. Possibly the Montreal Process Indicators 7.1D and E will be used directly in the future.

Analysis and interpretation

A lack of adequate information from some titles and tenures currently makes it difficult to ascribe particular practices to actual areas of forest resources, but the CRAs are expected to identify gaps and anomalies in the current legislative framework. Until these are addressed, no consistent Code of Practice across all jurisdictions is either likely or practicable. GIS-analysis of overlays and gaps between tenure type, legislative controls and IBRA boundaries could be systematically reported in tabular and text form.

Reporting scale

This indicator cannot be reported directly at Forest Region level (because of State legislative boundaries) but can be reported at regional and national level, given the use of additional GIS-analysis.

Output/reporting

Report annually internally as part of the CRA process within States and five-yearly in the national state of the environment/Montreal Process activity.

Linkages to other indicators

Links directly into the response indicator (1.9), to Criterion 7 of the Montreal Process and to other forest indicators. See Indicator 2.5 for a full description of the CRA program.

Issue 2: Physical changes to natural habitats
Indicators of Anthropogenic Pressure

Introduction

Several indicators proposed for this Issue had much in common with those suggested in the biodiversity indicator report (Saunders *et al*. 1998). These included:

- extent and rate of native vegetation clearing or major modification;
- location and configuration or fragmentation of remnant vegetation; and
- changes in the health and condition of native vegetation.

As native vegetation is in itself a key surrogate for biodiversity in Australia, it was most appropriate for the key indicators to be developed in the biodiversity report (Saunders *et al*. 1998). Supplementary contextual information on vegetation cover is provided here for interpretation of ecosystem functions according to land use and tenure conditions.

2.1. Key Indicator: Index of human accessibility related to landcover regions

Description

The level of accessibility of non-metropolitan communities to use or purchase of the full range of private and public sector goods and services — based on the equivalent road distance from the centre of each SLA to each of the nearest urban centres with populations in different size categories. This indicator should be related to the National Wilderness Inventory's "Wilderness Index" (1995), which provides a mirror-image of accessibility, described as intensity of human occupancy. It has also been considered as one of the attributes used in the NCPISA indicator of the socio-economic context of agricultural activities (SCARM 1998). By relating it to landcover regions, compatibility with the ILZ and ELZ can also be tested.

Rationale

This indicator reflects the impact of population density, plus services delivered, and is capable of assessment from local to national scale in a relatively simple manner using readily accessible data that can be obtained from existing, regularly updated statistics. It goes beyond the crude value that population density alone would provide for physical change to natural habitat by including total servicing (which is a surrogate for the range of human activities not covered by specific sectoral indicators), while still being easy to measure and regularly update. Assessment of a prototype indicator has been undertaken by Professor Graeme Hugo (University of Adelaide) and Dr Don Hayman for the NCPISA project (SCARM 1998).

Monitoring design

Annual estimates of resident population plotted as density of population at SLA scale as one GIS layer, and the equivalent road distance from the centre of each SLA to each nearest urban centre, with populations of ranked size measured comprehensively by polygon across the continent as the interpretive layer. These data can be updated regularly on an annual to triennial basis. Nested sampling for ground-truthing surveys should be related to regions showing the greatest change in the previous monitoring period.

Data sources

Population statistics can be obtained annually from the estimated resident population (ERP) figures produced by the Australian Bureau of Statistics as annual updates for each SLA for the years between censuses. These can be used to calculate the simple annual rate of population growth and decline, and densities are computed on revised area figures for each SLA.

Analysis and interpretation

Goods and services provided to Australian populations are closely related to, and in the case of public sector services determined by, population numbers in urban centres. Urban centres of service distribution would be ranked by population in five groups as follows: 250 000 or more; 50 000–249 999; 20 000–49 999; 5000–19 999; and below 5000. These would be plotted on AUSLIG 1:250 000 maps (which have all wards on them), together with the most recent census data on urban centres, location of centres and SLA boundaries so as to show changes in these features from report to report. The index would then be a ranking of 1 to 6 on accessibility by population density, constructed as isolines in mapped form.

Reporting scale

1:250 000 base maps and up to 1:5 million aggregation for national reports.

Output/reporting

Maps of ranked index values of accessibility.

Linkages to other indicators

This indicator should be compared with the wilderness index (National Wilderness Inventory), and the indicators of fragmentation and loss of native vegetation developed in the biodiversity indicators report (Saunders *et al*. 1998). It provides contextual information also for a number of other indicators in this report. Population density is covered in the Human Settlements report (Newton *et al*. in prep.) under indicators of demographic change and density distributions.

2.2. Key Indicator: Percent of each IBRA region lost to development relative to percent already affected by native vegetation loss

Description

Area of land (or numbers of developments), per IBRA region, lost to land development that has disrupted and altered native habitats; this includes communication routes, urban expansion, coastal structures (ports, marinas), new farmlands and irrigation schemes, tourist and recreation parks and manufacturing sites, reported by States and Territories. Reporting on a State and SLA basis will allow identification of regions most under threat.

Rationale

Fragmentation of native and naturalised habitats increases as land dissection progresses through more and more roads, subdivision and building of structures. In some European regions, this dissection is giving rise to real alarm over the conservation of all forms of biota (e.g. in England, where it is projected that a further 10% of land will be occupied by new houses in the next 15 years, while in western Germany 40% of land is expected to be). Changes occur in policy and attitude over time, and we can expect a continuance of shift by government in the relative amount of land approved for clearing. At State/Territory level, one State (South Australia) currently has legislation that requires approval for any native vegetation to be cleared, and two others have legislation requiring approval for areas of more than 0.4 ha (Victoria) and 1.0 ha (WA) to be cleared. In several States, historical approvals or requirements to clear exist as part of earlier land development schemes. Legislation and policy is still piecemeal in Queensland, New South Wales, the Northern Territory and Tasmania. Most urban and industrial expansion is approved at local government level, with variable provision for environmental protection. The legal framework of land clearing regulations (Table 6.8 in Chapter 6 of *Australia: State of the Environment 1996*) provides the baseline framework for assessment of future change.

Data sources

State, Territory and local government records of clearing permits, planning permits, government plans and development proposals. Data from Commonwealth and State departments of regional development, State departments of lands, agriculture, roads and transport, and annual budget statements to State parliaments can be supplemented by remote-sensed coverage from Landsat MSS and local government reports.

Analysis and interpretation

A priority ranking is needed to identify those biogeographic regions that are already significantly altered by complete habitat loss and severe habitat degradation, relative to those that are little affected. This ranking would be developed through Environment Australia's Biodiversity Group and other qualified sources, and applied to data across various IBRA regions to identify areas of higher risk of ecosystem disruption.

While ranking should take into account the uniqueness of the habitats involved (heritage, conservation gazettal status, refuge status for endangered species), it is the current status of ecosystem function of each IBRA region that should first determine the priority ranking for this indicator. Far less attention has been paid to this aspect (see Schulze and Mooney 1994) than to species-level biodiversity. The issue addressed here is the extent to which particular functions such as nutrient and metal filtering by wetlands in the landscape, protection from erosion by land cover, sequestration of carbon, and rainfall infiltration rather than run-off are being performed within particular habitats.

Reporting scale

Regional to national scales, using aggregation of local planning permits and calculated areas affected, on a three to five year timescale.

Output/reporting

Published lists of priority IBRA regions ranked on risk of habitat loss, with associated electoral and administrative boundaries.

Linkages to other indicators: This indicator should be used in conjunction with the Biodiversity Indicator "Integrated regional planning", and can supply data for indicators developed for Atmosphere relating to net carbon balance (sequestration and consumption). The pressure Indicators 1.12C and D (minesites and unsealed roads etc.) and 1.3 (Change in percent catchment permanently sealed) provide input data to this indicator. Response Indicators 2.7 and 3.5 should be assessed in parallel with this indicator.

Issue 2: Physical changes to natural habitats — Indicators of Condition

2.3. Key Indicator: Change in land use by catchments, AERs and landcover regions

Description

Area of each land use, described under a standard classification (agreed by AUSLIG, Environment Australia, NRIC with ABS in a consultative process) on the basis of including forestry, agriculture, pastoralism, non-agricultural Aboriginal lands, conservation and recreation, defence, water catchment, multiple use, and urban residential and commercial. Tenure type may be used as a surrogate in some cases. Estimates reported for three regional classifications: catchments, agro-ecological regions and landcover.

Rationale

Different land uses are the major reason for differences in environmental condition. However, data on change to land use are not routinely gathered by ABS in a geocoded manner, and land use change data in this form will need to be collected on a shire basis, using lands department and other records. Tenure titles are only a partial descriptor of actual land uses. For example, some Aboriginal lands are used for traditional hunting and gathering activities while others are run as pastoral properties continuing their historical use. Freehold rural lands may be harvested for timber as well as run as farms, and pastoral leasehold lands may support eco-tourism or mining exploration. Multiple-use tenures are common in forested regions and local government development zones.

Changes in land use are expected to continue to occur at the same rate as in the past ten years, or faster. The principal drivers to land-use change are economic, and economic interventions by governments (subsidies, taxes etc.). Current examples that are driving change are: economic failure from current land use (applies chiefly to rangelands); declining rural incomes (wheat–sheep belt); increased preferences for a semi-rural lifestyle; job growth reasons (through much of the eastern seaboard, south-western WA and the hinterland of the Melbourne–Sydney axis); and economic opportunities (intensification of agriculture, horticulture and mining scattered over many districts).

Data sources

While AUSLIG tenure mapping and State and Territory lands departments provide the major published information on tenure locations, data on actual land use must be obtained from a wide variety of different sources. For example, the boundaries of LGAs are established in State and Territory departments of lands, converted to SLA boundaries in the ABS, geocoded as such by AUSLIG, and then re-sorted and redefined by many agencies for special purposes. Copyright and ownership of these published forms is a complex issue. Some assistance can be obtained from interpretation of Landsat TM coverage, but ground surveys are needed to distinguish many agricultural activities, and activities in woodland coverage. ABS data sets from the Agricultural Census, Population and other socio-economic census collections have limited value below collection district level as yet because the data are not geocoded, but these data provide the best fine-grained information at that scale.

Analysis and interpretation

Definition of land uses require standardisation. Definitions according to Taxation Act requirements and tenure and title conditions are less satisfactory than bio-physically based definitions that reflect actual practices. There is no difference, from an ecosystem function perspective, between land management for pastoral and conservation activities in arid interior regions if the result in both cases is over-grazing — by sheep in one instance and rabbits in the other — and invasion by the same weed spectra. The difference between agriculture and pastoralism, however, provides a useful distinction in terms of number of inputs, diversity of operations, range of plants and animals deliberately introduced, total scale of landscape alteration through clearing, cultivation and replanting, built structures, density of population etc.

Reporting scale

Mapped at 1:250 000 with aggregation by SLAs to AERs, or by superimposition of polygons to landcover regions, to scales of 1:1 or 5 million.

Output/reporting

On a three to five year basis, by maps with accompanying text giving description of change with, where evidence exists, explanation of reasons for change.

Linkages to other indicators

Links to Indicator 2.1, and to 2.6 to 2.9 on response to physical changes to natural habitats, and to Marine Indicator 7.2 "Catchment development" (Ward *et al.* 1998).

2.4 Key Indicator: Landcover change: proportion of each region covered by forest, wood, shrubs and grasses compared with 1990 baseline, by landcover and tenure

Description

This indicator will update the areal change in structural vegetation forms within landcover regions initially described, geocoded and mapped for the period 1790–1990 by Graetz at al. (1995) at 100 m^2 for both the Extensive and Intensive Landuse Zones (ELZ and ILZ), and now being repeated at finer resolution using Landsat MSS under the Landcover Change Project 1990–1995 (managed by the Bureau of Resource Sciences), at 30 m^2 resolution for the ILZ, reported at 100 m^2. These studies form the baseline for a structural stratification of vegetation cover. The ELZ updates will be provided through the Rangeland Monitoring Strategy program.

Rationale

Structural changes in vegetation forms and habitats within a region are documented by this method. Structural classifications follow the scheme originally devised by Specht (1970) with notation of Beard and Webb (1974). The 1995 landcover classification (Graetz *et al.* 1995) distinguished change by fire, clearing, grazing and feral animal invasion by inference from other data sources. Other changes that may be assessed are changes to total vegetated area (by subtracting area of impervious sealed land, Indicator 1.3), afforestation or woody weed invasion. To be authentically validated, all need to be verified by ground-truthed records that confirm or disallow interpretations of remotely sensed scenes. The Landcover Change project will provide the most reliable structural database as a baseline in the more intensively used parts of the country (ILZ).

Changes in vegetational structural form — for example, from wood to grass — affect carbon and nitrogen cycling, litter and organic matter build-up and loss from soils, wetting and drying soil and hydrological regimes, and the gamut of interactions between decomposers and consumers, irrespective of biodiversity considerations. The landcover regionalisation is therefore the most appropriate to use here — not IBRA, which would not provide as much baseline information on the current structural status and associated influencing factors. A stratification within landcover categories for tenure was provided in the original 1995 baseline study. It was a somewhat arbitrary grouping of tenure types constructed to rank relative vulnerability of land to future disturbance. Future studies that analyse changes using this tenure grouping will be able to assess whether such rankings are justified.

Monitoring design

Comprehensive coverage using the ELZ and ILZ stratifications of Graetz *et al*. (1995), with refinements of the initial 1980–90 coarse coverages to finer-scale detection in the 1990–95 coverage and subsequent revisions. The ideal analysis will provide a more accurate identification of vegetation, rather than attempting attribution of the reasons for change (because other indicators will provide that in more detail than is possible for the land disturbance study). Where possible, information contained in the Comprehensive Adequate Representative Reserves system should be used as a detailed reference or baseline. A five-year repeat coverage is suggested, except in areas that are changing rapidly. Ancillary information on understorey vegetation is now available through the Atlas of Australian Vegetation Communities (Specht *et al*. 1996), with important information on rarity status for the biodiversity indicators.

Data sources

The primary source is the original and updated data sets of continental digitised Landsat TM and MSS scenes at resolutions of 0.005x0.005° and less. These are available on CD, and subsequent coverages will also be available if processed through Environment Australia's operations. Additional data sources which are needed for interpretation of remote-sensed scenes in wetter, cloud-covered or rapidly changing environments require various types of ground-truthing, such as monitored reference site records (see Indicator 1.1. and sub-indicator 1.2).

Analysis and interpretation

Change in vegetation structure reported every five years as percent change in area in each of the four categories forest, woodland, shrubland and grasses, presented in tabular form and with example image scenes, for each of the 34 landcover types. Annual crops and pastures are allocated to grasses, and perennial crops are allocated to either shrubland or woodland depending on size and density. There is a significant interpretation issue regarding the distinction between closed and open forest canopies at present, but the completion of the Landcover Change Project should remove this problem.

Reporting scale

Repeats on the basis of the original reports would involve a 25-hectare grid analysis of the whole continent presented in aggregates for the 34 regions, but future reports can also provide reporting at finer scales for selected catchments and sensitive areas.

Output/reporting

A continental summary, and tabulation of the percent change in the four structural types in each of the regions.

Linkages to other indicators

Links directly to pressure Indicator 2.1 and the biodiversity indicator "Extent of clearing and location and configuration of remnant native vegetation" (Saunders *et al*. 1998).

2.5. Extent of area by forest type, relative to total forest area, and location within catchments, by tenure

Description

This indicator is an extension of Montreal Process Indicator 1.1A, "Extent of area by forest type relative to total forest area", and measures the net area of closed (>70% crown cover) and open (30–70% crown cover) forest categories per reporting period, stratified by floristic and structural form (Commonwealth of Australia 1997 and Specht 1970-based classification). It has added to this by relating the location of forests to their position within catchments relative to terrain, and incorporating tenure class.

Rationale

Forests have particular ecosystem functions, particularly in higher rainfall environments. They generally form the natural watershed environment to higher topographic elements, protecting more steeply sloping lands from rapid erosion as well as providing most harvested timber, many distinctive habitats relevant to species biodiversity, and a number of highly valued aesthetic qualities. For this reason, it is recommended that the Montreal Process Indicator 1.1A be extended to include an analysis of the relationship between location of forests and topography. Other indicators of biological diversity under Criterion 1 that include measures of forest extent, age structure and fragmentation are treated in the biodiversity indicators report (Saunders *et al*. 1998).

The present report does not view the volume of timber extracted as a significant issue for state of the environment reporting responsibilities; as a trade and industry issue, it is reported annually by the Department of Primary Industries and Energy (ABARE Annual Reports). However, tenure classes are proposed as a significant reporting stratification because of the disputes and public concerns that have arisen over the degree to which forests in different categories of public ownership — particularly the 35% classified as "multiple use forests: Public 1" (Resource Assessment

Commission 1990) — are managed for timber production relative to other types of use. Our particular interest is in management for the preservation of ecosystem functions, of which control of watersheds against erosion, carbon sequestration and nutrient cycling are the most important.

The National Forest Policy Statement of the Commonwealth Government, March 1995, reviewed all forestry activities and established the process of Comprehensive Regional Assessments (CRAs) to identify the economic, social, environmental and heritage values of forests. These CRAs will eventually provide the information on long-term management of forests needed to safeguard the biodiversity, old growth, wilderness, amenity and catchment values of forests within a system of reserves, and allow commercial uses in areas outside. The system is being developed for forests, but not woodlands. It is expected that the CRAs will provide a set of final indicators, harmonised with the Montreal Process, that have been achieved through inter-governmental consensus. The present proposals should be viewed as interim suggestions (Hnatuik pers. comm.).

Monitoring design

Estimates of forest type and extent are made using vegetation maps derived from 1-km resolution AVHRR satellite data and 30-m resolution Landsat TM imagery by the National Forest Inventory (undertaken in the Bureau of Resource Sciences, 1990–94) and currently being updated by the Comprehensive Regional Assessments of Forests (BRS, 1996 and onwards). The aim is to compile an integrated data set by forest regions of the following categories: overall area of forest land; area under forest production stratified by private and public ownership; area of forest reserve and protection, areas of multiple use; and forested catchments designated for water supplies. Forests are mapped by forest type (dominant species and height), as percent of total forested area.

Data sources

By the next State of the Environment Report (2001), it is expected that the CRA process will have gathered most of the relevant data under the custodianship of Commonwealth agencies such as BRS, Environment Australia and NRIC. Current commercial timber extraction figures are gathered by ABARE and the National Plantations Inventory of Australia (1997), but thinning of non-commercial species, regrowth estimates and change in species composition will require additional data collection and analysis. To provide time series, historical data sets on earlier extents will have to be compiled from earlier mapping of land clearance activities using State and Territory lands department figures.

Analysis and interpretation

The reporting area should be broadened to include thinning or patch loss through extraction of commercial and non-commercial species, fires and disease. These data need to be geocoded and compared with the nine second digital terrain model (DTM) of catchments to identify where forests occur, by plotting on a terrain layer of GIS by forest structural type. The net standing biomass per forest type (standardised across regional jurisdictions), with total area of local thinning or replanting/regrowth, should be computed.

Reporting scale

Areal extent maps are currently available over scales of 1:25 000 to 1:1 million, depending on remoteness and the adequacy of Landsat coverage. CRAs are not intended to be aggregated to national scale. Historically, State and regional forest management and legislative frameworks have arisen separately, and these in part reflect real differences in forest type, structural form, growth and ecosystem dynamics. The main reporting scale will therefore be regional (Tasmania, Gippsland Victoria, South-East (NSW), Central Highlands, South-West WA etc.). Total values for major attributes (net annual biomass production, total forested area thinned, cleared etc.) can be reported nationally, however, from summation of the regional statistics without loss of validity. These will complement current commercial production figures produced annually.

Output/reporting

In 1998 there is a planned State of the Forests report separate from the Montreal Process, but in future the intention is for reporting on sustainable forest management to be tied more closely to the Montreal Process reports. Hence, there is a strong imperative to align Montreal and State of the Enviornment Reporting indicators as closely as possible. A separate critique of the relevance of other Montreal Process indicators to the Land Resources Indicators Report is given in Appendix 2.

Linkages to other indicators

This indicator links to the Vegetation Clearing indicator developed in the biodiversity report (Saunders *et al.* 1998), and to other specific forest indicators in this report (i.e. 1.9B and 2.4, as well as 5.2, 5.5 and 5.8 relating to carbon sequestration).

Issue 2: Physical changes to natural habitats

Indicators of Appropriate Response

2.6 Fire control measures compared with natural fires, related to landcover regions

Description

A composite indicator that assesses the frequency and location of fires deliberately initiated for vegetation control (forest services, pastoral and farming), compared with the number and extent of fires that are started accidentally or as deliberate vandalism by people, and those that are natural.

Rationale

Fire management is a complex issue in Australian ecosystems. Natural fires (caused by lightning) have been an integral part of the development of indigenous Australian flora since the Tertiary (White 1986), with many fossil records and present examples of species that require fire to germinate and regenerate. The extent of fire-dominant vegetation communities was enlarged significantly by Aboriginal practice, probably over most of the natural grassland regions and open forests of pre-European occupation (Pyne 1991), and as shown on the Carnahan 1788 map of Australian vegetation (AUSLIG 1992). Annual burning was common in these environments, whereas the wetter forest areas were probably not subject to fire more than once every 200 years or so, because many forest species are easily killed by fire. The location of today's frequent fires around the periphery of metropolitan areas in the southern and coastal parts of the continent is historically abnormal, as is the cessation and reduction in the amount of burning over much of the semi-arid interior since European settlement and, for example, the expansion of the Pilliga forest (NSW) due to reduction in burning. These changes have altered the essential nature of particular vegetational communities. In pastoral regions, the reduction in fire has been associated with expansion of some intractable weeds (e.g. rubber vine in Queensland and NT), while in areas that are now burnt annually but previously were burnt only infrequently both floral and faunal compositions have altered. The indicator proposed here is intended to summarise current attitudes and practices towards human-initiated fires and assess how well they accord with the areal extent of deliberately altered fire regimes (Indicator 6 in the biodiversity indicators report (Saunders *et al*. 1998) and natural fires.

Monitoring design

A suggested method could be to: 1. plot the location of recorded major bushfires and fire-fighting activities (classed as "human disaster fires"); 2. separately, compare maps of known fire scars (see data sources) for each State/Territory, and for landcover regions ("natural or inadvertent fires in remote areas"); and 3. assess the effects in areas deliberately burnt ("deliberate cool burns"), with research results on the effects of burning on biodiversity, vegetation growth and condition and biomass change. The intention is to distinguish fires which are the result of inadvertent or deliberate incendiary action by people, and which are dealt with as disasters to control, from those that occur in areas that are either subject to recurrent fire (often natural) remote from people, and from fires that are deliberately lit for vegetation control (e.g. cool forest burns and stubble management).

Data sources

National disaster and emergency fire-fighting statistics, State/Territory departments of lands administration data, and local fire board records. DOLA's remote sensing operational mapping is particularly impressive, and contradicts maps in ABS 1996 and the State of the Environment Report that suggest that fire-affected areas are predominantly in the coastal south-eastern and south-western regions. Data are also available from CSIRO's fire research unit, and from forestry department records (NB, forest services do not always show actual areas burnt, but only areas "treated for burning"). See Cheney *et al*. (1980).

Analysis and interpretation

The analysis should show the relationships between the reasons for fires, the attempts made to either initiate or control them, and the locations of fires relative to the historical and prehistorical pattern of fire in each landcover region. Analysis of population interactions may require some contextual indicators from the human settlements report (Newton *et al*. in prep). The fire management responses to each category (fire-fighting, research, legislation) relative to the areal extent of deliberately altered fire regimes (Indicator 6 of the biodiversity indicators report (Saunders *et al*. 1998) and all fires mapped would form the primary report.

Reporting scale

At landcover regional scale, with sufficient local detail to distinguish different types of fires in those regions where deliberate, natural and accidental fires occur.

Output/reporting

Maps of distribution of natural and initiated fires, with a tabular matrix of categories of fire relative to landcover regions. A classification system should be attempted, subject to available archaeological and palaeobotanical evidence that shows how far current regimes differ from those of the pre-European and pre-historic periods.

Linkages to other indicators

This indicator is linked to Indicators 6 and 21 of the biodiversity indicators report (Saunders *et al*. 1998), and to population density indicators developed by the human settlements indicators report (Newton *et al*. in prep.). It is a contextual indicator for the indicators of vegetation change and condition in this report, and the biodiversity indicators (Saunders *et al*. 1998) and atmosphere indicators reports (Manton and Jasper in prep).

2.7. Rate of urban infill and increase in housing density relative to rate of urban expansion and rural subdivision into non-built-up areas

Description

The degree to which housing and population density increases within current (1995 baseline) metropolitan and urban designated areas, relative to the extent to which expansion of metropolitan and urban limits continues. Areas of rural subdivision (into 5–20 ha parcels) to be plotted as indicative of future zones of expansion.

Rationale

Australian cities sprawl, and reflect the fact that most have been built on cheap, flat land during the car-dominant era, when within-city journeys have been of the order of 50 km, not 5 km as in earlier eras. With increasing population and standards of living, such extension in urban size has been significantly challenged by concerns over atmospheric pollution, inability to deliver essential services and the threat of loss of valuable natural habitats (especially as many cities are located on flood or coastal plains, with loss of wetlands and contamination of groundwaters occurring very frequently). Internationally, these concerns have been addressed by major resolutions (e.g. Habitat 2 United Nations conference, 1996), calling for renewal of city centres, infilling of low-density residential districts, and a halt to extensive fringe development beyond city limits.

Monitoring design

Using 1995 urban and metropolitan limits as the extent of current areas, examine metropolitan and urban planning strategies, plot designated residential zones beyond current limits, and rank local development plans and zoning projections on projected time-of-development for all major cities and towns. Assign a classification, based on area affected, of the relative proportions of infilling to expansion for each segment of major cities, and as a single quotient for each smaller town. Contextual information on areas of particular conservation significance that are threatened by both infilling and expansion will be required.

Data sources

Local government and State/Territory planning department records and published planning scenarios. Special projects and transport route projections from relevant departments. Aerial photo coverage for annual updates and assessments of change on the ground.

Analysis and interpretation

Relative areas and numbers of people affected by infilling and expansion per urban area to be ranked against National Heritage areas, conservation areas and locations of rare and endangered biota. Areas zoned for residential development to be ranked as areas of expansion, and areas of rural subdivision (greenfields developments) to be ranked as having a high probability of increased residential housing and road density in future.

Reporting scale

Regional, with a national summary.

Output/reporting

Table of ranked urban areas and associated habitats affected, with text explanation.

Linkages to other indicators

The human settlements report's (Newton *et al*. in prep.) indicators "Amount of land converted to urban use" and "Residential density" are complementary to this indicator. This indicator will assist in the interpretation of indicators of water quality in the inland waters (Fairweather and Napier 1998) and estuaries and the seas (Ward et al. 1998) indicators reports. Several biodiversity indicators (Sunders *et al*. 1998) are also relevant.

Issue 3: Hydrological imbalance

Indicators of Anthropogenic Pressure

3.1. Key Indicator: Ratio of area of catchment under perennial: annual vegetation, as proportion of total catchment (report also by State)

Description

A GIS-derived value of the area of each major catchment minus that of standing water and impervious land (Indicator 1.3), with the area under perennial vegetation estimated separately from that under annuals plus bare (unsealed) ground (Indicator 1.1). The indicator would be expressed as Aper:Aann / Areatotal - (impervious + water) . This indicator has most relevance to the ILZ. Because the identification of perennial and annual zones within a catchment may prove impracticable in parts of the rangelands, as woody perennial vegetation (eg. mulga) is interspersed with short-lived ephemerals after rain when surface soil wetting breaks seed dormancy, an intermediate category of "naturally interspersed" perennials plus annuals will be required in some IBRAs.

Rationale

The significance of deep-rooted perennial vegetation in controlling excessive discharge of salt and metal-laden waters to lower parts of landscapes and ground and surface waters has been repeatedly recognised in Australian environments (AWRC 1991). The form of vegetation is of less significance, with grasses, herbs and shrubs — such as phalaris, lucerne and tagasaste — being as effective as trees in many environments (Taylor *et al.* 1996). Annuals are less effective because of the limited rooting depth that they can attain, and shortness of respiration period relative to seasonal water movement and rainfall events. Infiltration through bare ground is of the same order as through annuals, whereas perennial grasses act as "wicks" in the landscape for water that would otherwise run off from out-of-season storms. Agricultural catchments that are largely dominated by annuals might start with a low ratio, but changes in practice (such as agro-forestry, stream-line fencing and stock removals) may increase the ratio over time as an indicator of adoption of sustainable practices.

Data sources

ABS statistics are of relatively limited value because agricultural production is not yet geocoded, and grazed lands are ubiquitously described as "pastures" without always distinguishing plant type or cultural practices. There are commonly large discrepancies between land areas summed from Agricultural Census statistics and total areas reported as being in agricultural land use (NCPISA evidence). Land uses in non-agricultural regions are not systematically reported for vegetation type. More reliance must be put on remote-sensed (Landsat TM and MSS) data than is ideal, but crop estimates (Crop Forecasting services to ABARE) provide annual minimum values of annual crop areas. Remote-sensed (aerial photography and Landsat TM) scenes of forest that can be unambiguously identified as permanent perennial vegetation are required as the basis.

Analysis and interpretation

The location of perennials within the landscape must be determined if the information contained in this indicator is to be fully utilised, and a digital terrain model (DTM) will be needed to interpret the effects of their distribution. Perennials located high in the landscape (see Indicator 1.5, "gullying index") may control water movement through recharge zones of groundwater bodies and overland flow that contributes to run-off and gullying. Perennials located at the base of slopes can utilise excess water shedding from slopes, especially where duplex soils give rise to sharp differences in hydraulic flow rate and direction, and deep-rooted perennials in low-lying parts of the landscape help reduce localised waterlogging. A GIS approach will allow the area and location of perennials to be estimated at catchment scale. Where the total proportion of catchments under perennial vegetation is less than a conservative threshold (e.g. 30% in South Australia), hydrological disturbance — including salt movement, phosphate movement and shallow groundwater rise — and erosion are likely to continue as threatening processes.

Reporting scale

Basic monitoring scale at catchment level, with aggregation up to AERs and States (because of differences in clearing legislation and farming systems), to national.

Output/reporting

As tables and maps, with text explanation, and trends plotted by major basins, AERs and States over time.

Linkages to other indicators

This indicator forms one of a set of three, together with 3.3 and 3.5, to report on the land management changes that affect hydrological regimes. Links also to inland waters indicators of groundwater (depth to watertable), and physical change (waterlogged soils, vegetated streamlength).

3.2. Number of freely flowing bores per artesian basin (by State and AER) relative to numbers capped or regulated

Description

Number of recorded, unregulated artesian bores, deliberately drilled for stock and other water purposes, and their location within each artesian basin underlying pastoral activities, relative to the number of such bores regulated or capped through Commonwealth–State/Territory bore capping programs in the same localities, per recording period.

Rationale

Artesian bore water is a significant resource for the pastoral industries, but the rates of replenishment are low compared with rates of extraction in some heavily used basins, and groundwater pressures are dropping. This issue is of concern to the sustainability of rural industry itself, and is also a contributing cause of extensive grazing pressure by all grazing species in the arid region because the density of bores is now so great in some basins that almost no vegetation is out of the daily range of herbivores except in conservation areas. It is estimated that about 95% of current artesian groundwater discharge is wasted because of the uncontrolled flows and use of open earthen drains to distribute water across properties (Russell 1996). Approximately 5000 flowing bores and some 25 000 sub-artesian bores have been drilled for pastoral, domestic and town supplies in the Great Artesian Basin alone, and flow rates have declined from 2000 ML per day in the early twentieth century to around 1200 ML per day today. More worrying is the fact that much of this has resulted from a spate of new bores drilled over the past two decades, as the result of recommendations to the pastoral industry to reduce the impact of localised over-grazing in the immediate vicinity of watering holes. The impact of the resulting increased extent of grazing pressure on a range of trophic levels has been assessed by James *et al.* (1996a and 1996b), who demonstrate the overall negative effect that increasing the number of stock bores, and decreasing the distance between them, has had on vegetation condition and biodiversity. Surveys of species distributions across transects showed that the majority of the chenopod and savanna-grassland pastoral regions are losing species as a result of the land being subject to grazing continuously, with few areas outside a day's grazing distance of a bore (12 km for cattle, 5 km for sheep).

Monitoring design

A comprehensive assessment, using all known registered bores with geocoded positions, and a classification based on as full a description of their current state as possible — using the following attributes wherever the data exist:

- purpose of bore (stock, household, town, other or none);
- status (free-flowing as a proportion of the total (i.e. including regulated, pumped), use and wastage of water);
- natural or created (mound-springs or drilled, conservation value or water loss); and
- degree of animal regulation (distance between stock bores, level of enclosure, valve control).

Utilisation of the data from the joint Commonwealth/State/landholder program to rehabilitate bores and cap unused bores, to allow an evaluation of the degree to which this program is capable of: a. achieving more sustainable water use; b. reducing adverse impacts on biodiversity; and c. assisting the control of pest and weed spread in the rangelands.

Data sources

Data can be obtained from AGSO and departments of mines, and from remote sensing (Landsat MSS), on numbers of bores and their status, and from DPIE on the bore-recapping program. Note should be taken of the number of recommendations and advisory publications issued through pastoral boards and State/Territory departments of agriculture and primary industries that have encouraged the drilling of additional bores, and the difference in attitudes between advisers in these departments and in departments of environment and water resources.

Analysis and interpretation

The spatial density of flowing bores per landcover region per recording period is the primary indicator of significance, but interpretation of the effectiveness of measures to provide water supplies for industry and social needs without adverse effects on natural resources and biodiversity must take in as many of the parameters listed above as possible. Results should be expressed in terms of progress, or lack of it, in controlling waste of water, grazing impact and control of weeds and feral animals.

Reporting scale

At the regional scales of 12 artesian basins, with regional values of artesian groundwater pressures given on a decadal time scale as context.

Output/reporting

1:250 000 to 1:1 million mapping scales, and five-year reporting units.

Linkages to other indicators

This indicator links closely to the vegetation cover indicators developed in both this report and the biodiversity indicators report (Saunders *et al.* 1998), and to the indicators relating to groundwater quantity and quality developed for the inland waters indicators report (Fairweather and Napier 1998).

Issue 3: Hydrological imbalance

Indicators of Condition

3.3. Percent area of land affected by dryland salinity and by acidity, by catchment and AER

Description

The areal extent of land that is reported as having saline (EC values of >4 dS/m[2]) and/or acid (pH <6.0 in water[1]) soils within the top metre, in regions of Australia of greater than 250 mm annual rainfall, stratified by major catchment and AER. This indicator can draw heavily upon the Soil Condition attribute of the "Land and water to sustain production" indicator of the NCPISA project, already developed.

Rationale

Because Australian soils are old and much-weathered, and developed in climates where salts tend to accumulate, naturally acidic, saline, alkaline and sodic soils occur widely. However, the distribution of acidic and saline soils has been extensively increased by agricultural practices over the past 200 years, particularly in higher rainfall environments (greater than 250 mm rainfall). Because acidification and the use of acid soils for agriculture results in low water use by plants, it also increases secondary salinity. It is important that we know which catchments and which agricultural environments are most affected, and that they are treated together because they frequently occur in related positions in the landscape with reduced water-use from acidity contributing to downslope, near-surface salinity.

The principal reasons for increasing acidity are the export of agricultural products high in calcium, the use of acid-producing fertilisers (particularly ones containing ammonium and sulphate), the leaching of soluble anions (particularly nitrate) below the shallow root zone of annual crops and pastures, and the failure of agricultural systems to replace the calcium lost with dressings of lime. The principal reason for the development of secondary salinity has been the removal of deep-rooted perennial native vegetation and its replacement with shallow-rooted annual species, leading to lowered use of rainfall by plants and a rise in saline water tables in the lower parts of the landscape. Excessive use of cheap water in irrigation areas has raised naturally saline groundwaters close to the surface in some areas, contributing to the extension of induced salinity.

Both processes result in reduced water-use efficiency by plants, particularly in agricultural systems reliant on few plant species. Both have the potential to affect other ecosystem functions, such as soil invertebrate numbers and nutrient cycling and the survival and reproduction of non-adapted native flora, and to mobilise abnormal amounts of heavy metals and other trace elements into waterbodies and subsoils where they have harmful effects on a number of trophic levels.

Monitoring design

Because existing regional data sets and monitoring locations already contribute greatly to our knowledge of these factors, any future monitoring design should incorporate catchments and districts already well monitored. To assess effects on ecosystem function, however, the monitoring should extend beyond the current preoccupation with agricultural catchments. Monitored catchments in the Murray–Darling Basin, south-western WA and some coastal catchments up the east coast form a framework on which additional airborne surveys of near-surface salinity could be developed. The ACLEP reference site network, if established, would provide the most effective and logically developed design so far proposed. In its absence, the best designs are those that take a catenal transect from hill crests to river channel across soil sequences and slope change.

Data sources

Detailed monitoring of dryland salinity and groundwater salinity is being conducted in some parts of agricultural areas (eg. SW Western Australia, Liverpool Plains, south and eastern Murray–Darling Basin) using a combination of radiometric airborne scanning, EM surveys, hydrogeological monitoring etc., but estimates are not available for all catchments or land uses. Peri-urban areas are not monitored, nor most conservation parks or wooded regions. Naturally acidic and saline soils have been mapped historically over much of Australia and the data assembled in the Atlas of Australian Soils (CSIRO and NRIC) at 1:1 million, and

[1] The cut-off value for acid soil pH varies in different publications. While it is scientifically correct to describe soils as acid when they fall below pH 7.0 in water, no impairment of plant or rhizosphere microbial function occurs for most domesticated plants until below pH 6.0. The NCPISA project followed Spouncer et al. (1996) in using pH 6.5 in water, as the agreed mapping classification of acid soils but acknowledged that farmers who lime would normally only find it profitable once pHs reach <5.0. It should also be noted that pH is also measured in 0.01M $CaCl_2$ is between 0.8 and 0.2 units lower as pH reading falls from 8 to 4.

large additional regional databases can now be located through the NRIC metadata-base of the Barson and Shelley (1996) web site. Agriculturally induced acidity has been intensively studied for a number of regions in south-eastern, south-western and eastern Australia within the 300–700 mm rainfall belt, and much of this work has been collated through Land and Water Resources R&D Corporation publications and reviews (AACM and LWRRDC 1995).

Analysis and interpretation

GIS-based map distribution of categories of acid and saline soils interrogated for changes since the last reporting date. Currently some regions have 1990–1995 coverage, but many have no current baseline. Separate listings of those areas that are "hot-spots" experiencing rapid increase in extent, with distributional maps of these related to surface freshwater bodies, conservation regions of high priority and other inland waters and biodiversity indicators, would be prepared using the approach developed for the Murray–Darling Basin Commission (CRC Catchment Hydrology). Extrapolation from point-source sampling sites can be carried out with kriging interpolative algorithms to provide mapped distributions (CRC Soil and Land Management, CRC Sustainable Cotton Production mapping methods and LWRRDC continental coverage, 1996).

Reporting scale

From major catchment (or drainage basin) scale upward to continental scales.

Output/reporting

GIS-based map distributions of classes of acid and saline soils, at regional catchment and AER scales, relative to total area of soil groups and landcover areas in each region.

Linkages to other indicators

Links to indicators of water quality in the inland waters indicator report (Fairweather and Napier 1998), and to indicators of hydrological disturbance and of nutrient cycling (5.1, 5.3, 5.4 and 5.7) in this report.

3.4. Variation in plant water utilisation with landcover change

Description

The amount of rain falling per unit area that is utilised by green plant response, measured as a surrogate by use of the Normalised Difference Vegetation Index developed from NOAA–AVHRR fortnightly coverage, and compared with calculated evapotranspiration fluxes at the same scale. The NDVI is converted to class interval of the difference between the lowest-ever green response and the present season (or set of seasons). A numerical index is developed between the amount of rain falling per pixel (interpolated) and the NDVI class value using a plant utilisation factor derived from the plant cover type (IBRA coverage) and digital terrain model for localising distributional anomalies in rainfall. An early version of this indicator has been used for the NCPISA Indicators for Sustainable Agriculture.

Rationale

The direct effects of low ground cover, increased albedo and higher temperatures have not been yet been sufficiently tested in different regions to establish whether widespread changes in vegetation cover contribute to rainfall changes at the meso-scale in lower latitudes, but there are some published examples where reduction in grazing across semi-arid regions has been considered the cause of an increase in rainfall — such as the removal of Bedouin grazing from the Negev desert in Israel, or where vegetation depletion has been ascribed to rainfall reduction (Lyons *et al.* 1993). However, Courel *et al.* (1984) were unable to demonstrate relationships between overgrazing, drought and albedo in the southern Sahara. While these relationships remain speculative, it is true that in a continent where rainfall is low, and vegetation sparse, water utilisation is a primary factor in ecosystem functioning.

The NCPISA study has attempted to examine the relationship between rainfall and vegetation greenness, with an estimated plant transpiration factor derived from landcover classes. Independent estimates of continental evapotranspiration have been attempted by the CRC for Catchment Hydrology in a project that computes potential, actual and "wet environment" evapotranspiration for 39 regions of Australia, and using a previous radiation-based continental and regional water vapour and rainfall transport model (CSIRO Land and Water, Michael Raupach coordinator).

Monitoring design

The NDVI values are produced as a comprehensive, continent-wide coverage, with a 1 km^2 pixel size. Rainfall statistics are available from the 129 climatological receiving stations and supplementary recording stations. Because the distribution of Bureau of Meteorology climate stations is very sparse in the interior of Australia, rainfall interpolation algorithms (eg

Esoclim (Hutchinson 1989)) are employed to develop isohyets from weekly rainfall statistics. Daily rainfall statistics are not used, because of the high noise to signal ratio, when relating the vegetation response to rainfall amounts (Clewett *et al.* 1991). A vegetation utilisation (plant water uptake) factor is applied to the NDVI/vegetation surface quotient using the landcover mapping regions (Graetz *et al.* 1995) to normalise differences in plant water use. Comparison with the recently developed series of evapotranspiration maps of Australia by a collaborative team from the CRC for Catchment Hydrology, the National Climate Centre and the Bureau of Meteorology could be used in future.

Date sources

NOAA-derived NDVI and vegetation classification and coverage from Environment Australia. Bare soil and topography spatial estimates from a 9' digital elevation model (DEM) continental coverage (NRIC, Environment Australia etc.). Rainfall historical data sets from BoM CD-ROM for all continental stations over the past 100 years, with supplementary data interpolated using Esoclim-type (CRES, ANU) algorithms. Extrapolation from point-source sampling sites is carried out with kriging interpolative algorithms to provide mapped distributions (eg. CRC for Soil and Land Management and LWRRDC continental coverage, 1996). A 39-map volume of potential, actual and wet environment isopleth maps of evapotranspiration will be published by the BoM, and a full report and tabular material on evapotranspiration are in preparation at the CRC for Catchment Hydrology (Melbourne).

Analysis and interpretation

Water utilisation is expressed as the integral of the area under the curve of NDVI/vegetation range in response over seasons, normalised for plant-type water use, and the quotient divided by the sum of seasonal rainfall, per pixel. The weakness of the NCPISA methodology is that it may reflect the pattern of rainfall rather than the capacity of the system to respond to rainfall, and the interpolation algorithms may smooth out real spatial variations that are significant at local and mesic scales. Comparisons between regions with reference to the potential and actual evapotranspiration would provide some measure of validation for spatial variations. The temporal comparisons (variations at a spot over time) are the primary focus of the method developed to date. Aggregation of index values beyond 100 pixels may not be warranted until the methodology has been further developed.

Reporting scale: From 1 km^2 to 100 km^2 if aggregation of index values is attempted. NDVI-derived products alone can be reported at any scale up to 1:10 million.

Output/reporting

As a suite of maps for vegetation (landcover) regions, or major catchments/drainage basins, accompanied by text explanation and graphs showing changes over time for any high-priority locations (eg. areas of exceptional drought or flood).

Linkages to other indicators

Provides contextual information to the inland waters indicator issue of surface water quantity, and to interpretation of the changes to vegetation condition and extent developed in the biodiversity indicators report (Saunders *et al.* 1998). This indicator supplements Indicators 1.3 and 3.1 to provide an understanding of hydrological regimes operating in different environments.

Issue 3: Hydrological imbalance

Indicators of Appropriate Response

3.5.: Key Indicator: Index of measures to increase perennial vegetation cover, by area of catchment and AER affected

Description

A score developed from the number of catchments and/or SLAs with application of any, all, or none of the listed measures that can be used to encourage perennial vegetation cover. Proposed reporting as a ranked score and change in that score from one reporting period to the next. The listed measures are: 1. removal of grazing animals from target areas; 2. fencing to exclude animals; 3. tree planting and reafforestation; 4. use of tree plantations; 5. replacing annual with perennial pastures; and 6. rabbit control.

Rationale

Perennial vegetation may be promoted by a wide range of different measures. While tree planting is often the first that comes to mind (Landcare = tree planting for many!), the most effective large-scale actions are:

1. removal of grazing stock and vertebrate pests from target areas — by **capping unused bores,** large animal culling, and **destocking;**

2. **fencing to exclude grazing animals from waterways** and **areas of remnant vegetation** (see inland waters (Fairweather and Napier 1998) and biodiversity reports (Saunders *et al.* 1998));

Other actions to promote perennials include:

3. **re-afforestation as part of best forest practice,** and tree-planting for aesthetic, wind-break and water control reasons;

4. development of tree plantations (eg. SW Western Australia, southern Victoria);

5. **sowing perennial pastures in place of annuals** (eg. Southern Tablelands — phalaris, cocksfoot, lucerne); and

6. control of rabbits (calcivirus impact monitoring).

Most of these are reported in agricultural or forestry statistics by government agencies.

Factors underlined have been developed as individual indicators in other parts of this report, so a full treatment of each is not given in the description of the proposed indicator here. A composite indicator is suggested that incorporates those factors that apply within particular environments. Clearly, some activities are applicable to pastoral rangelands (eg. bore-capping) whereas others are applicable to agricultural farmlands (eg. fencing out of remnant vegetation). A "score card" approach is proposed.

Monitoring design

Stratify by drainage basin and agro-ecological regions to identify the environments where each measure or practice can or cannot be used. A binary score system could be developed for the number of measures that are, or are not, used within the region under consideration. Apply at local catchment and SLA scale to each part of region, and sum the values for each catchment or SLA to provide aggregated regional values normalised to a score out of ten. Repeat at three-yearly intervals to plot change in number of active measures.

Data sources

Fencing for land conservation practice is reported by ABS and special surveys by ABARE. Removal of grazing stock is generally a temporary measure related to drought (see Indicator 1.7B), and the effectiveness of vertebrate pest control programs is reported through SCARM subcommittees. Land use change causes permanent change in stock numbers (see Indicator 2.3), and correlations can be made between land use change and domestic stock numbers by SLA, using AgStats. Information on the effectiveness of tree-planting (by individuals, community groups and local councils) and the replacement of annual by perennial pastures is the most difficult to obtain, principally because of the variable ways in which pastures are recorded in AgStats for different jurisdictions and the inadequacy of questions on tree planting in the Agricultural Census. At local to medium scales, corroborative evidence from remote sensing will assist with tree planting figures, but pasture assessments will require phone surveys to local agronomists and agricultural consultants. Normal GIS layer coverages for tenure, administrative and physical boundaries, cadastral information from NRIC and Environment Australia.

Analysis and interpretation

Each measure that could be used would be located within drainage basins or AERs, using expert advice

(State/Territory departments of agriculture and environment), according to topographic and hydrological decision-rule criteria. The locations of existing or absent measures would then be recorded within each regionalisation (using a GIS approach), and the total number tallied against the potential maximum for the region. If, for example, the upper north-eastern edge of the Great Artesian Basin, coincident with the upslope parts of the Darling Basin, was the target region, the ratio of bores flowing to capped, the degree of destocking in drought, the proportion of total vegetation cover that is composed of perennial species as compared with ephemeral annuals (Landsat-assisted interpretation) and the effectiveness of pest culling programs would be assessed per SLA. Over the past decade, the rating would decrease for bores and increase for perennials: ephemerals (because of the increase in woody weeds). A3 weighting factor would be needed, unless all measures are considered equally effective. Relative effectiveness has been researched in some regions.

Reporting scale

Statistical local areas (or LGAs), probably excluding metropolitan zones, and aggregations to AERs and national, or catchments aggregating to drainage basins and national.

Output/reporting

Table of number of measures practiced by catchments within basins, or SLAs within AERs, with trends over time plotted as graphs per region.

Linkages to other indicators: This indicator should be used in conjunction with the equivalent indicators of condition and pressure relating to changes in hydrological balance and physical habitat (Indicators 3.1 to 3.3, and 2.3 to 2.5).

Issue 4. Introduction of novel biota into native habitats and communities

Indicators of Anthropogenic Pressure

4.1. Key Indicator: Rate of extension of exotic species into each IBRA, and of change in their abundance

Description

The rate of change in the distribution and abundance of alien species — including pathogens, weeds and feral animals (vertebrate and invertebrate) — in terrestrial ecosystems. A complementary indicator in the estuaries and the sea (Ward et al. 1998) and inland waters (Fairweather and Napier 1998) reports describes the rate of extension in terrestrial and marine aquatic systems. This is a composite indicator with a number of sub-indicators, as described in the Analysis and interpretation section.

Rationale

Alien species, where introduced without their natural competitors, predators, parasites and diseases, have affected Australian habitats and ecosystems in a variety of ways. The most conspicuous are predation on native fauna by cats and foxes and overgrazing by rabbits and goats, but they also include less obvious habitat changes such as damage to many native plant species by pathogenic fungi and by inadvertently introduced insects and molluscs (such as beetles causing eucalypt "die back" on the New South Wales tablelands, and Mediterranean white snail infestations of wetlands). While substantial effort is expended on trying to control many historically introduced alien species that are recognised and declared as pests, weeds and diseases through agricultural protection boards, the Australian Quarantine and Inspection Service and research institutions, this is insufficient to halt the inexorable stream of new species that enter the continent each year, or their subsequent spread across nearly all ecosystems. In the case of many of the worst known threats to humans and to commercial agriculture — such as rabies, foot and mouth disease, Newcastle disease, and anthrax — quarantine risk strategies have been extensively developed. Native biota, however, do not receive the same attention and investment, despite their vulnerability to competition from exotic species.

NOTE: It must be acknowledged that Australian agriculture is totally dependent upon exotic species. All crops, improved pastures, domestic animal and bird stock, tree and vine crops and plantations fall into this category. In addition, several million Australian gardens and thousands of kilometres of urban streets contain many thousands of exotic plant species, with their associated pests and diseases. Within the established areas of agriculture, plantation forestry and domestic gardens there has been substantial replacement of indigenous with exotic species. This is the current effective baseline from which to evaluate further spread and replacement. Few cultivated, highly domesticated commercial species escape successfully to survive, spread and become threats to other ecosystems, but they can revert to wild progenitors, and companion pest and weed species frequently spread rapidly. Many previous exotic species are now considered naturalised in Australia, with weed species examples from the *Asteraceae* (daisies), *Fabaceae* (beans), *Iridaceae* (lilies), *Poaceae* (grasses), *Cyperaceae* (cypress) and *Salicaceae* (willows) being the most widespread. A recent report (quoted by AQIS 1996) found 290 exotic plant species have become naturalised over the past 25 years, although many may have invaded much earlier. Invasive pathogens and insect pests spread very much more widely and rapidly than plants.

Monitoring design

This indicator would benefit from a Community Watch type program, equivalent to the network achieved with Waterwatch, with groups and individuals able to access a national database maintained on the Internet. Any design is hampered by the uneven distribution of population across Australia, but all monitoring activities should have a core set of parameters to measure including location, extent, abundance and rate of change in distribution of target species (where possible, eg. the National Weeds Strategy's 20 most environmentally important organisms, SCARM/SCC/SCF 1996). Data should be collected and catalogued by vegetation type within IBRA regions on land (and the equivalent for marine regions). All current institutionalised monitoring and reporting systems for monitoring alien species should be invited to collaborate, and be collated by Environment Australia onto IBRA locations, where geocoding referencing is available.

Data sources

Reporting arrangements already in place, through SCARM, of noxious weed, pest and disease declarations. Statistics from organisations and programs such as the Australian Quarantine and Inspection Service, the National Weeds Strategy, the Vertebrate Pest Committee and the Northern Australia Quarantine Strategy are reported regularly through technical sub-committees to SCARM. Equivalent reporting arrangements for selected native species and feral animals exist through ANZECC, from State and Territory conservation and lands agencies. Data on diseases and pests are also collected by conservation agencies, Environment Australia, and the CSIRO Divisions of Entomology, Plant Industry, Forestry and Forest Products, Animal Health (Geelong Laboratories) and Wildlife and Ecology. ABS publications now summarise some of these (McLennan 1996). Monitoring of weeds, pests and diseases has tended to occur on an ad hoc basis, however. A convenient summary of Australian vertebrate pest legislation, responsible government agencies and reporting procedures is given by Braysher (1993). Total numbers, weight and extent of agricultural species are reported in the full Agricultural Census every three years, although these values are not yet geocoded (for application into IBRA format). Garden and local government species distributions would be difficult to obtain, unless through such avenues as horticultural societies and commercial interests.

Analysis and interpretation

Data reliability maps are required for this indicator. Output should include geographical rate of spread, estimates of changes in abundance, and regions where concentrations of alien species are highest. Because this indicator is being developed as a pressure indicator, the opportunity exists to incorporate risk assessment protocols — already used in relation to the relative impact and management of diseases, pests and weeds of agriculture — in estimating the relative impact of various categories of exotic species on ecosystem function. Modelling scenarios of rates of geographic spread of weeds and diseases now and under future climatic conditions, developed using computer models such as CLIMEX (reviewed in Corey *et al*. 1993), are already used in providing management strategies for some alien invasions that pose grave threats to economic activities. Similar modelling of invasions into National Parks and conservation reserves is done on an *ad hoc* basis (eg. for estimating the spread of *Mimosa pigra* in the Daly River region and Kakadu National Park), rather than using a systematic and planned approach.

AQIS classifies exotic species as recent or established, with the latter being described as naturalised if they have disseminated over a wide area for several decades, and this classification should be used[2]. Domestic species deliberately maintained for commercial purposes, recreation, and amenity value are distinguished by their value rather than cost to society, and if included would need to be separately so identified.

Reporting scale

To be reported for each scale, from local government to national.

Output/reporting

Tables showing number of alien organisms within reporting regions, and changes between reporting periods. Maps showing the extent of invasion into each IBRA region by major pressure risk groups (under categories such as grazers, carnivore predators, diseases of fauna and flora, habitat competitors). Existing land areas occupied by agriculture, gardens and plantation forestry should be mapped as a separate category of "replacement habitats".

Linkages to other indicators

This pressure Indicator links to the condition Indicators 4.3 and 4.4, and the response Indicator 4.6 describing activities taken to contain and minimise the impact of exotic species. It is also linked to Indicator 3.1 of the biodiversity indicators report – under the Issue "Alien Species" (Saunders *et al.* 1998), and to the inland waters indicators report – under the issue "Biotic Habitat Quality" and the indicator "Introduced Species" (Fairweather and Napier 1998). A complementary marine and estuarine indicator – under the "Habitat Quality" issue indicator "pest numbers" (Ward *et al.* 1998) has also been developed.

4.1A. Number of reports of all, and of new, weeds, pests and diseases per AER and IBRA region

Description

The number of published records of new weeds, pests and diseases per year, located with reference to both IBRA regions and Agro-ecological Regions, totalled over the reporting period. This is a sub-indicator of 4.1.

Rationale

This information attempts to place the current rate of incursions in context against the existing level of exotic and naturalised species. It provides a minimum data set on the status of new weeds, pests and disease species, but will underestimate the total by the number that have no official status and are not covered by quarantine and other legislative requirements. Such species are frequently those that have either no economic impact on agricultural and forestry industries or change their status over time as environmental conditions or controls change. For example, a recent review of incursions of forest pathogens (Dudzinski, Old, Johnson and Kile, CSIRO 1995, quoted in AQIS 1996), noted that such incursions are difficult to detect because recognition relies on opportunistic discovery. It noted the irregular nature of surveys of even high-value commercial stands. Some previously insignificant weeds of crops, such as evening primrose and annual rye grass, have become resistant to herbicides. Others, such as *Parthenium* and rubber vine, out-compete natives as the habitat degrades. These are examples where the existence, or distributions, of weeds that have gone unnoticed in the past have been belated recognised.

Data sources

An excellent source of information has recently been gathered together for AQIS in four areas of incursion — pests (including vertebrates) and diseases of animals; pests and diseases of forest trees and products; pathogens of plants; and weeds. A further report on insect pests of plants is being prepared currently in the BRS (Clarke in preparation, quoted in AQIS 1996). The location of incursions and establishments is not always sufficient for reports to be identified for mapping purposes.

Analysis and interpretation

Spatial distribution, persistence and subsequent spread are three aspects of exotic incursions that are of particular significance environmentally. In most instances, however, it is the economic and human health consequences that are most rigorously investigated. Attempts to control exotics depend almost entirely on these two factors, as viewed by

[2] Not all reported incursions establish themselves. AQIS's recent report of the review of pests and diseases of animals incursions over the past 25 years lists 65 new incursions, with 18 of these established before 1971 but not detected till much later. By comparison, 562 plant pathogens were detected with 389 establishments, or a rate of two a year.

particular sectors of society. Rabbits and sheep both cause very significant erosion problems in certain parts of the rangelands, but CSIRO and State research agencies have invested enormous sums over the years in trying to eradicate the one and preserve the other. European blackberry *(Rubus* spp.) has been a declared noxious weed in many areas and is the subject of costly eradication programs, but is now being reviewed as a potential refuge for smaller Australian vertebrates against such introduced predators as domestic and feral cats and dogs. Certain native species whose natural distributions and/or numbers have been greatly extended by human activities (eg. galahs, kookaburras) may be considered as great a threat to some elements of native biodiversity as introduced species, but are not reported upon in the same manner. Kangaroos and dingoes, regarded as vertebrate pests by primary industry agencies, are not so classified by conservation agencies (see the distinction between the Vertebrate Pest and the Feral Animal Strategies of ARMCANZ and ANZECC). A thorough risk assessment of new organism threats, which reviews these reported incursions relative to environmental impact, should ideally be undertaken.

Reporting scale

As for Indicator 4.1.

Output/reporting

As for Indicator 4.1. Text should include a ranking of various categories (plants, animals, fungi, bacteria, viruses), their mode of entry where known, and location of their establishment.

Linkages to other indicators

In addition to supplementing the context of Indicator 4.1, this indicator may be used to assist in assessing society's view of different species — as to whether they are rated as beneficial or threatening, and to what (economic activity, human health, amenity and aesthetics).

4.1B. Number of passenger and cargo entries per port or entry location by IBRA region

Description

The total number of authorised and unauthorised international passenger and cargo load entries recorded by Customs and Quarantine services via each international shipping port and airport per reporting period, with ports located by IBRA region.

Rationale

The threat of exotic biota entering an island continent is related to the total traffic into the country. The increasing number of commercial services to and from other parts of the world has increased the potential for inadvertent or deliberate entry of micro-organisms, insect and vertebrate pests, and pathogens in plant, animal and wood products. The Lindsay Review (1988) of AQIS operations recommended that risk analyses of the pathways by which exotic organisms enter Australia would assist in the targeting of AQIS operations and directing resources to high risk areas. AQIS surveillance of port entries includes close scrutiny of container ships, cargo planes, passenger luggage and several million passenger entries per year, with rates increasing. There is also a considerable threat from unauthorised boat entry to northern coastal regions that are close to islands in the Torres Strait. The Northern Australia Quarantine Strategy monitors the threat posed by such entries in terms of the spread of highly damaging diseases such as foot and mouth disease and rabies. Border activity surveillance does not rate organisms by the risk they pose to ecosystem function, but only to wildlife protection.

Monitoring design

Review of all passenger and cargo entry figures, relative to the number of declared and detected prohibited species, by geographic location. Develop a risk ranking of the total impact of passenger and cargo imports, in relation to threat of biotic incursion, by port location.

Data sources

All important data sources are with AQIS, the Australian Customs Service and port authorities. The Australian joint Armed Forces surveillance assists in detection of such entries. This indicator would only be sensibly developed under their guidance. (Note also the *Wildlife Protection, Regulation of Exports and Imports Act 1982* and recommendations of the AQIS border activities review, 1995).

Analysis and interpretation

While spread of incursions is mainly dependent on the degree to which the adaptive biology of the species assists its spread and the absence of significant predators or resistance in Australian environments, the relationship between port locations, total numbers of cargoes and passengers and incursions should be established as a part of the risk analysis approach to management of biotic stressors. This information may then be used by pest and disease control agencies, and conservation departments.

Reporting scale

Local port conditions, and national total numbers and distributions of entries.

Output/reporting

Tables, locational maps and descriptive text ranked by risk assessments where possible, by category of organism and habitats or ecosystems likely to be affected.

Linkages to other indicators

Useful for assessment of the threat posed by exotic biota to different IBRA regions in land, inland waters and biodiversity contexts. The issue of exotics entering coastal and estuarine habitats from ballast water discharge is treated separately in the estuaries and the sea indicators report (Ward *et al*. 1998).

4.2. Impact of agriculture on conservation land, by AER and State/Territory

Description

This indicator has been developed for the NCPISA project and is used here in the same form. It is derived from two sub-components, the impact of agriculture on conservation reserves and the impact of agriculture on the conservation of biodiversity on agricultural land, and measured as a composite of the boundary lengths of adjacent contact zones, the ratio of total conservation to agricultural land, and the intensity of agricultural production.

Rationale

This composite indicator was developed to provide an assessment of the "off-site environmental impact of agriculture" in the NCPISA reporting process. Sustainable agriculture seeks to maintain agricultural activity for the long term and to avoid adverse effects on other ecosystems (SCA 1991). Initially conceived as the length of contact between agricultural and conservation land (SCARM 1993), it was found to need additional sub-components to provide a more comprehensive measure of the relationship between the two different types of land use (SCARM 1998, as developed by Dr Annette Cowie). Agriculture may affect the ability of conservation reserves to maintain ecological processes and conserve biodiversity. Important considerations are:

- the length of the boundary between the two — an area of destabilisation and an interchange route for weeds, feral pests, altered water regimes, agri-chemicals and nutrients;
- the extent of natural habitat relative to that of agriculture — since a low ratio of conservation to agricultural land increases the likelihood of salinity, waterlogging, altered fire regimes and native habitat decline; and
- the intensity of land use, which is related to the number of physical inputs that may be mobilised through all landscapes.

Monitoring design

The indicator is compiled in a comprehensive manner across the continent by measuring: 1. the actual boundary lengths; 2. areas of the agricultural and conservation (or non-agriculturally used, vacant) lands per AER, catchment or IBRA region, using a GIS mapping approach, and then computing the measurements using a formula (see next section) for each region assessed; and 3. the intensity of agriculture, assessed as the percentage of the total agricultural area occupied by sown pasture or cropping.

Data sources

Areas and boundaries of conservation and agricultural land from the AUSLIG 1993 digital map outlines — incorporating IUCN-defined "protected areas" of reserves plus freehold land subject to protective covenant or title, and agricultural land including all freehold, pastoral leasehold and Aboriginal land used for agriculture (as defined by the taxation law). Intensity of crop and pasture area figures from AgStats. Covenanted lands not shown in the AUSLIG coverage will be added from State agency records where possible; the AUSLIG data sets are out of date, not showing the considerable increase in conservation on private lands since 1991. The National Forest Inventory has a more recent digitised data set for forest protected areas on private land. AgStats provide the data for intensity of agriculture. Graetz *et al*. (1995) data sets are used for the 34 vegetation types and the areas cleared.

Analysis and interpretation

The potential for agriculture to affect conservation reserves, rather than actual impacts, is measured by the first component. Regions where the impact is likely to be greatest will have the largest *B/C, A/C and Intensity ratios,* where *B/C* is the ratio of the lengths between conservation and agriculture and *A/C* is the ratio of their areas. These ratios are plotted as the x, y and z axes of a three-component "star" as a composite indicator for each region. The larger the star, the greater the potential impact. The impact on biodiversity within agricultural land is measured by assessing the area of uncleared land on agricultural titles, categorised by vegetation types that require conservation protection. Over time the number will go down if new conservation measures are put in place. For each AER or State/Territory, the percentage of the original extent of each vegetation type that is now in protected areas *(O)* (see biodiversity report (Saunders *et al*. 1998)) is determined, together with the extent of still-uncleared agricultural land of that vegetation type *(E),* and the vulnerability of that vegetation type (being a ratio of the two, *E/O).* For each AER, and vegetation type in the region, the vulnerability of existing native vegetation is calculated. This component is largely a reflection of historical land allocation policy.

Reporting scale

Agro-ecological regions, States/Territories and continental coverage.

Output/reporting

The three components of the indicator can be plotted in a three-way diagram at each reporting scale, for each region (reserve status, by vulnerability of remaining native vegetated land, by intensity of agricultural activity).

Linkages to other indicators

The indicator links closely to indicators of clearing and extent of native vegetation developed in the biodiversity indicators report (Saunders *et al*. 1998), and to the indicators of change in land use (Indicators 2.3, 2.5 etc.).

Issue 4: Introduction of novel biota into native habitats and communities

Indicators of Condition

4.3. Key Indicator: Percent of total land area carrying different proportions of exotic families, estimated for each IBRA region

Description

The proposed indicator estimates the degree of replacement of native with exotic plant and animal (vertebrate) families, in each IBRA region, on a spatial basis and in terms of abundance of families (or orders if data are grossly incomplete), and ranked relative to the IBRA codes of dominant condition (A, L, M and H in Table 15, Thackway and Creswell 1995).

Rationale

This proposed indicator has not been considered previously, but has biological merit for assisting interpretation of ecosystem functions by providing information on the spatial extent of domesticated and other exotic biota compared with endemic forms in a manner that can be compared between reporting periods. While some regions have been closely studied for this purpose (for example, the wheatbelts of Western Australia and New South Wales, where replacement of original endemic forms by introduced biota exceeds 90% in some cases), other regions are far less well documented. The family level of hierarchy, rather than species or genus, has been proposed because the effect of competition and replacement of endemic flora and fauna is being assessed in terms of ecosystem function rather than species diversity[3]. Functionally, most members of the *Mimosaceae,* for example, have a similar role — being woody perennial shrubs to small trees, extracting subsoil moisture, having the capacity to occupy low-nutritional sites, fixing nitrogen and scavenging phosphorus, being susceptible to fire, being pollinated by insects, and being dispersed by animals and birds. The proposed indicator can be applied to the existing IBRA regionalisation and the National Reserve System to provide contextual information on the threat to

3 Family level classification is also used by Specht and Graetz *et al.* in their vegetation classifications (Eucalypts, Acacias and others basically), thus providing a direct link to the indicator proposed here. Concern has been expressed by some referees that many species within families have different functional niches within one ecosystem. For a detailed discussion of the appropriate level of biological classification hierachies for monitoring and reporting, see the Biodiversity Report in the same series.

reserves and their ranked representativeness within the IBRAs (Tables 14 and 15 in Thackway and Creswell 1995). The IBRA codes of condition (A = dominantly modified, L = coexisting indigenous and exotic, M = indigenous with some disturbance, and H = indigenous dominant with no known risk) would be used as the baseline.

Monitoring design

Using a GIS-mapping framework of continental coverage of current IBRA status, plot a nested system upon this base map layer of the areal extent of major exotic vegetational replacement across the continent. Geographic extent of declared weeds (declared as noxious under relevant State and Territory Acts), and feral pests that are already authenticated (see Indicators 4.1 and 4.1A) would form additional base layers. Other layers would be composed of the more localised exotic vertebrate, invertebrate, plant and micro-organism groups, where possible in terms of actual current distribution and abundance. All weed, pest and disease locational reports (geocoded where possible) to be added as they become available through subsequent reporting by government agencies and from academic and museum records. Numbers of superimposed layers, and total extent of the region affected per IBRA, would then be computed from the GIS.

Data sources

Base layers of IBRA regions (ERIN), present actual extent of agricultural crops and improved pastures, and metropolitan suburban environments to SLA level from ABS and remote sensing sources (see Indicator 2.3). Baseline extent of weeds, pests and diseases (mostly documented through their economic significance to primary industries) from as many sources as possible (BRS, AQIS, CSIRO, museums, departments of primary industries and of conservation and environment).

Analysis and interpretation

Recent expansions or contractions of extent and abundance derived from special reporting procedures to SCARM and ANZECC committees and research studies undertaken for rural industries R&D Corporations and the Australian Research Council should form the basic reporting framework. A special research project would be required to gather and evaluate these sources of information. Some expression of confidence limits and reliability of data therefore will need to be included in the presentation of the information, probably in a mapped form comparable to that used by CSIRO–NRIC for the digitised Atlas of Australian Soils (available from their web site). This shows the relative reliability of data for different mapping regions.

Reporting scale

Many early warnings of small, localised expansions of exotics may be undetected or considered insignificant in the national reporting process, but rapid, large-areal expansions are of greatest significance on the national scale. IBRA regions vary from 2372 km^2 to 423 751 km^2, and reporting scales would need to accommodate all.

Output/reporting

GIS map layers, with accompanying tabular summaries on proportional extent affected, rates of expansion and abundance of families.

Linkages to other indicators

This is directly linked to Indicators 4.1, 4.4 and 4.5, and is required as contextual information for a number of biodiversity indicators in the Issue "ecosystem diversity".

4.4. Weed infestation index: rate of spread x habitats affected

Description

An indicator developed from the records contained in Indicator 4.1 (rate of extension of exotic species into each IBRA region), selecting those species classified as weeds and tracking them for their rate of spread over time against number of native vegetation categories affected.

This indicator requires community assistance and may not be practicable without a special scheme of localised monitoring.

Rationale

The rate of spread of weeds is very variable. Some weed species are relatively well controlled through agricultural management regimes (principally cultivation, herbicide application and development of bio-control agents of which the most famous Australian example has been the cochineal insect on prickly pear). Some weeds that have been long introduced and are now considered naturalised may suddenly become a problem. An example is the spread of *Mimosa pigra* (thorny scrub pear) in waterways in the northern parts of Australia; this plant arrived in the country in the 1890s, but only started to be a serious pest in the 1970s. Weed ecologists consider such rapid expansions one of the most obvious indicators of degradation of rangelands and pastures in agricultural systems. “Woody weeds” include a significant number of endemic species that have spread to dominate previously open savanna woodlands across much of Queensland and western New South Wales, as the result of inappropriate grazing with no fire management. Assigning national priorities for managing Australia’s weeds has been exceptionally difficult, because hundreds of species are involved that vary with region, season and biology. The National Weeds Strategy (SCARM/SCC/SCF 1996) is the first attempt to have a coordinated management plan for weed control across all jurisdictions, which recognises the need to manage weeds on a whole-ecosystem basis.

Monitoring design

This indicator relies on information having been monitored from a wide range of local habitats. It requires community group and volunteer input to be effective. While there are initiatives for southern Australian agricultural areas (promoted by the National Weeds Strategy and the CRC for Weed Management Systems), these are in their formative stage and no national, coordinated weed monitoring system has been achieved similar to Waterwatch.

Data sources

Mapped distributions and surveys such as those by Tothill and Gillies (1992) and Carnahan (see AUSLIG 1990), and historical records of State and Territory weed control agencies, CSIRO Divisions and museums compiled through National Weeds Strategy operations that are currently being initiated. Updated reports of new infestations, and continued refining of knowledge of the current extent and severity of existing weeds, are required. AQIS web site: http://www.dpie.gov.au/dpie/committee/quarantine/report/quarrev/html.

Analysis and interpretation

Selected species with particularly damaging ecosystem consequences, wide extent or rapid rate of expansion will form the indicator species spectrum for reporting purposes. Interpretation of the reasons why particular weeds are extending will devolve onto specialist knowledge of the biology of each species. Data analysis will be based on a GIS framework of IBRA regions, land tenures and the areal extent of major weed layers; reported extensions to existing recorded infestations will be plotted regularly. Modelling of projected extensions of existing weed infestations, and the potential of new weeds to spread (see AQIS Review Committee reports), could be used to aid selection of areas for particular monitoring, and information on weed control progress directed through the National Weeds Strategy can be used to check the accuracy of maps produced.

Reporting scale

Local SLAs aggregated to AERs and to IBRA regions, with national summaries, on a three to five year time series.

Output/reporting

Text reports, maps showing spread (or halting and eradication if this should occur), and some graphs showing particular weeds over time.

Linkages to other indicators

Indicators of the effects of different management practices such as herbicide use (Indicators 6.4, 6.8 and 6.12), use of fire (Indicator 2.6) and overgrazing (Indicators 1.2, 1.7 and 1.8) will all contribute to interpretation of this indicator.

Issue 4: Introduction of novel biota into native habitats and communities

Indicators of Appropriate Response

4.5 Key Indicator: Effectiveness of reduction in damage caused by weeds, pests and diseases that are harmful at ecosystem scale, by IBRA regions

Description

Effectiveness of measures taken, defined as monitored reduction in damage done to other biota at ecosystem scale by declared major weeds, insect and vertebrate pests, and plant and vertebrate diseases, in each IBRA region per reporting period.

Rationale

Expenditure on control of pests, weeds and diseases of agricultural and conservation lands is high in all parts of Australia, and constitutes a significant proportion of State annual budgets of primary industry and conservation service agencies. Commercial expenditure on control exceeds this significantly, with $0.5 billion spent on herbicides, mainly applied to agricultural and horticultural crops, and about the same on other pesticides and control measures against insects such as locusts, blowfly and crop pests such as the Heliothis moth (*Helicoverpa* spp). Containment and control measures against vertebrate pests by landholders (trapping, warren-ripping, culling, bird-scarers etc.) conservatively cost a further $10–50 million. The real concern of governments and ecologists alike is that much of this effort may be ineffective, or inappropriate, because it is piecemeal, insufficiently related to the biology of the species concerned, lacking coordination, or targeted at the wrong species.

These concerns have prompted Commonwealth Government initiative such as the Vertebrate Pest Strategy (Braysher 1993) and National Weeds Strategy (SCARM, SCC, SCF 1996), but the lack of coordination across jurisdictions, and between agricultural and conservation agencies and landholders, is still a major constraint to effective implementation in most cases. Two issues of particular concern are expressed in this indicator:

- the threat to native biota from off-target agri-chemical contamination — so little is known about much of the native biota (particularly in the critical area of invertebrates) that we cannot begin to assess some of the results of spray drift, water transport and dust aerosols; and
- despite all the current and historical effort and expenditure, control measures are ineffective in halting the expansion of species most damaging at ecosystem scale such as the rabbit, prickly acacia (*Acacia nilotica*), parthenium weed (*Parthenium hysterophorus*) and feral cats.

Monitoring design

1. Ranking of pests, weeds and diseases on their impact on ecosystems. 2. Evaluation of the potential effectiveness of current methods of control (none available, ineffective, sometimes effective, usually effective, very effective). 3. Number of reports of noxious weeds, declared diseases and pests, and the extent of control measures taken against them recorded across all jurisdictions, compared with the known extent and spread of new pests, weeds and diseases and reports of their effects. Special research studies on the off-site impacts of control measures on conservation lands should be done within districts where the measures are being applied to agricultural lands. (Increased weed and feral animal invasion across the interface boundaries of different land uses is well documented.)

Data sources

Major data sources are held by State and Territory departments of conservation and environment, and the pest control units of primary industries departments. Specht *et al.*'s Atlas (1996(?)) and the records of State herbaria and museums provide a wealth of records of the location and occurrence of exotics and their naturalised status. Recommendations for the most conspicuous pests and plants are listed in Tables 9.3.9 and 9.3.10 in Australian Bureau of Statistics 1996

Note: There are several hundred extant laws and programs in existence that can be called upon, but most are ineffective. A catalogue of those that are useful when implemented, those that are not implemented, and those that are ineffective and waste money would be a useful review. Special eradication and control programs have their own reporting procedures (eg. the National Calcivirus Monitoring Program tracking the progress of rabbit control since the release of the virus).

Analysis and interpretation

The primary ecological concern of off-target adverse effects has received so little institutional attention to date, other than in aquatic environments, that it remains an area requiring immediate research funding rather than an operational monitoring program.

The effectiveness of measures used against targeted organisms may be assessed nationally in relative terms by comparing across land uses and jurisdictions with different containment measures, expenditures and legislative requirements. Assessment of the effectiveness of control activities for non-classified species would require research to establish the hazard posed to different parts of an ecosystem and subsequent classification into groups — by anticipated effect or risk to each major ecosystem (see Graetz *et al.* 1995 for type of ranked grouping that could be used), or according to the risk protocols used by the Northern Australia Quarantine Strategy (NAQS) program. An economic analysis (benefit: cost type) would be enlightening in many cases — where total expenditure over a ten-year period may have had no effect, other than cosmetic, on a particular weed population. Such benefit: cost analyses have been done for individual weed, pest and disease RandD projects funded through the rural industry R&D Corporations (eg. the Grains RDC), and the values range from zero (or negative) to several hundred fold, depending on the individual pest.

Reporting scale

Regional, but in some cases a pest has national distribution and impact. Locally severe, but nationally trivial, instances would only be considered where the pest threatens an already endangered native species.

Output/reporting

Scores of effectiveness of control measures listed against groups of major pests, weeds and diseases (stratified by type of pressure on the ecosystem), by IBRAs.

Linkages to other indicators

This indicator is closely related to Indicators 19.1–19.3 of the biodiversity indicators report (Saunders *et al.* 1998), where the emphasis is on the genetic pressure placed on various elements of biodiversity. Here we are more concerned with the pressure placed on such functions as food chains and nutrient cycling, and effects on erosion and the hydrological regime. Parallel indicators have been developed for aquatic ecosystems in the Inland Waters and Estuaries and the Sea Reports.

Issue 5: Nutrient and salt cycling

Indicators of Anthropogenic Pressure

5.1. Key Indicator: Total nutrient export Nitrogen, Phosphorus and Potassium from each AER and drainage basin

Description

The sum of totally anthropogenic losses of nutrient content from all agricultural and forestry products extracted from each region — distinguished where possible from combined natural and anthropogenic losses of nutrients in dust, sediment and soluble forms transported to oceans, and from mostly natural losses through volatilisation to the atmosphere and leaching to groundwaters. Applied to agro-ecological regions and drainage basins per reporting period.

Rationale

Nitrogen (N), phosphorus (P) and potassium (K) are the nutrients required in largest quantities by plants for healthy growth. Native supplies of N, P and K vary across Australia, depending upon the composition of parent rocks and soils, and the geological accumulation of P and K in some situations (summarised in CSIRO 1983). Rates of extraction by export of agricultural and forest products may exceed input rates in some regions (eg. the rangelands where no fertilisers are applied to make good the continued export of animal products), but may be small and slow compared with the massive losses occurring from coastal catchments in the wet tropics. While the nutrient balance indicator (see Indicator 5.4) demonstrates those regions that are in deficit, credit or balance, a loss budget provides quantitative comparisons of rates of loss from different environments.

Monitoring design

At continental scale, the export of nutrients by primary industries can be measured by calculation of the volume or weight of products removed, converted to elemental weights of the major plant nutrients, N, P and K, that are required by all higher organisms in large quantities. This has been done in the past from actual tonnages exported (McLaughlin *et al.* 1994), but at smaller scales the re-use and cycling of nutrients domestically makes the calculation and any sampling design very difficult. In addition, losses of P and N in erosion products and in soluble forms in waters, and the export of N gases volatilised from native (swamps, termites etc.) and added (fertilisers and domestic animal losses) sources, are very much more difficult to quantify and measure. Detailed studies have been done in coastal and major inland catchments to provide reliable values for the different components of particular systems (Rose 1996; Harris 1996), and these could be used in a selective sampling pattern that relates individual studies to ecosystem type and land use classification. Additional studies would be required to cover catchments in the northern, north-western and central regions.

Loss budgets have also been calculated for agricultural regions under different farming systems (eg. continuous cropping compared with pastures containing N-fixing *Rhizobia*, or forests with P-absorbing mycorrhiza). These provide input data to predictive models of nitrogen and phosphorus cycling, such as "NEXIS — a Nutrient Export System" developed by R. Davis, CSIRO, which provides the basis for comprehensive estimates for major basins. Internally and externally draining basins, and location of regions of internalising exports (high-rainfall grazing, horticulture and dairy closer to cities), compared with those exporting nutrients completely (broad-acre, grain, cotton, sugarcane, and lower-rainfall grazing) could provide an initial stratification.

Data sources

Farm product exports from ABS AgStats and elemental compositions of plant and animal products exported (Reuter and Robinson 1997). Statistics on export of N and P from urban communities (sewage works) can be obtained from Water Services Association of Australia reports (WSAA 1996). Information on land use system and catchment studies on different processes operating and quantities of N, P and K lost is available from published literature, water board monitoring records and reviews (eg. White and Sharpley 1996). Estimates of N and P losses for different environments from modelled predictions would need to take care that double accounting does not occur from one basin to another.

Analysis and interpretation

Estimated and measured quantities of different elements removed from particular regions will be computed separately, with confidence limits derived from mean annual values and range within and between seasons, so that the relative importance of different modes of loss can be compared across AERs and drainage basins. Measurements do not exist for all regions, and estimates may be interpolated for remote and seldom-monitored areas. Maps of soil levels of available N, P and K are available from company and State primary industry and chemistry laboratory sampling programs, providing supplementary evidence of relative areas of depletion and gain. The relative significance of each element and the ideal ratios of each to the other within total ecosystem functioning are important, but as yet inadequately understood, aspects of this indicator.

Reporting scale

From local (eg. urban) to drainage basin and AERs, and update of continental budget reported by McLaughlin *et al*. (1994).

Output/reporting

Tabular and graphical quantitative reports for each scale of reporting, and maps showing major export catchments and localities with text and five-yearly updates.

Linkages to other indicators

A required indicator input to the "Rates of land carbon (organic matter) sequestration by AER and IBRA region" 5.5, and assisting the interpretation of indicators of erosion (1.1 to 1.10). Links to inland waters (Fairweather and Napier 1998) and marine (Ward *et al*. 1998) indicators of nutrient flows.

5.1A. Key Indicator: Rates and distribution of Nitrogen, Phosphorus, and Potassium accessions into each AER and drainage basin

Description

The weights and distribution of Nitrogen (N) , Phosphorus (P) and Potassium (K) being added through fertilisers, imported products, and human and animal wastes to different parts of each region that do not move beyond the confines of particular regions per reporting period, stratified by AER and drainage basin.

Rationale

Additions of these major plant nutrients to lands uses for agriculture, pastoralism and forestry are needed to counteract the soil losses experienced from export of harvested products, but often the additions do not match the weights lost, nor is the spatial distribution of added nutrients necessarily the same as that of the losses. Many additions through fertilisers and wastes occur to small areas or point locations in concentrated form. These may create localised areas of nutrient contamination to waterbodies, with leakage into groundwaters and algal bloom conditions in rivers and estuaries the best-known outcomes. Conversely, large areas of pastoral land are not replenished by any external nutrient sources, and soil fertility declines through export of animal product, accelerated erosion loss of topsoil and selective overgrazing of N-fixing legumes. Comparison between regions requires a knowledge of the rates of accession.

Monitoring design

As for Indicator 5.1, application of fertilisers may be roughly estimated across all agricultural areas from AgStats. However, calculations of the weights of elements applied cannot be accurate because questionnaires do not require identification of the amounts of each fertiliser formulation to be specified. Calculated inputs in forested regions that are logged may be possible from company records. Computing inputs from animal excreta and human wastes requires modelling or knowledge of the cycling and flow patterns in and out of different parts of drainage basins (eg. between catchments). Selected catchments that are well monitored may provide the most reliable locations, but extrapolations to provide a comprehensive assessment at large region or continental scales will contain large error terms.

Data sources

As for Indicator 5.1, but additional information can be obtained from fertiliser company records. These are not freely available, but are a very rich source of information. For example, CSBP has analysed between 60 000 and 80 000 surface soil samples in south-western WA per year for the past fifteen years, and mapped these on a GIS basis. Analyses on a similar scale have been undertaken in SA (SARDI), Victoria, parts of NSW and south-eastern Queensland by other institutions. EPAs collect data on sewage nutrient weights at outfalls via licensing arrangements, but these must be examined to see whether they will remain within, or be exported from, particular AERs or drainage basins. Estimates of nutrient weights applied through intensive animal industries may be roughly calculated from animal numbers and throughput (ABS and industry figures).

Analysis and interpretation

Estimates of total nutrient loading for each region per year will be relatively rough because of uncertainty about the proportion of water-transported nutrient leaving some catchments that are not regularly monitored. Location of nutrient loading is relatively safely assessed at SLA level from AgStats, but estimates of fertiliser amounts will have large error terms associated with them. Industry-specific figures (eg. dairy, wine, horticulture) are more reliable, but are difficult to obtain. Comprehensive or spatially averaged figures require associated process-level studies wherever possible, to allow calculation of partitioning into principal sources and relative amounts.

Reporting scale, Outputs/reporting, Linkages to other indicators

As for Indicator 5.1.

5.1B. Sources of Phosphorus derived from land activities reaching rivers, by catchment

Description

Location and forms of dispersed and point-source phosphorus (P) within those major catchments that contribute to algal blooms in surface waters — classified as point-source, particulate dispersed, and soluble dispersed (dissolved active P) forms, with estimates of the relative quantities of P entering waterways from each.

Rationale

Phosphorus is the rate-limiting nutrient in the development and containment of algal blooms in surface waters and estuaries. P accessions to waterways may occur through point sources (sewage works, intensive primary industries) and in a variety of dispersed forms. The latter dominate in most catchments. Most sources have a direct or indirect anthropogenic component. Direct origins include all point sources, dispersed phosphatic fertilisers in surface soils and grazing animal excreta. P becomes entrained in eroded sediments, or leached through the soil profile. Indirect anthropogenic origins include sediments from gully erosion (accelerated gully formation arising from overgrazing and tree clearing). Fluvial erosion processes dominate the in-stream volume and movement in major channels, but land activities mobilise the near-surface phosphate that contributes most of the biologically available fraction. Differences in sources are related to climate (rainfall intensity and seasonal distribution), erodibility of surfaces (a result of slope, cover, topography), land use, and the sorption capacity of the soil. High P-fixing or leaching soils are generally coarse textured, and P-fixing soils contain iron and aluminium oxides. Dispersive (sodic clay) and duplex soils have a preponderance of particulate-P, adsorbed to clay and soil particles. Most P is moved into waterbodies during storm events. Measures taken to control P reaching rivers, lakes and dams require effective management of accelerated erosion. The effects of practices such as maintaining permanent cover across catchments, timing of fertiliser application, irrigation scheduling, and recycling of animal and human wastes are monitored under different indicators (see Linkages).

Monitoring design

Current monitoring of P provides information on sources, rates and quantities for some catchments, but the distribution of effort is not comprehensive. There is a concentration on catchments in south-eastern Australia, with a paucity of data for the wet tropic northern rivers and for most of central and western Australia, other than the far south-west. Much of the detailed monitoring record is of sediment yield, not P itself (Olley *et al*. 1995), so that attribution of source to particular parts of the landscape or land-use practices has been uncertain and the cause of debate. Because of the significant human and environmental health issues related to algal blooms, monitoring programs should be extended to provide a more representative coverage and greater consistency of methodologies. The National Eutrophication Management Program (Murray–Darling Basin Commission with the Land and Water Resources R&D Corporation), established in 1995, is attempting to resolve areas of knowledge gaps. The research and monitoring design concentrates on four catchments in widely differing environments — the Wilson Inlet (WA), the Goulburn–Broken catchment (Victoria), the Namoi (NSW) and the Fitzroy (Queensland).

Data sources

Data banks of rural water boards, member organisations of the Murray–Darling Basin Commission, departments of agriculture research staff, and research hydrologists in various institutions provide the most comprehensive historical records. A report by Aquatech (1995) lists 1365 water quality monitoring programs carried out across Australia — 65% by State, Territory and local governments — in 1993. Data on urban and industrial wastewater and sewage treatment nutrient loads are maintained by State environment protection authorities and the Water Services Association of Australia (Melbourne), although much localised, intensive rural industry activity is not monitored.

Analysis and interpretation

National-scale analysis and interpretation of catchment monitoring studies is not undertaken on a regular basis, but some drainage basins and major catchments are the object of close study — eg. the Murrumbidgee, Murray, Brisbane, Swan, and Hawkesbury–Nepean rivers. A major aim of all current analyses is to establish the relative contributions of different sources of P with more certainty. Areas of debate and doubt persist regarding the relationship between the amount of particulate and dissolved P in water and the distance from the land source, the forms of P in water compared with that in soil, and the processes dominating in peri-urban and "rurban" catchments of multiple land-use and high levels of artificial dissection.

Reporting scale

Principal catchments, coincident with the needs of the Inland Waters and Estuaries and the Sea Indicator Reports.

Output/reporting

Concentrations and loads of P entering individual catchments (expressed as parts per million or weights per litre), preferably related to areal extent and location of sources within catchments. This is seldom possible, and back-calculations from stream concentrations to estimated sources are the surrogate.

Linkages to other indicators

Needed for the inland waters (Fairweather and Napier 1998) indicators in Issue 4: Water Quality, and Class 5: Water/Sediment quality indicators of the estuaries and the sea report (Ward *et al*. 1998). Provides interpretive information to most Land Resources indicators of accelerated erosion, and some in nutrient cycling.

5.2. Terrestrial carbon (organic matter) loss rate by IBRA region

Description

The sum of carbon losses from soil erosion, organic matter oxidation by cultivation of soil, burning of native vegetation and crop residues, and removal of harvested biota (forest and agricultural products) by region. This indicator is also being treated in the atmosphere indicators report under the Greenhouse Gas Inventory response to the UN Framework Convention on Climate Change. Forested regions will be reported separately to the CRAs, potentially through the Montreal Process Indicator 4.1D "Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties" in future, but no separate data are available for that indicator at present (Commonwealth of Australia 1997).

Rationale

Carbon cycling is a primary ecosystem function that is greatly affected by land use activities. Loss of soil carbon reduces the overall fertility and productivity of the ecosystem in many deleterious ways. Depletion of the primary energy source of the decomposer group of biota reduces their abundance, activity and diversity, and this in turn reduces the capacity of the soil to act as a buffer against contaminants and pollution. The soil carbon pool is estimated to be the largest component of geosphere carbon — larger than the atmosphere, surface oceans and standing biosphere (ratio of 2:1:1:0.7 respectively). Much of the initial calculation of initial continental carbon stocks and annual rates of turnover, and projected changes resulting from increased CO2, has been completed in recent years (Gifford *et al.* 1992; NGGI 1994; Grace and Post 1996), and updates on these initial calculations are now being developed using the IBRA regionalisations that have been computed, adjusting for changes to land practices noted in other indicators (Noble 1997).

Monitoring design

Following the approach of the authors listed above — using a combination of modelled calculations of the mean carbon in live standing biomass and soil carbon stocks, and GIS-compilation of modelled grid cells across IBRA vegetation classes, Atlas of Australian Soils soil types and historical climate sets, adjusted for recent changes in land use (in particular, changes to land cover and land use from Indicators 1.2 and 2.2). Partitioning is as fine or coarse as the grid cell size allows (from 0.5° to 0.1° in earlier estimates), depending on the quality of the input data on vegetation and land use change. Calculations can be made for specific groups of environments. For example, data on carbon loss and gain from clearing and regrowth of native forests and plantations will be a primary product of the National Landcover Program (Barson unpublished). The accuracy of updates on soil carbon depends upon continued revision and update of soil mapping and analysis undertaken and values from Indicator 1.4 (changes in surface soil loss). Initial calculations were unable to give sufficient precision to net primary productivity (NPP), and this is therefore identified as a separate indicator.

Data sources

Digitised map coverages of vegetation, soils, climatic parameters (full historical records of climate stations from the Bureau of Meteorology); landcover disturbance etc. data from ERIN and NRIC as referenced; models for carbon turnover as described in the National Greenhouse Gas Inventory workbooks (National Greenhouse Gas Inventory Committee, 1996); changes in extent of agricultural land use, product removal and fires from data sets assembled for those indicators (AgStats, ABARE, departments of lands etc.).

Analysis and interpretation

Comparisons with published values, and closer scrutiny of any deviations from predicted trends for specific grid cells or land uses, will allow tables of net carbon loss from each soil and litter pool and standing vegetation pool to be computed. Areas of negative value identified may then be mapped, and related to other indicators that have contextual or interpretive value. Climatic fluctuations from long-term averages are likely to be the most significant short-term (2–5 year) factors influencing such deviations from expected values, while very rapid erosion rates, frequent and extensive bush fires, and intensification in cropping may have localised effects on some grids.

Reporting scale

From local to continental at whatever grid aggregation or vegetation cover category is required (1 km^2 upward).

Output/reporting

Tables of soil and vegetation carbon losses by IBRA region or other aggregations, with summary isopleth maps showing areas of relative loss by class intervals, with explanatory text.

Linkages to other indicators

Requires climate variation indicators for interpretation (see Atmosphere Indicators Report) and Indicators 1.2, 1.4, 2.1 and 2.4 data for compilation.

5.3 Change in area and location of salinised land, compared across regional catchments and AERs

Description

Changes in the extent of areas affected by dryland and irrigation soil salinity (secondary salinity, resulting from anthropogenic activities) and identification of new affected locations during the monitoring period, compared between major catchments and AERs.

Rationale

Secondary salinity has unexpected consequences on vegetational assemblages, water quality and other ecosystem properties. This additional indicator on salinity (main condition indicator being described as Indicator 3.4) is included because of the frequency with which salinity is identified in areas where it was not expected by the community, planners, or water and land industry specialists. A good example, in an area of known salinity, is the difference between official estimates of dryland salinity in the south-west of Western Australia from ABS statistics based on farmer perception (3.1%), and the estimates of government hydrologists using advanced detection methods (9%) across the same area (Goss *et al*. 1995). Urban salinity is another area where there is significant under-estimation, because of concerns over asset values and costs of replacement of built structures.

Monitoring design

Using prior hydrogeological knowledge (such as mapped salinity of the Murray–Darling Basin), select potential "hot-spot" regions for local electro-magnetic surveys, supported by remote-sensing coverage (see CSIRO 1997) and hydrogeological drill record. Monitoring (in collaboration with Natural Heritage Trust projects, and research supported by LWRRDC and MDBC's Natural Resources Management Strategy) across areas of suspected salinity such as salt-bearing sedimentary basins, breaks of slope in agricultural areas cleared of original vegetation, irrigation districts, and coastal regions of higher rainfall where salt mobilisation is occurring through disruption to vegetation and hydrology from urban expansion.

Data sources

The Australian Geological Survey Organisation's coverage of the major sedimentary basins (particularly the Murray–Darling, completely mapped at 1:250 000), and locations of major salt mounds and regolith salt loads mapped by rural water boards and State/Territory mines departments. Airborne scanning surveys and radiometric reconnaissance data (AGSO, DOLA, Leeuwin Centre WA, commercial companies), and metadata bases via NRIC.

Analysis and interpretation

Dryland salinity mapping accuracy of over 90% has been achieved from use of Landsat TM analysis by the Leeuwin Centre (WA) using a classification approach applied to multiple dates of TM data and interpretation of associated landforms by Digital Elevation Models. Regional summaries are prepared routinely in south-western WA, and changes to area affected over time reported to relevant agencies and organisations. Extension to other parts of Australia is feasible but not currently operational, but some intensive study areas (eg. the five catchments of the National Dryland Salinity Program) have now been flown for radiometric survey and TM a number of times. Interpretation should compare official statistics on salinity in cleared landscapes that are considered to have low salinity problems with actual detection levels (using the combination of methods described here). Particular concern should be paid to the eastern break-of-slope rim of the Murray–Darling Basin.

Reporting scale

Most effective where local or sub-regional scales are adopted.

Output/reporting

Regular text reports and local maps.

Linkages to other indicators

To be considered in relation to Indicator 3.3, and needed contextually for indicators of water quality in the Inland Waters Indicators Report.

Issue 5: Nutrient and salt cycling

Indicators of Condition

5.4. Key Indicator: Net nutrient balance for the major elements Nitrogen, Phosphorus and Potassium per year by land use mapped across IBRA regions and drainage basins

Description

This indicator corresponds to the NCPISA indicator of nutrient balance in agricultural lands, and is an extension of that indicator to all environments. It is a derived indicator of the Nutrient Loss and Accession indicators (5.1A and 5.1B), but stratified for land uses within drainage basins.

Rationale

The net nutrient budget for N, P and K among different land areas provides an ecosystem-scale view of nutrient flows that identifies sources of relative loss and gain between landscape elements. It is a compromise in so far as nutrient budgets that have most relevance to natural ecosystems would stratify according to IBRA regions, but most data required to compute nutrient exports are located according to primary industries SLAs, and catchment sediment loads. The indicator is therefore reported according to land use, through which primary industry locations and catchment management can be estimated, but it could be displayed spatially against a framework of IBRA mapping boundaries.

Monitoring design

Step 1. Determine location of land areas for which actual measurements and statistical data are available compared with those for which only computed estimates can be made. Step 2. Compute annual values of nutrient export (Indicator 5.1A) and accession (Indicator 5.1.B) for each major land use by geographic region (eg. tropical agriculture, forestry, rangeland pastoralism, and conservation lands) for each element. Step 3. Identify areas for which no data are available, and obtain computed values (N, P, K) using nutrient modelling (see Net Primary Productivity Indicator 5.6), with statistical analysis of error terms associated with each method.

Data sources

A large number of different data sources are required to compile nutrient balances (McLaughlin *et al.* 1994). These include fertiliser industry figures, ABS statistics for products harvested, nutrient concentrations in catchment surface waters, estimates of areas of N-fixing legumes (both native and exotic), together with computed (modelled) estimates of evolution of gaseous N and leaching of N, K and P into groundwaters and deep parts of the regolith, and pedological information on the storage of nutrients in different soil types (ACLEP and the BRS metadata base on soil surveys). The National Greenhouse Gas Inventories of the NGGI Committee provide the most comprehensive analysis of N-oxide emissions, with published methodologies (workbooks).

Analysis and interpretation

Computation and analysis requires a team approach. Some terms, in the N budget in particular, can only be best guesses, with major discrepancies found between measurements taken at different scales. Scale considerations are a major problem, and for that reason selection of data derived from integrated measurements (catchment outfalls, bulk values of products harvested) provides a better initial data set than very finely localised measurements that must then be extrapolated over very much larger scales (Harris 1996). It is essential that error terms are established for each element within particular land uses. Error terms for K will be less than those for P, which will be less than those for N, because of the numbers of pathways to losses and gains.

Reporting scale

Should be attempted for medium-scale metropolitan, irrigation, horticultural and forest regions (100 to 1000 km^2), with markedly different nutrient balances, up to IBRA regional scales (3000 to 43 000 km^2). A comprehensive continental calculation was last done in 1992 (McLaughlin *et al.* 1994), and should be repeated separately.

Output/reporting

Tabular values of each element against land uses on a regular (four to five year) basis, with explanatory texts. Maps showing the relative reliability of estimated balances should be developed for each region and at continental scale (similar to that used by NRIC–CSIRO for continental soil mapping).

Linkages to other indicators

Compiled from Indicators 5.1A and 5.1B, with contextual relevance to most indicators in Issue 5, and to indicators in the inland waters and estuaries and the sea themes.

5.5. Rates of land carbon (organic matter) sequestration by AER and IBRA region

Description

A calculated value of carbon sequestration, with amount of carbon stored in standing vegetation, litter and soil (Mt/unit area) computed as separate components and averaged over the reporting period, by AER and IBRA regionalisations. In future, the Montreal Process Indicators 5.1A and 5.1B "Total forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class and successional stages" and "Contribution of forest ecosystems to the total global carbon budget, including absorption and release of carbon (standing biomass, coarse woody debris, peat and soil carbon)" will provide this indicator's values for forest ecosystems.

Rationale

This indicator is separated from 5.2 because losses are considered a pressure on current ecosystems while gains are viewed as the compensating trend. Practices that increase terrestrial carbon, particularly as soil organic matter and surface litter, assist in maintaining and increasing the nutrient fertility base for all biological production and providing the principal energy source for all decomposers. This is well appreciated and understood in agricultural systems, and has been the basis for continued investment in improved pastures throughout high and medium rainfall agricultural districts of Australia, even during periods when profits from grazing industries have been low. The fastest rates of carbon sequestration occur when land is protected from grazing animals, fire and ploughing, and under such conditions biomass can double in 2–4 years. Young, fast-growing eucalypt and acacia woodlands sequester carbon two to four times faster than mature stands, so age of vegetation is a reliable guide to sequestration rate. Time since last fire, and growth rates for characteristic trees, shrubs, ephemeral herbage, perennial and annual crops and pastures can be used to refine the estimates of active (new since last estimate) sequestration (Gifford *et al*. 1992; National Greenhouse Gas Inventory Committee 1996).

Monitoring design

Using the agreed procedures of the second National Greenhouse Gas Inventory, and sampling sufficiently fine to cover all IBRA regions and managed plant communities (agroforestry, plantations, irrigated and horticultural lands etc.).

Data sources

As for Indicators 2.2, 2.3 and 2.4, with added information from data sources used for 1.1 (and sub-indicators).

Analysis and interpretation

Previous estimates of relative rates of carbon sequestration by different parts of the environment (soil, litter, standing vegetation) have given variable estimates of the role of soil and litter because the data on carbon levels in some soil groups have been sparse and some have overestimated the sequestration in standing biomass. Current research has demonstrated the ubiquitous nature of very fine charcoal (inert carbon) as a diluting factor to previous calculations of soil organic matter across all Australian soils sampled (Skjemstad, Amato and Grace pers. comm.). The capability now exists to estimate changes to natural ecosystem carbon flux and land use flux separately (Grace and Post 1996), and this should improve the reliability of terrestrial sequestration calculations.

Reporting scale

Not easily applicable below landcover or IBRA regional scale, but capable of aggregation from this scale to continental.

Output/reporting

As for Indicators 5.2 and 5.6.

Linkages to other indicators

Links directly to 5.2 in order to calculate net carbon balances and provide information for overall assessment of fertility increase and decline across IBRA regions (soil and litter components), and to net sequestration figures for the NGGI.

5.6. Key indicator: Change to net primary productivity by IBRA regions, grouped by catchments

Description

Calculated net primary productivity (NPP) of total standing vegetation (kg/m^2/yr), using a 1990 baseline of landcover vegetation types, with seasonal variations expressed as variances around the long-term mean derived from historical climate records.

Rationale

Net primary productivity of biomass provides the essential baseline of the relative productivity of all ecosystems. Monotonic trends in primary productivity accompany major changes to vegetation cover and land use, which may be distinguished from annual fluctuations resulting from wetter and drier years (Dunin pers. comm.). This information is essential to calculations of carbon sequestration and loss, and provides values for assessing the potential productivity of particular ecosystems against which their actual performance can be compared under different systems of managed land use (Milthorpe and Moorby 1979). Primary productivity is set by climate, with warm and wet environments achieving higher productivity than cold or dry ones (Whittaker 1975), but is strongly modified by topography and soil type at smaller scales (10–100 km^2). Baseline values of primary productivity calculated for land-cover vegetation types (Gifford *et al.* 1992) vary from 0.09 to 1.25 $kg/m^2/y$ (sandy deserts and irrigated crop land respectively), and average vegetation turnover periodicity ranges from 1 to 40 years (tropical humid forests to interrupted fields and woods). Accurate measurement of net primary productivity, and even of standing biomass, in areas that have been burnt presents significant challenges.

Monitoring design

This indicator should initially be recalculated regularly on a five-year basis, using revised methodology and vegetation cover areas described in Gifford *et al.* (1992), modified to include improved calculations reported by Gifford (1996) and more recent land use changes and vegetation cover alterations (Noble 1997). Spatial heterogeneity limits the validity of estimates calculated from point source measurements, and poor records of fires and clearing dates for some forest types make the error terms on values for forest regions doubtful. The alternative method used by Grace and Post (1996) agrees well with the revised values of Gifford (1996).

Data sources

As listed by Gifford *et al.*, Grace and Post, and Noble, with supplementary data sets now available from Graetz *et al.* (1995) and the National Landcover Project, and improved experimental studies published in the literature for annual biomass production and net productivity for some less-monitored vegetation assemblages — in particular for tropical and dry sclerophyll forests, which have been poorly monitored in the past.

Analysis and interpretation

The most valuable information will relate to changes since the last estimates, and identifying the environments in which such changes are taking place. Estimates being undertaken for the next NGGI values require considerable back-checking against values derived from local on-ground measurements for major vegetation cover types.

Reporting scale

Local to IBRA regions, with national values for total standing biomass and net primary productivity as a separate output when used for carbon balance calculations (National Greenhouse Strategy).

Output/reporting

Tabular per reporting period, and trend lines per landcover region over time (10-year period minimum).

Linkages to other indicators

Required as part of Indicators 5.2 and 5.5, providing information for fire control index (Indicator 2.6) and interpretive context for all indicators of vegetation cover change and condition. Montreal Process Criterion 2 "Maintenance of productive capacity of forest ecosystems" contains indicators that would benefit from calculations of annual net primary productivity of forest biomass.

Issue 5: Nutrient and salt cycling

Indicators of Appropriate Response

5.7. Key Indicator: Proportion of each forestry and farming system with stable nutrient balance by major catchment, AER

Description

Primary industry nutrient balance sheets for N, P, K (and Ca if possible), dis-aggregated for each AER and Forest Region where possible, per reporting period, to provide trends over time. This indicator will assist the development of Montreal Process proposed Indicators 3.2.D "annual removal of wood products compared to the volume determined to be sustainable" and 3.4.D. "area and percent of forest land with significantly diminished soil organic matter and/or changes to other chemical properties".

Rationale

To demonstrate which regions are in major nutrient deficit or credit, or in balance, as a result of primary industry activities that are within the direct control of management practice.

Good management practice will aim towards net zero balance (inputs equalling exports over time, with soil store remaining the same) within particular climatic and soil associations. Strongly positive balances will tend to leach nutrients into water systems beyond the region, and strongly negative balances will reduce primary productivity and result in low plant water-use efficiency in higher rainfall areas. Consideration of calcium is suggested here to allow for the particular significance of calcium in maintaining a soil pH environment adequate for the continued production of many domesticated plant species which have a narrower range of pH tolerance than adapted native species (and to assist interpretation of Indicator 3.4), and to control off-site acidification of waters that now flow out of acidifying regions. A number of farming and forestry systems have a particularly heavy demand for calcium (eg. irrigated lucerne pastures cut and exported for hay), but the use of agricultural lime is strongly related to its varying cost in different parts of the country rather than to calcium or pH requirements (AACM and LWRRDC 1995). Agricultural nutrient balance has been the focus of NCPISA indicator development but, although nutrient requirements for plantation forestry are well established (Reuter *et al*. 1997), no similar assessment of forestry nutrient balance has been proposed.

Monitoring design

Running averages over five or ten year periods of representative values for selected primary industries' export of major nutrients (and calcium), calculated from average elemental compositions and harvested product weights per AER and designated Forest Regions, and estimated industry-related use of fertilisers and agricultural lime. Surface soil values of available N, P and K, and pH for soils in each climatic and production region (estimated, or actual sampling values where available — see data sources). Information for some harvested native forest regions may be unavailable (eg. private forests), and confounded where fires have been frequent. Most soil values will be estimates with large variances, because of low density of sampling. It is more important to get a picture of the relative ranking of the effects of different practices on nutrient budget status than a comprehensive continental coverage.

Data sources

As for Indicators 5.1A, 5.1B and 5.1C, together with Limestone Association and departments of mines figures on agricultural lime use (plus ABS figures for some years and States, and 1995 onwards), supplemented by detailed studies of forestry plantation nutrient balances and multiple use catchments where differences in nutrient budgets under different land uses have been studied — eg. the South Johnstone River (led by QDPI/DNR) and Herbert River (led by CSIRO) catchment studies in Queensland. Soils data identified by the BRS (Barson and Shelley metadata base on soil surveys), and surface soil nutrient status from fertiliser company, State chemistry laboratory and forestry commission records.

Analysis and interpretation

Spatial distribution of positive, neutral and negative balances mapped by land use across major catchments would be used as the primary information base from which interpretation would be made of the likely impacts and trends in N, P and K flows beyond the confines of each region, and of the significance of the Ca trend relative to pH. Forest regions to be analysed separately to assist in addressing indicators relevant to the Montreal Process.

Reporting scale

Catchment scale or SLAs, depending on availability of data, with some aggregation, if valid, to AERs — particularly important to the ILZ part of the continent.

Output/reporting

Regional maps of positive, neutral and negative budgets for each element by catchment or forest/farming region (eg. irrigated areas) or SLA. Where data are geocoded the regional boundaries can be varied, but for historical (especially ABS) data this will not be possible.

Linkages to other indicators

Direct links to Indicators 5.1A, B and C and 5.8 and indirect to Indicator 3.4. Contextual value to indicators of estuarine and inland water quality.

5.8. Estimated success of programs to reduce land carbon loss and increase sequestration, by landcover regions

Description

Existence, implementation and success of proposed policies — such as the Natural Heritage Trust's Revegetation program and Cooperative Agreements program, and vegetation clearing restrictions — to reduce emissions of carbon from land activities in different jurisdictions (local, State/Territory and Commonwealth), cross-referenced spatially to IBRA regions.

Rationale

The NGGI 1994 inventory showed that vegetation and forest management accounted for 25% of emissions and that agricultural practices accounted for 16%, and identified sources of loss which also impact on ecosystem fertility, climate and biodiversity. Significant gains in carbon sequestration can be made through improved forestry and agricultural management practices, and most of all by cessation of clearing of native vegetation. Other activities that can assist in reducing carbon dioxide emissions are reductions in deliberate burning operations (crop residues, forest trash, cool burns of undergrowth), revegetation programs and tree planting (targeted under the Natural Heritage Trust for significantly increased expenditure), and agricultural practices that conserve or build up soil organic matter (minimum tillage, retention of cover). This indicator will also be valuable in monitoring the recommendations of the *1997 National Greenhouse Response Strategy.*

Monitoring design

The monitoring and evaluation schemes developed for the relevant national programs to assess the real success on the ground of replanting, cessation of clearing and adoption of reduced cultivation practices will be used. For example, data for trees planted under Greening Australia are kept by each State (eg. 46 million tree seedlings in SA from 1989 to 1996), although records of trees surviving are not kept. The National Landcover Program (Barson, BRS) will significantly improve the estimates of clearing and revegetation balances in the ILZ. Limitations to the use of modelled continental estimates of soil-sequestered carbon and vegetation changes have been recognised by the modellers. These result from the low-level data available for Australian soils; variations in depths of soil profiles relative to topography, geology and climate are unknown across much of the continent, and local variations in soil organic matter with land cover make such calculations rough at best. Nevertheless, work to date has shown the importance of both soils and existing vegetation as sinks for carbon — particularly the role of soils, and topsoil conservation (see DEST Climate Change Workshop 21 February 1996 report and recommendations, unpublished). The relative effectiveness of improvements in surface cover and soil organic matter etc. would then be mapped against IBRA or landcover regions, using both the biophysical data on estimates of carbon change and program performance statistics for each jurisdiction (as with the example from Greening Australia given above).

Data sources

Figures for carbon budget changes per IBRA from the same data sets as used in Indicators 5.3 and 5.6; and any additional information from data sources used for biodiversity indicators of vegetation loss and fragmentation, and from land indicators 1.1(A–D) and 2.3 and 2.4 that assess changes to vegetation cover and bare soil areas. Data on the effectiveness of programs designed to increase soil organic matter and land cover from studies carried out on program performance (eg. Department of Finance evaluations), and program performance measures used by the portfolios responsible for particular programs (EA, DPIE, DIST and their State/Territory equivalents).

Analysis and interpretation

Comparison between carbon balance estimates per IBRA and government program activities in the same regions (probably only possible aggregated to

States/Territories or other administrative regions such as the Murray Darling Basin Commission). Where positive balances were correlated with positive program implementation, the score would be positive; where positive balances occurred without any program activity the score would be zero (or neutral); and where negative balances occurred without program activity the score would be negative, and with program activity doubly negative.

Reporting scale

The most important scale is the IBRA or landcover region scale. Summing totals over the continent would probably produce meaningless averages, but variation between local and State-level jurisdictions add significantly to interpretation.

Output/reporting

Tables of "scores", or a league table of IBRAs over time, cross-referenced for States/Territories.

Linkages to other indicators

Links directly to Indicators 5.3 and 5.6, and has contextual relevance for all indicators that assess the impact of clearing, revegetation and soil conservation or loss.

5.9. Proportion of farmers using soil and plant tissue testing regularly, by industry and AER

Description

Numbers of farmers with records of soil and plant tissue testing used for nutrient management of farmlands, relative to total numbers of farmers stratified by farm industry (dairy, horticulture, sugarcane, cotton, mixed farming, grains, animal grazing, intensive livestock, pastoral) and AER location, in a reporting period. Does not include analyses of contaminants in harvested products (see Indicator 6.7).

Rationale

Rural industry consumption of fertilisers is closely linked to the prices of fertilisers as a proportion of all input costs. Where fertilisers are a small proportion of total input costs, overuse may result, and where farming systems are seldom profitable and fertilisers are a relatively high cost, inadequate nutrient replacement occurs. At present, it is estimated that fewer than 15% of all farmers use soil and plant diagnostic services (Reuter pers. comm.), reflecting a relatively low level of professional management practice in relation to soil fertility and total nutrient management. Leading fertiliser manufacturing and sales companies have expanded their advisory and diagnostic services, sometimes in conjunction with State chemistry services, and can provide a low-cost, rapid-turn-around service. Increases in numbers of users of such services should reflect a more informed and appropriate approach to nutrient requirements in rural districts.

Monitoring design

Survey of all major diagnostic service companies and organisations of numbers of clients, stratified by local district (SLA basis) and/or by type of farming (or crop species in the case of plant tissue analysis). Corroborative evidence from special surveys by ABARE, and information on the use of fertilisers (ABS AgStats and data from Indicators 5.1B and 5.4).

Data sources

Fertiliser company records are very extensive, and are kept on geocoded data systems — particularly those of CSBP (Perth), Pivot (Melbourne) and Incitec (Brisbane). They form the best database on the numbers and distributions of farmers using analytical services, but accessibility of the data is restricted for commercial reasons. State government chemical laboratory and agriculture agencies in some States (eg. Victoria, SA and Queensland) have large record bases on the status of soil fertility in those States, but not on the numbers of farmers contributing samples as their samples come from a variety of client groups. Commercial and government analytical laboratories that service particular industries (eg. the Yanco Research Institute, NSW, services the rice industry) perform large numbers of tissue testing services directly for farmers. Industry associations, statutory marketing authorities (SMAs), dairies, wineries etc. and marketing firms perform very large numbers of sample tests for product quality, and feed some of the data back to farmers on a batch basis. Occasional special surveys are undertaken by ABARE on such issues — generally as commissioned work, and focused on particular industries.

Analysis and interpretation

Plotting of numbers using diagnostic services, relative to total numbers of farmers per AER and major catchment, against farming system and crops grown. Contextual and corroborative evidence (prices received, fertilisers as proportion of total costs, fertilisers applied) from other indicators, and interpretation from independent soil and plant nutrient specialists such as the Australian Soil and Plant Analysis Committee (ASPAC), who monitor analytical laboratory standards.

Reporting scale

Regional, by rural industry (AERs) and major catchment, to national.

Output/reporting

Maps of regions with different proportions of farmers using diagnostic services, with interpretive text and tables.

Linkages to other indicators

Links to Indicator 1.9 (percent managers with best practice), and indicators developed in the inland waters (Fairweather and Napier 1998) and biodiversity report (Saunders *et al*. 1998) relating to Landcare activities.

5.10A. Percent intensive rural industries with effluent management cycling systems

Description

Proportion of intensive rural production and processing plants with contained effluent disposal and treatment systems that minimise entry of contaminated water and solid wastes into waterways and groundwaters, per drainage basin.

Rationale

Very large numbers of intensive animal rearing units (feedlots, aquaculture farms, piggeries, poultry farms, dairies) and plant and animal processing plants (abattoirs, tanneries, wineries, canneries) are located close to catchment water supplies, because they need to use substantial amounts of water in their operation and have large amounts of effluent to dispose of. Numbers have risen steeply in the last decade, with many thousands of intensive rural industry sites established along the Murray alone. A 10 000-head feedlot produces the same amount of sewage waste in a week as a human settlement of 100 000 people, and poses the same risk of ecosystem nutrient and metabolism overloading. Varying degrees of regulatory control over waste disposal systems exist across different jurisdictions, but some industries are encouraging a high level of voluntary compliance with international standards or internally developed best practice guidelines (eg. the Australian Wine and Brandy Association for disposal and reuse of winery wastewater). Increases in irrigation water pricing and in-stream discharge regulation will force greater compliance with these standards in the future. An indicator that charts this progress, and allows interpretation with catchment and industry stratification, is required.

Monitoring design

Repeat surveys of all registers of licences for intensive rural industries by States/Territories (covering several government agencies in each: agriculture, water authorities, trade and commerce etc.), cross-referenced to State EPAs (in those States that have them) for statistics on effluent management systems by intensive industries. In-depth study of selected river catchments that are particularly heavily used (eg. the Murray, Murrumbidgee, Lachlan, Goulburn–Broken, Hawkesbury–Nepean, Swan) to stratify by types of industry.

Data sources

State and Commonwealth EPAs, State/Territory departments for registered water users, and processing and intensive animal production industry licensees. Level of treatment and amount of full recycling from industry associations, MDBC and local government council records in selected studies.

Analysis and interpretation

Total numbers of intensive rural industries point sources from environmental industry consulting firm and government reports, located where possible by geocoding (to within postcodes) for GIS analysis and presentation in a basal topographic/drainage basin framework. Numbers of operators with various classes (1–3) of effluent disposal and recycling then plotted, with locational analysis of catchments most at risk or improving.

Reporting scale

Local catchments to regional drainage basins. National summary by industries.

Output/reporting

Maps of catchments affected by intensive industries, and performance maps for selected catchments showing numbers with and without recycling or advanced disposal per reporting period.

Linkages to other indicators

A complementary indicator to Indicator 5.10B.

5.10B. Percent urban settlements with and without tertiary wastewater treatment, by major catchment

Description

Number of urban settlements, stratified by size (using Population Census classifications), with wastewater effluent provision at primary, secondary and tertiary levels of treatment, and change over the reporting period, sorted by major catchment.

Rationale

Primary wastewater treatment removes settleable solids and gross solid wastes, while secondary treatment involves microbial decomposition, aeration and settlement. Both leave water containing some organic compounds, heavy metals and nutrient loads as contaminants. Tertiary treatments remove most contaminants, except nitrogen and some salt. Depending on the eventual use or disposal of the treated water, a secondary or tertiary level of treatment may be appropriate, but at present a significant number of catchments and coastal regions are still subject to effluents that have only had primary treatment. For example, the effluent from only 17% of the population serviced by Sydney Water Corporation has secondary or tertiary sewage treatment, compared with 100% for the population serviced by Yarra Valley Water in Melbourne and ACTEW Corporation in Canberra. Progress towards uniformly high standards of sewage disposal and wastewater treatment will reduce contaminant pressure on all aquatic systems.

Monitoring design

Comprehensive records of all settlements connected to wastewater services and of water businesses providing services, geocoded for mapping distribution by catchments, assessed annually or within the reporting period. Information on treatment plants to be stratified into the categories of primary, secondary and tertiary systems.

Data sources

Water Services Association of Australia (WWSA) annual handbooks, State and Commonwealth EPAs, Interdata Environmental handbook (5th edition) for water services organisations, and State and Territory EPAs and government agencies for licensing records. ABS for population statistics (Population Census). Catchment and drainage basin map coverage from AUSLIG, ERIN and NRIC.

Analysis and interpretation

Combined interrogation of information sources and classification of treatment level on a geocoded basis for plotting within river systems and drainage basins. Degree to which level of treatment includes management or removal of nitrogen and salt, as well as phosphorus loads (precipitated by use of alum or other salts). Assessment of the appropriateness of water disposal in regions where secondary or primary treatments are still in operation could assist in interpreting the risk posed by those water services and communities not on full tertiary treatment systems.

Reporting scale

National to smallest-scale population centres of threshold value eligible for reticulated wastewater services, by catchments.

Output/reporting

Three to five yearly progress should be reported by major catchment, and estuarine region, using tabular, graphic and locational map outputs.

Linkages to other indicators

This indicator is needed for inland waters and estuaries and the sea indicators of water quality, biodiversity indicators of threats to ecosystem health, and human settlements indicators in relation to quality of life.

Issue 6: Soil and land pollution

Indicators of Anthropogenic Pressure

6.1. Key Indicator: Total immobile contaminant load on land area by catchment

Description

Estimated near-surface land area affected by, and location of, relatively immobile contaminants such as heavy metals, long half-life pesticides (organochlorines), animal health products (anthelmintics, hormones) and PAHs by catchment and reporting period, expressed as an index such as:

Land Contaminant Load = the known proportion of land area affected by all such contaminants x the total number of identified contaminants x the ANZECC/NHMRC 1992 response level for environmental use.

— but excluding high concentrations of nitrogen and phosphorus and minesite-specific contaminants (see Indicators 5.1B, 5.4 and 6.3).

NOTE: Development of this indicator should be conditional on the direction and speed of work in progress under the National Registration Authority's "Existing Chemicals Review Program", and should be complementary to that.

Rationale

Two main types of land-based contamination are recognised: 1. dispersed, low-concentration soil contamination that is generally caused by widespread application of agri-chemicals such as pesticides and fertilisers containing heavy metals; and 2. contamination from localised industrial and urban activities that tend to result in "point source" sites of contamination, where organic compounds and heavy metals from fuels and industrial processing occur in much higher concentrations. Both types of contamination may occur, but with differing impacts on ecosystem function. The first has a more ubiquitous background effect that may go undetected until a large number of applications has occurred (eg. ten or fifteen years' use of a herbicide or drench), and then causes population shifts in soil microbial flora and mesofauna. On the other hand, the second type causes detectable changes to groundwaters, wetlands and other surface waterbodies relatively rapidly. An indicator that monitors the total number of contaminant applications per unit area over time, and land uses where contaminants are routinely used, will allow better identification of the ecosystems at risk.

Monitoring design

Ideally, benchmark sites should be established in localities representing different types of land use and across the range of major soil and climate groups (eg. 50 urban sites spanning residential to industrial, and 300 rural and remote sites including some in pristine conservation environments), with all known sources, chemical compositions and soil concentrations of contaminants monitored. Failing this type of national network, EPA records of industrial process licences, and agricultural and forestry statistics (fertiliser and agri-chemicals via Indicators 5.1A–C, 5.4 and 6.3), would be used to calculate the cumulative number and frequency of contaminant loadings relative to land use per catchment or IBRA region. A baseline value for all cumulative past loadings still extant could be estimated on a relative basis for different regions, as described for Indicator 6.6.

Data sources

As described under monitoring design, with the principal sources of information being EPAs, Avcare, the National Registration Authority (DPIE) and the sources described in Indicators 5.1A–C, 5.4 and 6.3 for contaminant loading, with base maps of land use and land tenure via AUSLIG and Environment Australia . In future, the National Pollutant Inventory will be able to supply data on the location and current use of point-source loads (see Indicator 6.8), and data will be available from community monitoring schemes such the National Toxics Network (which is GIS-based) described in White and Alexandra (1996). Avcare's Obsolete Pesticide Drum Recall program will provide valuable local information.

Analysis and interpretation

Historically significant dates when particular contaminants started to be used should be established for different land uses and regions as the baseline to cumulative loading, with estimates of spread in use being made by expert advisers with knowledge of the physico-chemical behaviour of the chemicals in different terrestrial systems. For example, DDT was widely used between the 1950s and 1980s in all input-based agricultural areas and then phased out — but at different times for different States and industries — as the result of concerns over its effects on raptor population numbers and its widespread occurrence in mammalian fatty tissue. Atrazine-type herbicides were not introduced until the 1970s, but have been used consistently since and have only become detectable in groundwaters after 20 years' application in clay soil areas (such as the sorghum-growing area of NSW). Interpretation of total point-source loads from industrial activities would generally be based on numbers of licences and size of industrial operations. Assessment of the residence times and final terrestrial destinations of industrial, mining and sewage compounds — as distinct from their discharge through waterways and into seas and groundwater — may require a combination of modelling and retrospective monitoring surveys. Decline–function models for microbial decomposition and removal of a portion of the total product loading, relative to soil retention (sorption and transformation) and leaching capacity (climate-based), are available for some groups of compounds (eg. organophosphates and trizine herbicides), and would improve the predictive capacity of model outputs.

Reporting scale

Ideally at catchment scale, but requires area and details of catchments to be known. More probably, reporting would only be feasible at State or AER scale, with national figures for groups of contaminants, in the first instance.

Output/reporting

Text on relative loads across different regions and intensities and types of land use, and graphs showing load over time for specific environments.

Linkages to other indicators

Requires several other indicators for data provision, and should be related to most other indicators in Issue 6, and indicators of invertebrate biodiversity and water quality.

6.2. Key Indicator: Dollar value of pesticides sold per land use, by catchment

Description

Dollar value (deflated to constant dollars) of all pesticides sold by pesticide categories (that is, by group screen tests as used in the National Pesticide Residue Survey), located by total value of sales per category in each population centre, on an annual basis, as a surrogate for total volumes of classes of compounds sold or used.

Rationale

Dollar value of pesticides sold is a compromise surrogate indicator for volumes of chemical compounds sold, which in turn is a surrogate for actual application rates and areas targeted, which in turn are surrogates for total loads of biologically harmful ingredients in each ecosystem. This latter attribute is the subject of only limited research, and no reporting procedures. Research on the impacts of pesticides on environmental health and ecosystem function has been very much less than that on the impact on food quality (Environment Australia 1997, unpublished report on extent of monitoring of environmental effects of agricultural and veterinary chemicals). The research done has been individual *ad hoc* academic studies on particular species and taxa. One reason for the paucity of data has been the overwhelming concentration of research funding, and government and industry concern, on the impact of pesticides entering the human food chain and trade-related issues. As a result, the National Residue Survey and National Basket Survey (see Indicator 6.7) have been established for three decades, but no equivalent national environmental survey is yet established operationally.

Another reason is the very large number of registered chemicals (approximately 400 with National Registration Authority licences), and the thousands of daughter products these can possibly transform to in various parts of the terrestrial and aquatic environment. The dollar value of pesticides has been used successfully as an indicator to demonstrate the need for Integrated Pest Management in target industries such as cotton, deciduous fruit (eg. apple and pear growers) and viticulture, with voluntary compliance by producers and industry associations. It therefore has policy acceptance, and is seen as effective. Nevertheless, the poor documentation, owing to acute industry sensitivity, of the volumes of active ingredients sold and areas of application remains a major gap in Australian statistics. This level of commercial sensitivity is not expressed by the same companies when faced with the demands of EU countries, however, which require very much more detailed statistical reporting.

Monitoring design

Sales figures from manufacturing and wholesaling company statistics and Avcare estimates (historical), for each group of chemicals located by modelling projection, across each AER, and regions of known application or exclusion from use. Any comprehensive monitoring would require compliance by all user industries, so that they could take part in the type of monitoring carried out by the viticulture industry of actual pesticide usage (rather than dollar value substitutes). Current aggregated sale values reported by ABARE (factory gate) are not sufficient.

Data sources

ABARE summaries of the factory-gate value of pesticide sales would need to be dis-aggregated at least by major category (herbicides, insecticides, fungicides, and animal health care products) to be useful. Limited ABS data from AgStats give SLA-scale values, but census questions provide only binary-level information on use of agri-chemicals and no information from major user groups such as local governments, railway and main-roads authorities and forestry commissions. EPA and Rural Industry Research Corporation reports on specific chemical use and impacts (where possible, spatially located to within IBRA regions or major catchments).

Analysis and interpretation

Scrutiny of the list of compounds registered under the National Registration Authority (Canberra), with grouping of chemicals into classes based on mode of action, applicable industries, and modes of permitted use. Identification of catchments and parts of AERs where most applications would be anticipated (eg. horticultural and irrigation regions growing several crops per year), and comparison with actual dollar amounts of each set of chemicals sold. Some estimate of historical trend may be possible from earlier Avcare audits (State-based) on wholesale sales figures, but these audits have now been discontinued. Locational analysis by inductive methodology as described in Monitoring design, with ground-truthing from commissioned investigations where possible (or recent studies undertaken).

Reporting scale

Significant environmental impacts are often local in origin, even when not point-source. For example, they may be concentrated along road and rail lines, with off-target impacts crisscrossing regions laced by these transport lines. Ideally, reporting should provide some information at local scale as well as at regional and national scales, but dis-aggregation may be difficult.

Output/reporting

Tables of value by chemical groups, agricultural and non-agricultural usage, and location (at the least to AER, State/Territory, and major catchment level). Maps of zones of potential use of agri-chemicals based on location of sales.

Linkages to other indicators

This indicator is needed to interpret Indicator 6.11 (Implementation of IPM and agri-chemical risk reduction by rural industry), and is a contributor to Indicators 6.1, 6.3 and 6.6.

Issue 6: Soil and land pollution

Indicators of Condition

6.3. Key Indicator: Change in status of highly contaminated sites per catchment

Description

Change in status, where status equates with number of, condition of, and measures to remediate, contain and monitor highly contaminated sites. Contaminated sites considered are those where levels of contamination exceed ANZECC/NHMRC and international threshold values by a significant amount. Includes any assessments on environmental risk posed by such sites, over the reporting period.

Rationale

The total number of contaminated sites in Australia is unknown (Edwards *et al.* 1994). Although it will be small by European and North American standards where the legacy of the industrial revolution has left great numbers of toxic and intractable dumps, polluted areas and discharges, there are nevertheless perhaps 100 000 sites requiring remediation in the more populous States of Victoria and NSW. Most such sites have a mixture of organic and inorganic contaminants, and an estimated 8000 tonnes of hexachlorobenzene and 2300 tonnes of PCBs are stored in Australia in managed sites, ie. those that are regularly monitored (Independent Panel on Intractable Wastes 1992). The amount and location of wastes in unmanaged sites — particularly those where soil is contaminated, as is the case with former cattle dip sites containing an estimated 20 tonnes of DDT, other chlorinated hydrocarbons and arsenic — form the focus of improved reporting and management action, and the focus of this indicator. Currently, treatment technologies for most of these sites consist of on-site management by monitoring for any leaks or leaching losses and capping with clean topsoil or asphalt, or excavation and removal of the material to another registered landfill site. More sophisticated treatments (Burns *et al.* 1996) are only being considered in an exploratory manner, although a number of these are well established in other OECD countries.

Monitoring design

Examination of the listed status of managed and unmanaged sites with ranking according to environmental hazard status, separately from the health, safety and legal classifications also used by EPAs for registered sites. Environmental hazard criteria would include the proximity of sites to aquifers, local hydrogeology, soil permeability and sorption characteristics, depth to water tables, local weather conditions and surrounding land use and vegetation status. Current status (monitored, unmonitored, contained, uncontained etc.) would be compared with the environmental hazard ranking.

Data sources

State and Commonwealth EPA records, Independent Panel on Intractable Wastes, Toxic Waste Network database, National Pollutant Inventory (future).

Analysis and interpretation

In its crudest form, this indicator would report on trends in the number and impact of highly contaminated sites. The number should go down over time if environmental management is improving. The significant issue for environmental management (as distinct from human health risk management) of highly contaminated sites is whether the contaminants are causing disruption to ecosystem functions. Effects could be seen, for example, in the reproductive behaviour of different biotic kingdoms or in loss or proliferation of key taxa — particularly soil decomposer groups that are essential for the breakdown of toxic organics and nutrient cycling, or plant groups that are absorbers and storers of metals. Analysis should therefore focus on direct studies done of environmental impact and knowledge of the expected impact predicted from status reports on the condition and management level of sites.

Reporting scale

Five-yearly updating of State and Territory reports, with selected regions within sensitive areas (eg. sites located in coastal catchments, or where discharges can affect sensitive wetlands) being monitored more closely.

Output/reporting

Text report with numerical tables stratified by types of site, and levels of environmental risk.

Linkages to other indicators

Closely linked to Indicators 6.8 and 6.10.

6.4. Condition of environments surrounding high-radiation sites

Description

Level of radiation risk in the immediate vicinity of uranium mines, military storage sites, historical testing grounds and the Lucas Heights reactor.

Rationale

Australia has significant deposits of radioactive minerals. Most are unexploited and subject to stringent regulatory and political control, but there are two operating mines (Roxby Downs and Ranger), with other closed mines and a number of historical nuclear testing sites and storage facilities, plus one small reactor at Lucas Heights. Environmental studies are conducted of the environment surrounding the reactor, and investigations of the other regions are conducted by a range of authorities (eg. the SA Health Commission regulates Roxby Downs). Current operations are subject to the strictest regulations, but former activities such as uranium mining at Rum Jungle (NT) and nuclear testing at Woomera (SA) were not subject to the same careful management or scrutiny. Because of the intense public anxiety concerning radiation sources, openness of reporting procedure has great merit and environmental monitoring has a significant benefit in allaying public fear over genetic mutation in biota. Reductions in breeding populations of organisms close to leached radioactive materials in aquatic systems are the most obvious environmental response to leaked radioactivity. These were noted, for example, in the 1970s around the Finniss River, NT, after the closure of the Rum Jungle mine. Site remediation in the early 1980s has reduced the radioactivity risk, but the closed mine still causes heavy metal contamination. This indicator is needed for reasons of public communication.

Monitoring design

Regular assessments of biologically sensitive organisms, mammalian organ condition and radiation levels found in soil, water, sediments, plants and animals in land surrounding currently used and former radiation sites, and in surface and groundwaters intersected, following National Radiation Safety Council guidelines.

Data sources

ANSTO; State, Territory and Commonwealth health commissions; commissioned investigations; and survey records (historical). Note: Defence Department restricted-access records may be involved.

Analysis and interpretation

Rating of groups of organisms, habitats and environments at risk, following internationally agreed radioactive health standards, with the aim of the risk being at the level of background radiation to which all biota are exposed.

Reporting scale

Local for specific site conditions, and national (percent violations of international standards).

Output/reporting

Five-yearly report with tabular quantitative data on radionuclides monitored; levels detected in installations, soil, surface waters and groundwater; and range of organisms assessed and their condition.

Linkages to other indicators

Relates to Indicator 6.3 and to the inland waters indicator report – health indicators (Fairweather and Napier 1998).

6.5. Quality of mining operations relative to total mine sites, and regulation requirements, by drainage basin

Description

The number of mine sites with ongoing and final rehabilitation programs that are effective and operational, relative to the total number of registered and located sites, per reporting period.

Rationale

Mine sites are potential sources of surface and groundwater contamination, both from acid drainage which can mobilise metals and absorb toxic gases, and from treatment processing on-site (such as cyanide ponds for gold extraction). All new mines are registered with State or Commonwealth departments of mines and/or EPAs, and have a requirement to conform to environmental guidelines following from environmental impact statements, but conditions and rigour of implementation vary between jurisdictions and with the scale and type of mining (listed in the Mine Rehabilitation Handbook, AMIC 1991). Historical mine sites that fall outside individual company responsibilities present special problems (see Indicator 6.1). Mine sites in upland, high-rainfall or earthquake-prone areas pose the greatest risk of long-term environmental contamination, and most Australian mining is relatively low-risk on a world scale. Specific instances that are the object of particular monitoring are reported in Taylor (1996).

Monitoring design

Step 1. Comparison of regulatory and best practice recommendations between jurisdictions to provide a baseline on the relative effectiveness of minesite rehabilitation in each State/Territory. Step 2. Comparison of Australian Mining Industry Council company reports for mines in each jurisdiction with legal requirements, and with independent monitoring reports (eg. CSIRO Minesite Indicator project assessing whether current methods of rehabilitation of particular mine sites are succeeding, Tongway *et al*. 1997). The ANZECC/ NHMRC Guidelines for assessment and management of contaminated sites provide general standards for monitoring of impact with a gradation of risk based on human health needs, but industry best practice for the operational management and rehabilitation of open mines now goes beyond this (see AMIC Codes). Because of the cost of comprehensive coverage, selective sampling will probably be most cost effective. The most sensitive monitoring indicator is the turbidity and metal content of waters from mines. Appropriate treatments for contaminated soil from different mining and processing operations are listed in Table 4 of Taylor (1996), who points out that excavation and re-burial has been an easier and more commonly used option in Australia than in North America and Europe because of the low population density and dry climate of the interior, but that on-site treatment will increasingly replace this in future, especially for mines located in the ILZ and coastal regions.

Data sources

Minesite Rehabilitation Handbook 1991 (Minerals Council of Australia), ANZECC/NHMRC Guidelines for the assessment and management of contaminated sites 1992, Australian Minerals Industry Code for Environmental Management, Australian Mining and Engineering Council reports, and State and Commonwealth EPA guidelines on minesite monitoring, environmental impact standards, and regulations. Information on minesite conditions from independent published reports of scientific monitoring, and on the impact of mine drainage from regular monitoring programs, by regional water boards and AGSO, that monitor water quality and turbidity downstream (see inland waters report (Fairweather and Napier 1998)).

Analysis and interpretation: A statistical comparison between minesite condition and rehabilitation management for each of four categories (metallic, non-metallic, building materials and fuels) across jurisdictions, and the relative impact (ranked) on each main catchment. A ranking system is needed because of the potential for greater or lesser impact depending on climate and the degree of hazard of the wastes to biota.

Reporting scale

Local to regional are the principal scales, with national summaries to track progress towards overall best practice standards.

Output/reporting

Graphs and tables showing relative degree of compliance with State/Territory standards, against a baseline classification showing differences between jurisdictions.

Linkages to other indicators

This is a contextual indicator for inland waters and estuaries and the sea indicators of water quality, and should be considered at the same time as Indicators 1.1.C and 6.5.

6.6. Key Indicator: Estimated area of pesticide application by catchment

Description

Estimated areas of lands to which herbicides, insecticides, fungicides, and anthelmintics have been — and are now — regularly applied directly (by spraying) or indirectly (through treated animals) across all land uses as relative environmental loadings, in lieu of actual known areas of land to which pesticides have been applied.

Rationale

Baseline data are lacking on the areas to which agri-chemical pesticides have been applied regularly, both historically and today. However, routine applications of insecticides have been used against such pests as plague locusts, with spraying across large areas of arid and semi-arid regions, and ants and termites in urban areas. Herbicides have been sprayed for noxious weed eradication along roads, waterways and railway lines. Droppings from drenched animals have been deposited throughout the 66% of land that is agricultural, in addition to the conventional agri-chemical applications in farmlands and reafforested forest lands. While many historical applications have now disappeared, the areas that have been affected should still be recorded. The total residual load of such agri-chemicals over time (required for Indicator 6.3) provides valuable background baseline data from which to assess the risks of any current and future intended agri-chemical use. It also provides a relative ranking on the likelihood of disturbance and alteration of functional groups of soil micro-organisms, invertebrate taxa and vegetation communities. Such alterations may include elimination, shift in population structures, and development of resistant types (see Indicator 6.2).

Monitoring design

Use a land-use and cadastral base mapping framework to identify likely and non-likely groups of chemicals that could have been applied to different IBRA regions. For example, in-crop selective herbicides, which form one of the largest groups of chemicals by value, are not used in non-cropping regions (other than very locally around houses and transport lines), and the majority of application is confined to the 3% of Australia that is cropped regularly. Products used on animals on the other hand, especially anthelmintic drenches and dips, have distributed some chemicals that are persistent and relatively immobile — such as organochlorines (eg. dieldrin) — widely throughout all grazing regions. Sampling for off-target as well as on-target residues will require establishment of paired sites across selected IBRA region. Currently, the majority of detailed investigations on impact are carried out as commissioned studies by EPAs and rural industry R&D Corporations; these consider the fate and behaviour of single specified chemicals or usages (eg. environmental impact of strychnine baits following this chemical's widespread use as a rodenticide during recent mouse plagues in southern Australia).

Data sources

Historical data on applications from areas known to have been used for different purposes over the past forty years, State agency records[4] and scientific publications (entomology, agronomy, animal science), with current usage patterns estimated from EPA and Avcare records, the National Toxics Network, ALGA monitoring schemes listed in Listening to the Land (White and Alexandra 1996) and spray contractors registered in each district (via Avcare operator registration records).

Analysis and interpretation

The key requirement is to establish what the total load of agri-chemicals has been to date per region, with an estimate of the residual load from historical applications, and a ranking of current impacts on major classes of ecosystem function such as soil microbial activity, net primary productivity of main plant types, water and soil nutrient cycling and biological activity in waterways. For example, in a high-rainfall, peri-urban coastal environment that has supported market gardening, local council weed management, home gardening, domestic and commercial building, intensive animal industries and open parks and woodlands, there will have been frequent, localised applications of termaticides, herbicides, some anthelmintics, antibiotics and insecticides. In a broad-acre rainfed farming region, there will have been much less use of insecticides and termaticides, low use of organochlorine and organophosphate pesticides, long-term and widespread use of selected groups of herbicides (eg. diuron, 2-4D, bipyridyls, glyphosate and sulphonyl ureas), most of which are rapidly decomposed but can lead to resistance in the target weed, and regular, widespread use of animal drenches such as anthelmintics (avomectins). The total loading has probably been higher in the first example, with a temporary — and possibly persistent — impact on many ecosystem functions. While the total loading and long-term impact is probably less in the latter case, the farming district would be regarded by most of the urban community as the one more to be affected by "agri-chemicals". A risk ranking based on the known decomposition rates of major groups of chemicals could also be developed; this would be a valuable aid to interpretation of impact.

Reporting scale

By major catchment, AERs, ILZ to ELZ and national, with establishment of a year 2000 baseline the first priority.

Output/reporting

Local and regional maps, using a GIS (landcover) base, with total loading by categories of persistence and

4 However, it should be noted that data on land contamination held in some State and Territory agencies are confidential, e.g. Victorian data held under the *Livestock Disease Control Act* can only be released with the consent of the landholder.

impact of chemicals as the principal output; explanatory text and supplementary tables.

Linkages to other indicators

This indicator is a necessary intermediary step to achieving Indicator 6.9 (proposed as a future indicator), and would replace Indicator 6.2 if actual areas of pesticide applications can become reported.

6.7. Rate of violations in residue levels (metals and organics) in harvested rural produce and foodstuffs

Description

This can only be viewed as a surrogate indicator for assessing the extent to which some groups of anthropogenically derived chemical compounds may move through food chains. Combined reports from the National Residue Survey and National Basket Survey, by category of chemical compound (herbicides, insecticides, fungicides, anthelmintics, carcinogens, heavy metals, antibiotics), with proportions of violations, would be collated. Where possible, numbers of tracebacks to particular regions or industries affected would be included per reporting period. A similar indicator (using the NRS data at national level) is being used as one of the attributes of the "Off-site impact of agriculture on other systems" in the NCPISA project. In its present form, it is only available at national scale and cannot be disaggregated to State or regional scales. Some States have their own scheme, eg. the Victorian Produce Monitoring Survey.

Rationale

The primary objective of the NRS and NBS is to provide trade and human health assurance of the contaminant-free status of Australia's agricultural produce. The NRS provides information on bulk commodities — principally destined for export with a particularly strong focus on meats where trade requirements are very strict — and the NBS provides information on processed goods in terms of human health standards set by the NHMRC. These are selected from the average "basket" of goods available from retailers in centres around Australia. Neither survey can offer direct information on the bio-availability or accumulation of residues in non-commercial biota, but they provide the best surrogate available as to the likelihood of contaminant accumulations in higher plant and animal taxa. The NRS makes a distinction between chemicals which are currently registered for use in agriculture and "environmental chemicals" such as heavy metals and residues of chemicals no longer registered but present in the environment (such as DDT), thereby providing some information on the bio-availability of such chemicals. However, their availability for uptake and metabolism may be greater in many cases for domesticated species — which may be exposed for longer periods, or to larger intake of, say, pasture grasses — than for non-domesticated equivalents.

NOTE: Neither survey is a good surrogate for the effects of residues on environmental health or native biota, as the Maximum Residue Levels (MRLs) they employ are directed at protecting human health. Nevertheless, they do provide some information on the expected uptake by different types of plant and animal life forms.

Monitoring design

Both surveys are undertaken according to established random-sampling statistical design across a wide range of commodities and products selected for their risk profiles relative to human health, the amount of previous monitoring and knowledge of the transfer pathways, and community or trade concern over particular chemicals. NRS samples are taken at points of collection, pre-treatment or blending (eg. abattoirs, grain silos, dairies), according to the appropriate level of product stratification and chemical combination, at a rate of 300 samples per combination per year (50 000 in all). NBS monitoring is carried out four times every two years in all States/Territories, with 32 composite samples taken per quarter. There is only limited opportunity for trace-back to smaller-than-district scale, except where violations require further detailed investigation. The information would be of greater value environmentally if the analyses included some off-target plants and animals (eg. galahs, acacias, bush foods). Some kangaroo meat samples are now included in the NRS.

Data sources

Data supplied through the survey programs (DPIE and National Food Authority). Both surveys integrate differences between soils, variations in soil–plant transfer, and transport–handling–packaging effects.

Analysis and interpretation

Already undertaken by both surveys, but interpretation of the significance of the results for environmental purposes may be further developed if primary data (at sampling locations) were made available for the purpose.

Reporting scale

National currently available, but regional — particularly in relation to environmentally sensitive regions — would be preferable if Environment Australia collaborated with the NRS and MBS in identifying and supporting the testing of some off-target plants and animals.

Output/reporting

Regular reports are produced by both surveys, but for environmental implications a joint portfolio additional report would be valuable.

Linkages to other indicators

Used in interpretation of indicators of pesticide and heavy metal impact in Issue 6.

Issue 6: Soil and land pollution Indicators of Appropriate Response

6.8. Key Indicator: Reduction in emissions of land pollutants listed on the proposed National Pollutant Inventory, by drainage basin

Description

The reduction, over the reporting period of five years, in the emissions of chemical pollutants listed on the National Pollutant Inventory (NPI) per monitoring district. Chemicals proposed are point-source based and are known to, or reasonably expected to, cause severe damage to the environment (and human health). They will be listed by location and amounts of chemicals released.

Rationale

Development of the National Pollutant Inventory (NPI) was agreed to by the National Environment Protection Council (established under the *NEPC Act 1994*) in November 1996. The NPI will establish a list of harmful emissions to land, air and water, with information presented geographically. It will be developed cooperatively between the Commonwealth, States and industry via the National Environment Protection Measure (NEPM), following public consultation in the second half of 1997. The proposed indicator may only be valid if the NPI becomes fully operational, with listings of chemicals agreed and point sources located. Diffuse sources are not being included at this juncture, but consideration of diffuse sources will be covered in other government strategies. If the NPI is effective in its declared objective of promoting waste minimisation and cleaner production by industry, there should be a reduction in the number of sources and in the amount of listed emissions over time. This indicator would track that progress.

Monitoring design

Selection of a sample of districts on a stratified basis, to include the full range of land uses and population densities, across major catchments or basins. Tracing of changes in selected chemicals known to have an impact on land ecosystems (eg. heavy metals from biosolid disposal on land, PVC plastics in landfill) across sample districts, and from that deriving an estimate of the trend in point-source chemical contaminants load.

Data sources

National Pollutant Inventory, Environment Australia, with much of the information available electronically (current web site http://www.erin.gov.au/net/npi.html). Reductions (or increases) in numbers of chemicals, sources and levels of emissions will not be available for some time as the NPI is not yet fully developed and established. At this stage, the NPI will concentrate on point sources of terrestrial pollutants; agri-chemicals are not included. The proposal that fertilisers be considered as pollutants has been strongly challenged by agricultural interests because of the critical need for nutrient replacement in low-fertility Australian soils. As separate indicators are proposed to monitor nutrient cycling and budgets, this is not an indicator issue.

Analysis and interpretation

Numbers obtained would be checked against those calculated for Indicator 6.3 (total contaminant load). The NPI will focus initially on particular types of scheduled wastes, particularly those which are manufactured, processed and handled commercially by larger businesses and institutions (as covered by the Australia and New Zealand Standard Industry Codes). The selection of substances to be included or excluded from the list will involve negotiation and consultation through the political process, and will reflect international reporting requirements (weighted to marine and atmospheric pollutants). The selection of contaminants in Indicator 6.3 will be through consideration of specific impacts on environmental health and ecosystem function.

Reporting scale

National to local government or shire.

Output/reporting

Tabular, of changes to selected chemicals across regions, with mapped summaries.

Linkages to other indicators

Indicator 6.3 (as mentioned above) and Indicator 6.9.

6.9. Progress to a national set of baseline data on pesticide applications

Description

Progress — by consensus of the chemical and rural industries, the community and all tiers of government — to establishment of a national set of baseline data on pesticides applied in all environments to assist in their most effective use for sustainable production systems, and the use of voluntary reporting procedures (such as chemical diaries) by all users of agri-chemicals.

Rationale

Agri-chemicals are applied across very large areas of land by various means (spraying, animal excreta, spray drift, solution in water), and their inclusion in the National Pollutant Inventory poses a problem at present. Nevertheless, several government and industry activities have repeatedly identified the need to establish baseline data banks on the amounts of agri-chemicals used, the areal extent over which they have an impact, and the most significant and long-term impacts of such use. The difficulties in obtaining valid information on current usage, and a lack of knowledge on the pathways of dispersed chemicals in the environment (see previous indicators in this section), make it a matter of urgency that other avenues, such as the National Pesticide Reduction Strategy (SCARM Task Force Committee, established in 1996), are monitored.

Monitoring design

Surveys of policy and information documentation, views of industry and government representative bodies, and Ministerial Council resolutions. Identification and tracking of the rate of progress in agencies (such as some in Victoria) and industries (such as viticulture for the wine industry) that are leading in recording all chemical applications for their own and client needs, compared with progress in those jurisdictions and industries where there is no or little action, or where opposition is voiced to instituting such schemes.

Data sources

SCARM agenda papers, BRS and Avcare records, policy and information documentation from Environment Australia, public consultation reports and submissions, and agenda papers of ANZECC and NEPC.

Analysis and interpretation

Progress to be measured in terms of numbers of jurisdictions and stakeholder organisations agreeing to the formation of this type of inventory, with particular note being made of voluntary industry publications and reporting on agri-chemical usage.

Reporting scale

National to local government.

Output/reporting

Regular text reports.

Linkages to other indicators

An extension of Indicator 6.6.

6.10. Change in number of open landfill, industrial waste and orphan sites, by catchments and States/Territories

Description

Change in the number and capacity of open tips, fly-ash deposition sites and abandoned former industrial sites with solid, liquid and gaseous contamination that are not remediated with adequate pollution containment or remedial processes, by major catchment, per reporting period.

Rationale

Large amounts of solid and liquid waste are a consequence of industrialised societies, but a range of remedial technologies exists to render them of minimal environmental threat when integrated waste management is used. Australia disposes of about 776 kg of solid waste per person per year, and an increasing shortage of landfill sites and community concern are forcing authorities to provide alternative disposal methods and waste minimisation strategies.

Tracking the reduction in number of landfill sites in various jurisdictions is an effective surrogate for monitoring progress to waste minimisation and recycling.

Fly ash — the residue from coal combustion in electricity production — is produced at a rate of 8 million tonnes per year in Australia, and has high concentrations of soluble salts and some toxic elements. Other point sources of toxic wastes of mixed organic and inorganic compounds include old gasworks sites (about 150 recorded in Australia), petrol stations, and foundry and metal-working sites. They contain inorganic poisons such as cyanide and ammonia, heavy metals such as arsenic, cadmium and mercury, volatile aromatics (benzene and derivatives), phenolics, and a wide range of polynuclear aromatic hydrocarbons (PAHs) which migrate out slowly, leaching into groundwaters and streams. Sealing, containment and removal of soil for decontamination processing are current commercial options, with bio-remediation and conversion of contaminants through biological processes a preferred future option. Reduction in numbers of identified sites represents progress in reducing environmental hazard. This is particularly important, because legislation to deal specifically with contaminated land currently exists only in three States — NSW, Victoria and Queensland.

Monitoring design

Periodic examination of all registers of sites, site classification by type and possibly risk, identification of locations within catchments and reports on their status, with follow-up questionnaires on any change in condition or remedial treatment.

Data sources

State and Commonwealth EPAs maintain registers of the majority of such sites, although undisclosed or poorly located historical and abandoned sites probably occur in all jurisdictions.

Analysis and interpretation

Plot of trends in numbers in main categories and closure of open sites, and assessment of reasons for change.

Reporting scale

State, local government and catchments where applicable. Because of sensitivities relating to commercial and legal issues, reporting will not be able to identify precise locations.

Output/reporting

Graphs of numbers over time, with explanatory text, by category.

Linkages to other indicators

To be considered in parallel with dispersed sources of contaminants (eg. 5.1A and 5.1B, and 6.5), and numbers relative to those found in 6.3.

6.11. Key Indicator: Implementation of integrated pest management (IPM) and agri-chemical risk reduction by rural industry

Description

The rate of adoption of, and corresponding proportion of the relevant industry affected by, Integrated Pest Management (including management of weeds, insect pests and diseases of agricultural animals and plants, but not including vertebrate animal pests) and recognised practices aimed at reducing both on- and off-target adverse effects of agri-chemicals.

IPM: to include substitution of broad-spectrum for target-specific chemicals, improved modes of delivery by spraying, and targeted timing of any pesticide application to specific parts of the pest life cycle. IPM also includes utilisation of alternative methods of pest, weed and disease control including: breeding of resistance in crops; use of crop rotations; good grazing management of pastures; retention of residues in crop and timber harvesting; out-of season vegetable production; and the development of bio-control organisms.

Risk reduction protocols: to include those established by Avcare, working in consultation with the National Strategy for Ag-Vet Chemicals (SCARM), Environment Australia's Environmental Protection Group and each rural industry.

Rationale

Modern rural industries are totally dependent on a range of weed, disease and pest management strategies to maintain production levels necessary for current and future population demands and economic returns. Australia's rural industries would collapse by at least one-third of current production volume without the use of agricultural and veterinary chemicals (Martin and Hamblin 1989), and would be completely wiped out without the associated use of plant breeding for pathogen resistance, crop and pasture rotations to control weeds and root pathogens, cultivations for weed and pest control, and other management practices generally grouped together as Integrated Pest Management. Different production systems require different strategies, but IPM always involves a more judicious and effective use of agri-chemicals and a greater use of alternative control strategies than existed before. Some high agri-chemical use industries, such as irrigated horticulture, cotton, and viticulture, have developed the most comprehensive systems of IPM, and have a sufficient level of advisory and diagnostic servicing to achieve adoption of IPM by the majority of producers. Other industries, such as the animal-based grazing industries, are less highly coordinated and have a poorer record of adoption of IPM. Local and State government agencies continue to use large quantities of herbicides, with less use of alternative strategies than rural industries in many cases. Chemical companies, wholesalers, and agri-service companies are also critical elements in the proper utilisation of agri-chemicals. Adoption of voluntary compliance schemes for industry best practice is only partial at best among this group of users.

Monitoring design

Selected industries and user groups (including rural producers, rural and forestry industry bodies, local government councils, State/Territory transport departments and agri-chemical producers and distributors) sampled via questionnaires and surveys to assess the level of adoption of IPM. Model use of IPM relative to pest and disease forecasts (some already operational on web sites, eg. *Helicoverpa* spp (Heliothis moth) at: http://fassbinder.ento.ctpm.uq.edu.au/forecast/intro.html) for leading industries such as cotton and viticulture.

Note: The viticulture industry is already operating such a survey, supported by research funding from the Australian Dried Fruits Association. It is now standard practice for more than 2500 growers to keep a spray diary that is used by the winery to ensure that permitted levels of registered agri-chemicals are not exceeded. This voluntary compliance has arisen through the demands of the export trade and the coordination exerted through large company wineries and the Australian Wine Research Institute. Records are kept by individual large winery companies and industry associations.

Data sources

Very varied, but include rural industry research, trade and marketing bodies (eg. the Australian Wheat Board, Meat Research Corporation etc.), Environment Australia's Environmental Protection Group, ABS AgStats (limited number of questions on the full census, but variable by State), independent agricultural consultants (Register of Consultants) and State/Territory advisory services, some Landcare groups (National Landcare Program records, DPIE) and BRS records.

Analysis and interpretation

Analysis of levels of adoption and methods of risk minimisation from IPM for each major user group, where groups are stratified by industry and statistical definition of occupation (ie. to be inclusive of servicing groups such as transport operators and local government councils). IPM classification by groups of target organisms (eg. annual and perennial weeds, insect pests, fungal and bacterial pathogens etc.). Geographical location of proportional use relative to all operators to be plotted on regional maps, and compared with IBRA regions. This will require a special study, but has the advantage that systemic and areal distributions of different groups of target species can be identified relative to native biotic distributions.

Reporting scale

District (SLA where possible) to regional, with IBRA regions the largest regional scale attempted. Total proportion of IPM by user group is more meaningful than aggregation to national level, but national values would be advantageous in OECD/FAO reporting.

Output/reporting

Regional tables by user group and IBRAs affected, and maps of distribution of adoption levels.

Linkages to other indicators

This indicator complements the indicators of pressure (6.2, dollar value of pesticides sold) and condition (6.6 and 6.7, estimated area of pesticide application, and residue levels).

Relevance of Indicators to Specific Land Uses

At the initial Workshop for Land Resource Indicators (DEST 1996), a preliminary set of indicators was considered classified according to major land uses. This created the problem of reiterating many indicators that have generic application, because of their importance to key ecosystem functions. It is, nevertheless, of critical importance that the indicators proposed here are considered in relation to current and future land uses, given the influence that a particular land use may have on both threatening processes and the feasibility of appropriate responses to adverse environmental conditions.

This section has used a combination of AUSLIG (1990) and Graetz *et al*. (1995) to provide a simple framework for major land uses in Australia, with a number of land titles represented in each category. Because nearly half the total land area is used for pastoralism, and another 14% for agriculture and horticulture, these categories have the largest number of specific indicators, but many indicators are applicable across most or all categories of land use.

Government agencies and institutions that have responsibility for management of the anthropogenic activities and threats represented by these indicators have historically developed from these rural industries. Thus business conducted by technical and standing committees of ARMCANZ is very frequently of relevance to environmental portfolios and responsibilities. One of the pleasing developments stemming from the adoption of strategies for sustainable development and the UNCED Conference 1992 has been the increasing interaction between primary industry and environmental agencies in many jurisdictions, mirroring the increased sensitivity to environmental concerns in some private and commercial sectors. This degree of collaboration and joint action might serve as a valuable response indicator of the state of the environment.

Conservation, protected and vacant lands

Conservation land uses are defined to cover all those land areas that are under gazetted national, State/Territory or local government registers, and include areas covenanted for conservation on freehold titles (eg. on farms). Other protected lands include Commonwealth Defence lands and the protected lands of Australian Territories. Vacant lands are the unalienated Crown lands, now mainly confined to the inland and western deserts, where there are few human settlements, roads, fencelines or watering points. All these areas are preserved by a variety of legislative and management measures from persistent increase in human settlement and activity, although some conservation areas (National Parks) are under considerable pressure because of their relatively small size, high accessibility and tourism potential (eg. Kosciusko National Park near Canberra, the Royal National Park near Sydney). While Commonwealth Defence lands are used for military activities, the total disturbance to land is generally small, and they have significant importance as areas of refuge for certain elements of biodiversity where surrounding lands are used more intensively.

The indicators that have most relevance to these lands are contained in Issue 1: Accelerated erosion and loss of surface soil, Issue 2: Physical changes to natural habitats and Issue 4: Introduction of novel biota into native habitats and communities.

Despite the measure of protection given to all these land areas by legislation and management practice, there is constant pressure on smaller conservation areas and Defence lands from incursions by exotic biota, particularly where surrounding lands are less well vegetated or represent a source of weeds and pests. Probably the two most important indicators of all are:

- 2.1 Index of human accessibility related to landcover regions.
- 4.1 Rate of extension of exotic species into each IBRA, and of change in their abundance.

Other relevant indicators are:

- 1.2. Total grazing pressure relative to net primary productivity (biomass) by landcover regions and AERs.

The sub-indicators:

- 1.2B Non-domestic vertebrate herbivores per landcover region and AER.
- 1.4 Surface soil loss index.
- 1.7A Area of pastoral properties reducing grazing damage by alternate use and feral animal control, by State and landcover region.

- 4.2 Impact of agriculture on conservation land, by AER and State/Territory.

- 4.3 Percent of total land area carrying different proportions of exotic families, estimated for each IBRA region.

- 4.4 Weed infestation index: rate of spread x habitats affected.

- 4.5 Effectiveness of reduction in damage caused by weeds, pests and diseases that are harmful at ecosystem scale, by IBRA regions.

Forested regions

Forested regions have been the subject of a number of concerted government initiatives in recent years, following concern at international and national levels about the perceived rapid loss of forest reserves world-wide. Australian forested regions have now been more closely defined, old-growth native forests have been identified in each climatic region, and a political process — initiated between the Commonwealth and State/Territory Governments and enshrined in the Comprehensive Regional Assessments — will provide long-term management of forests that ensures optimisation between the various forest attributes valued by different sections of the community — productive timber and other products, water yield, biodiversity, and aesthetic and cultural values.

This report has deliberately attempted to marry proposed indicators with those that are being considered by the Montreal Process for international and national reporting on the state of the forests. Initially, a State of the Forests Report will be published separately (expected to be published in 1998) but in future Montreal Process reporting and state of the forests reporting are expected to be merged (Hnatuik, Humphries pers comm.). Proposed indicators for the Montreal Process are still being considered by the collaborating countries (chaired by Canada), and some criteria covered in the Montreal Process are outside the scope of this report. These include: most of Criterion 1 (biodiversity), which is covered in the biodiversity indicators report (Saunders *et al*. 1998), although Indicator 1.1A has been incorporated here; Criterion 2 (productive capacity of forests), apart from noting the relevance of the proposed Net Primary Productivity indicator (5.6); and Criterion 6, which deal principally with productive capacity and socio-economic functions. This report has concentrated therefore on Criteria 3 (maintenance of forest ecosystem health and vitality) and 4 (conservation and maintenance of soil and water resources), with a sub-indicator dealing with Criterion 5 (maintenance of forest contribution to global carbon cycles).

The indicators of special relevance to forest regions are:

- 1.1B Area and percent of forests with significant soil erosion, by tenure and catchments.

- 1.9B Area of forested lands in which the legal framework encourages best practice codes of forest management, and the conservation of special environmental values.

- 2.2 Percent of each IBRA region lost to development relative to percent already affected by native vegetation loss.

- 2.4 Landcover change: proportion of each region covered by forest, wood, shrubs and grasses compared with 1990 baseline, by landcover and tenure

- 2.5 Extent of area by forest type, relative to total forest area, and location within catchments, by tenure.

- 3.5 Index of measures to increase perennial vegetation cover, by area of catchment and AER affected.

- 4.3. Percent of total land area carrying different proportions of exotic families, estimated for each IBRA region

- 5.5 Rate of land carbon (organic matter) sequestration by AER and IBRA region.

- 5.6 Change to net primary productivity by IBRA regions, grouped by catchments.

- 5.7 Proportion of each forestry and farming system with stable nutrient balance by major catchment, AER.

Explanations for how these indicators have been arrived at — and why, in some cases, they deviate from those proposed in the Montreal Process — are given with the descriptions of the indicators in the previous section. A number of the proposed Montreal Process indicators have been modified because they are unmeasurable in their original form; they are without historical data sets in Australia, or have very limited relevance to Australian conditions. Because of the large range of forest types in Australia (from temperate to tropical) and the large number of jurisdictions involved, the stratification suggested deliberately considers the effects of differences in tenure and State/Territory legislation in interpreting the results.

Agricultural lands (excluding pastoralism)

Agricultural lands are taken to be those which, as defined in the Taxation Act, allow for a full range of agricultural activities to take place — including clearing of native vegetation; harvesting of deliberately produced trees, crops, vines and pastures; rearing of animals; installation of irrigation and special structures; and cultivation of the soil. Pastoralism is considered separately because the range of deliberate alterations to most of the land area by clearing, cultivation and replanting with exotic crops, trees and pastures is minimal, and there are no deliberate inputs of irrigation water, fertilisers and agri-chemicals that affect the majority of the land area.

Most agricultural activities take place on freehold-title lands, in an arc within 600 km of the coastline from latitude 17° in Queensland to latitude 28° in WA and in small isolated patches in the NT. The area of crops and sown pastures is 50 million hectares (ABS 1996), or only 6.5% of Australia, whereas the total area of farm establishments as defined for statistical purposes includes the very much greater area of livestock grazing. This extends over another 55% of Australia occupying 420 million hectares, mainly in the semi-arid and arid interior and northern regions. The agricultural region is largely confined within the Intensive Landuse Zone (ILZ) of Graetz *et al*. (1995), and the pastoral region within the Extensive Landuse Zone (ELZ).

Agricultural lands require indicators in each Issue category. Indicators in italics below are ones being used in the National Collaborative Project on Indicators for Sustainable Agriculture. Indicators that have been developed specifically to address the effects of agricultural practices are:

Issue 1: Accelerated erosion and loss of surface soil

- 1.1A Percentage cultivated land area with exposed soils by catchment and by agro-ecological region (AER)
- 1.4 Surface soil loss index.
- 1.5 Gullying index per major catchment.
- 1.7B Percentage of shires destocking when feed reaches advised threshold, by AER and landcover region.
- 1.8 Implementation of new drought policies.
- 1.9 Percent of land managers using agreed Best Practice by land use and/or catchment.
- 1.9A Percent cropped land with reduced tillage plus stubble retention, by AER.

Issue 2: Physical changes to natural habitats

- 2.3 Change in land use by catchments, AERs and landcover regions.

Issue 3: Hydrological imbalance

- 3.1 Ratio of area of catchment under perennial: annual vegetation, as proportion of total catchment (report also by State).
- 3.3 Percent area of land affected by dryland salinity and by acidity, by catchment and AER.
- 3.4 Variation in plant water utilisation with landcover change.
- 3.5 Index of measures to increase perennial vegetation cover, by area of catchment and AER affected.

Issue 4: Introduction of novel biota into native habitats and communities

- 4.1A Number of reports of all, and of new, weeds, pests and diseases per AER and IBRA region.
- *4.2 Impact of agriculture on conservation land, by AER and State/Territory.*
- 4.5 Effectiveness of reduction in damage caused by weeds, pests and diseases that are harmful at ecosystem scale, by IBRA regions.

Issue 5: Nutrient and salt cycling

- 5.1B Sources of Phosphorus derived from land activities reaching rivers by catchment.
- 5.3 Change in area and location of salinised land, compared across regional catchments and AERs.
- *5.4 Net nutrient balance for the major elements Nitrogen, Phosphorus and Potassium per year by land use mapped across IBRA regions and drainage basins.*
- 5.7 Proportion of each forestry and farming system with stable nutrient balance by major catchment, AER.

- 5.9 Proportion of farmers using soil and plant tissue testing regularly, by industry and AER.
- 5.10A Percent intensive rural industries with effluent management cycling systems.

Issue 6: Soil and land pollution

- 6.2. Dollar value of pesticides sold per land use, by catchment.
- 6.6 Estimated area of pesticide application by catchment.
- *6.7 Rate of violations in residue levels (metals and organics) in harvested rural produce and foodstuffs.*
- 6.9 Progress to a national set of baseline data on pesticide applications.
- 6.11 Implementation of integrated pest management (IPM) and agri-chemical risk reduction by rural industry.

Rangelands used for pastoralism

Pastoral lands are used for pastoral grazing — that is, keeping domestic stock principally on native vegetation — with restrictions to other uses of the land through leasing arrangements under State and Territory Acts, acting for the Crown. Aboriginal lands that are also being used for pastoralism (a significant proportion of those in the NT and some in SA and WA) are also included here as the same types of impacts occur. Pastoral grazing is the principal land use across most of Australia. Although fewer than 300 000 people live in the semi-arid and arid rangelands, the impact of animal production industries there on environmental conditions has been, and continues to be, highly significant (Graetz *et al*. 1995).

Specific indicators of relevance to the rangelands occur principally in Issues 1 (Accelerated erosion), 3 (Hydrological imbalance) and 4 (Introduction of novel biota into native habitats).

Issue 1: Accelerated erosion and loss of surface soil

- 1.1 Change in total exposed soil surface contributing to erosion, as a percentage of land area per landcover region, stratified by major land use
- 1.1D. Area of unsealed roads and earthworks as a proportion of total land area, per catchment.
- 1.2 Total grazing pressure relative to net primary productivity (biomass) by landcover regions and AERs.
- 1.2A Domestic vertebrate grazing pressure per landcover region, and AER.
- 1.2B Non-domestic vertebrate herbivores per landcover region and AER.
- 1.4 Surface soil loss index.
- 1.6 Change in dust storm index relative to high-wind events by AERs and landcover regions.
- 1.7. Percent, number and area affected of pastoral shires with stock at or below conservative stocking rates, by AER and landcover regions
- 1.7A Area of pastoral properties reducing grazing damage by alternate use and feral animal control, by State and landcover region.
- 1.7B. Percentage of shires destocking when feed reaches advised threshold, by AER and landcover region.
- 1.8 Implementation of new drought policies.

Issue 2: Physical changes to natural habitats

- 2.4. Landcover change: proportion of each region covered by forest, wood, shrubs and grasses compared with 1990 baseline, by landcover and tenure

Issue 3: Hydrological imbalance

- 3.2. Number of freely flowing bores per artesian basin (by State and AER) relative to numbers capped or regulated
- 3.4 Variation in plant water utilisation with landcover change.

Issue 4: Introduction of novel biota into native habitats and communities

- 4.1 Rate of extension of exotic species into each IBRA, and of change in their abundance.
- 4.2 Impact of agriculture on conservation land, by AER and State/Territory.
- 4.3 Percent of total land area carrying different proportions of exotic families, estimated for each IBRA region.

Urban, peri-urban and multiple land use

The human settlements indicators report (Newton *et al*. in prep.) will contain the majority of specific indicators for urban lands, but a few of the indicators developed for land have particular relevance to the more densely settled regions, and particularly to industrial, processing and waste disposal activities that are located in urban and peri-urban districts. A recent phenomenon that is expected to continue to increase in future is the expansion of semi-urban, medium-intensity settlement into previously rural and wooded districts — principally along much of the east coast (from southern NSW to central Queensland), along the inland transport corridors to the west of the Dividing Range in Victoria and NSW, in the Adelaide Hills region, and south of the Perth metropolitan area to Bunbury. These population inflows are characterised by low to medium housing densities, increased transport routes, fragmentation of existing vegetation communities and increasing nutrient and pollutant loadings. Their location affects about a quarter of the IBRA regions.

The single most important indicator of particular relevance to urban, peri-urban and multiple-use regions occurs in Issue 2 (Physical changes to natural habitats). It is:

- 2.2 Percent of each IBRA region lost to development relative to percent already affected by native vegetation loss.

Other important indicators are:

- 2.1 Index of human accessibility related to landcover regions.
- 2.3 Change in land use by catchments, AERs and landcover regions.
- 2.5 Extent of area by forest type, relative to total forest area, and location within catchments, by tenure.
- 2.7 Rate of urban infill and increase in housing density relative to rate of urban expansion and rural subdivision into non-built-up areas.
- 4.1 Rate of extension of exotic species into each IBRA, and of change in their abundance.
- 5.10B Percent urban settlements with and without tertiary wastewater treatment, by major catchment.
- 6.1 Total immobile contaminant load on land area by catchment.
- 6.8. Reduction in emissions of land pollutants listed on the proposed National Pollutant Inventory, by drainage basin.
- 6.10 Change in number of open landfill, industrial waste and orphan sites, by catchments and States/Territories.

Mining areas

Australia is a mineral and petroleum-gas rich continent, and mining plays a major role in the economy, responsible for more than 40% of export earnings. It is carried out in all parts of terrestrial and marine environments. Mining is characterised by very localised, but complete, disturbance of terrain (particularly in the case of the majority of Australian mines, which use open-cut mining), and associated road, rail and port developments for both exploration and transport purposes. The impact of mining on the environment is generally small, relative to that of other land uses and to the value of the activity to the economy, but mining and associated processing operations require high levels of management care because the majority of materials being mined carry significant human health, and some environmental, risk. The Australian Mining Industry Council has reviewed the needs and priorities for environmental research and management in the industry, and ranks ecosystem establishment and resilience as the most important, followed by treatment of final voids, minimising impacts on biodiversity, control of acid draining, tailings and waste, and reducing greenhouse gas emissions. Because of the highly organised, commercial nature of the industry, voluntary compliance by large mining operations is a viable option for most sections of the industry, and the indicators proposed attempt to reflect this.

Principal indicators of particular importance to mining are:

- 1.1C Total area of open minesite bare ground, by catchment.
- 1.1D Area of unsealed roads and earthworks as a proportion of total land area, per catchment.
- 6.3 Change in status of highly contaminated sites per catchment.
- 6.4. Condition of environments surrounding high-radiation sites.
- 6.5 Quality of mining operations relative to total mine sites, and regulation requirements, by drainage basin.
- 6.8. Reduction in emissions of land pollutants listed on the proposed National Pollutant Inventory, by drainage basin.

RESEARCH NEEDS

A number of indicators have been proposed that are hard to achieve currently because of the lack of baseline values and the piecemeal nature of past and current research required to bring the indicator to the level of operational reporting. A typical example is the comparison between the long-established and well-functioning monitoring and reporting system for agri-chemical and heavy metal residues in agricultural products intended for sale, and the dearth of equivalent information on residues in off-target organisms and on ecosystem effects where environmental concerns are foremost.

The single most critical need would thus appear to be for recognition that Environment Australia should develop a comprehensive research strategy that is supported by dedicated research funding (comparable to the system established for rural industries under the *Rural Industries Research Funds Acts*), with levy or voluntary contributions from those groups of stakeholders most affected (other tiers of government, and water, mining and other industry groups).

At present, much of the environmental research and monitoring is carried out by scientists who have positions in research agencies devoted to primary industries, and who must therefore provide an adequate service to those clients first. Collaborative schemes with joint-venture funding across portfolios have already begun to fill the gap, with the Department of Industry, Science and Tourism's Cooperative Research Centres Program being one successful example; twelve out of sixty-five CRCs are devoted to environmental issues. The Land and Water Resources R&D Corporation, and the various programs of the Murray–Darling Basin Commission that deal with natural resource issues (eutrophication, salinity, river health etc.), have similarly brokered joint research projects in critical areas where several industries or stakeholders are involved. The Natural Heritage Trust is the most recent example of cross-portfolio management of such activities.

A few proposed indicators are already operational for other purposes, but the majority proposed here have been selected for the specific purposes of state of the environment reporting and will need further research and development before they can be used. These are identified by an asterisk in the Summary Table at the start of this report, or by two asterisks where there is great need and little current research. (*) signifies that research is currently under way, but needs to be on-going to ensure a worthwhile product is obtained.

Processes and biological pathways involved in environmental phenomena are complex, and the uncertainty that exists in our present level of knowledge about the relationships that societies have with their environment make it both inevitable and necessary for research to play a large part in this further development. A number of government-funded programs already support environmental research, spread across a range of Commonwealth and State/Territory portfolios and agencies. Increasing commitment to the principles of Ecologically Sustainable Development and International Best Practice requires such programs to work more closely together, and in partnership with the community and private sector. These opportunities should be seized upon in developing the ongoing research and monitoring framework necessary for the complex and challenging task that reporting on the state of the environment represents.

Fewer than ten indicators in the recommended list of 60 are sufficiently developed to be useable already, or without significant further research effort. Some of the most pressing research areas identified in the report are:

- the nature of the relationships between two or more of the threatening processes, resultant environmental conditions and trade-offs among potential responses;
- a range of research issues relating to the past and present use of agricultural chemicals, including where they are used, what off-target organisms are affected, and the total chemical loading carried in different regions that is of environmental significance;
- methodologies for extrapolating point-source data to various larger scales; and
- support for coordination of monitoring and other observations carried out by voluntary groups — in relation to activities such as Landcare, Greening Australia etc. — that can feed into indicators relating to pests, weeds and diseases of environmental significance and numbers and location of non-domestic vertebrate herbivores, and other indicators that require detailed local knowledge beyond the capacity of under-resourced government agencies to obtain.

Most proposed indicators rely on being able to obtain data from government sources. Many traditional sources are now being either disbanded, cost-recovered between government agencies thus adding to total cost, or providing data of dubious and unreliable quality. Environmental monitoring and reporting are vitally dependent upon good, consistent, long-term record-keeping, and these trends are considered likely to jeopardise the ability to develop reliable and credible indicators in the national interest.

Compared with the support both given to, and provided by, community groups towards environmental monitoring of biodiversity and coastal and freshwater aquatic ecosystems, there has been little attempt to date to harness the resources of such programs as Landcare, Save the Bush and Greening Australia for reporting on various land resource Threatening Processes.

Some proposed indicators — such as the extent and numbers of non-domesticated herbivores, the extent of weeds, pests and diseases, the incursion of exotics, the extent of past pesticide usage, and areas of land that have been contaminated from a range of pollutants — need the contribution that only local knowledge and observation can provide. Environment Australia is in a position to provide assistance in harnessing the activities already under way in such groups to provide very much richer and more comprehensive data in key areas by following the model already operating successfully in Waterwatch.

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Appendix 1: Considered and Rejected Indicators

Table 7

Indicators proposed by a selection of published reports pertaining to the land initially considered but rejected by this report. (In cases marked a, b and iw these have been considered by other Theme Coordinators: a = atmosphere, b = biodiversity and iw = inland waters.)

Indicator Theme	Variations include	P,C,R	Source	Why rejected	
Atmospheric pollution	C, N, S compounds, halons	C	OECD	3, 7	
Biodiversity	Numbers of species by habitat type	C	Mont, STI	2, 4, 7	b
	Trends in biodiversity indices	C	Mont	5, 7	b
	Numbers of species at risk by habitat type	C	Mont, STI	5, 7	b
	Changes in distribution and abundance	C	PF	2, 5, 4, 7	b
	Frogwatch records	C	PF	7	iw
Clearing/vegetation loss	Clearing rate (as opposed to extent cleared)	P	LQI	7	b
Climate	Rainfall patterns—departure from historic	C	PF	7	a
	Global mean temperature	C	OECD	7	a
	Ground level UVB radiation	C	OECD, STI	7	a
Eco. taxes/charges	Licensing of fishing	R	PF	7	b
	Polluter pays	R	PF	7	iw
	Eco charges	R	OECD	5	
Environmental expenditure	Expenditure on environment by various land managements	R	OECD	7	b
Groundwater availability	Population supported by groundwater	P	PF, STI	7	iw
	Groundwater discharging/recharging by area	C	PF, LQI	1	
	Area of land underlain by shallow water tables	C	PF, LQI, STI	7	iw
Groundwater quality	Groundwater analysis (pH, EC, cations, dissolved O2 etc.)	C	LQI, OECD,	PF 7	iw
	Turbidity	C	PF, STI	7	iw
Landcare activities	Numbers of Landcare-related programs/ Landcare groups	R	LQI, PF	7	b
	Funds for Landcare-related programs	R	PF	4	b
	Percent farmers having access to funds	R	LQI	5	
	Rehabilitation/monitoring schemes	R	PF	4	b
Market prices/shares	Market prices for energy, fuelwood	R	LQI, OECD	7	
	Market share of unleaded petrol				
	Market share of phosphate-free detergents	R	OECD, PF	7	iw
Production	Actual to target/potential yield ratio	C	LQI	2, 4	
	Growing stocks	C	Mont	3	
Salinity	Cultivation of salt-tolerant crops	R	LQI	5	
	% catchment capable of infiltrating water by land use	R	AH prelim	8	

Table 7 (cont.) Considered and rejected indicators

Indicator Theme	Variations include	P,C,R	Source	Why rejected	
Socio-environmental	Land:livestock, land:population ratios	P	LQI	1, 7	b
	Rural population density	P		1, 7	b
	Rate of migration	R	LQI	2, 6	
	Farmer:extension officer ratio	R	LQI	3, 4	
	Number of farmer associations/groups	R	LQI	3, 4	b
	Number of conflicts over land resources	R	LQI	2, 3, 5	
	Abandonment of formerly cultivated land	R	LQI	3, 6	
	Conflict between pastoralists and neighbours	R	LQI	3	
	Percent farmers with title/tenure	C	LQI	5	
	Net farm profits	C	LQI	2, 3	
Standing biomass	Total chlorophyll	C	PF	2, 7	
Surface water availability	Distance of irrigators to water	C	LQI, PF	7, 3	iw
	Water storage capacity	P	PF, STI	7	iw
Surface water quality	Populations of waterfaring animals/plants/ microbes	C	PF, STI	7	iw
	Water analyses (other than C, N and P compounds)	C	PF	7	iw
	Turbidity	C	PF, STI	7	iw
	Algal blooms	C	PF, STI	7	iw
Vegetation status	Palatable:unpalatable vegetation ratio	C	LQI	2	
Watercourse change	Change in stream depth	C	PF, STI	7	
	Changes in stream flow	C	PF, STI	7	
	Creation of channels	C	PF	1, 7	
	Change in biological activity	C	PF	1, 2	
	Flood frequency	C	PF	2, 7	
Waterlogging	Area of waterlogged land	C	PF	3	
	Crop failures/farm abandonments due to waterlogging	C	LQI	4	
Other	Threatening processes in relation to ecological integrity	C	Mont	2, 5	
	Recreational activities	R	PF	5	
	Percent of stunted children	C	LQI	6	
	Percent cars with catalytic converters	R	OECD	7	
	Change in surface albedo by catchment	R	AH prelim.	8	
	Rate of onset of pesticide resistance in target species	R	AH prelim.	8	

Reasons for rejection:

1 Already incorporated in another indicator in either Land Resources report or other report.

2 Difficult to measure or implement; variation too large to derive meaningful interpretation.

3 Indicative of localised area only; not an indicator of wider environment; can be confounded by non-environmental influences (e.g. economic, political).

4 Not capable of routine application for national purposes.

5 Not universally defined; too ambiguous.

6 Not useful in the Australian context.

7 More properly under the jurisdiction of another report.

8 Rejected by majority of referees at final draft stage.

Sources (and comments):

LQI - Pieri C., J. Dumanski, A. Hamblin and A. Young (1995) Land Quality Indicators: a discussion paper. The World Bank, Washington DC.

Mont. - Draft document: "A framework of regional (sub-national) level criteria and indicators of sustainable forest management in Australia."

OECD - Organisation for Economic Co-operation and Development (1993) Core set of indicators for environmental performance reviews. Environment Monograph No. 83. OECD, Paris.

PF - A preliminary list of indicators proposed by the Inland Waters coordinator, Peter Fairweather.

WSP - State of the Environment Australia (1996) Proceedings of a workshop on key environmental indicators for land resources in state of the environment reporting. State of the Environment Reporting Unit, DEST, Canberra. (Note that no indicators proposed by the WSP occur in Table 7; all are effectively accounted for as used indicators or appear in Table 8 or 9.)

STI - State/Territory Indicators proposed for state of the environment reporting and collated by Environment Australia, 1997.

AH prelim. Proposed by A. Hamblin for inclusion in drafts of this report.

Table 8

Indicators initially proposed for the Land report but transferred to other Coordinators.

Transferred indicator	Report adopting indicator	Pressure, Condition or Response
Drainage and loss of wetlands	Inland Waters	P
Efficiency of irrigation water-use index per irrigation area	Inland Waters	P
Price of irrigation water relative to real costs of delivery	Inland Waters	P
Change in groundwater pressure per artesian basin	Inland Waters	C
Rate of rise in watertable in irrigation areas	Inland Waters	C
Changes in Ca, N and P levels in surface water [and groundwaters]	Inland Waters	C
Regulation of river channels relative to total river length	Inland Waters	C
Government support to land conservation in priority catchments	Inland Waters	R
Existence/lack of conservation plans for wetlands	Inland Waters	R
% river lengths [not] covered for environmental flow volumes	Inland Waters	R
Number of obsolete weirs, locks removed per catchment	Inland Waters	R
Vegetated length of permanent streams relative to total length	Inland Waters	R
Rate of removal of subsidies on water use by State and catchment	Inland Waters	R
Extent of natural vegetation (IBRA) fragmented by all land uses	Biodiversity	C
Class of vegetation change by habitat alteration and loss, by IBR	Biodiversity	C
Percent land cleared for all activities, by IBRA region and land use	Biodiversity	P
Vegetation condition index by IBRA, landcover and AER	Biodiversity	C
Vegetation age structure by IBRA, landcover and AER	Biodiversity	C
Percent vegetation type diseased, at full chlorophyll level, by landcover	Biodiversity	C
% each IBRA region scheduled for development relative to percent affected by habitat loss	Biodiversity	R
Number of IBRA regions covered by clearing bans, by State, Territory.	Biodiversity	R
Number of infringements of clearing bans in force, by State, Territory	Biodiversity	R
Ratio of land approved to disallowed for clearing by IBRA	Biodiversity	C
Percent mine sites with [without] effluent treatments	Biodiversity	R
Human population growth and change in density	Human Settlements	P
Human population distribution and density	Human Settlements	C
Levels of carbon dioxide, and greenhouse gases from vegetation change	Atmosphere	P
Estuarine sediment plumes	Estuaries and the Sea	P

Table 9

Indicators initially considered for the Land report that proved not to be viable.

Indicator	P, C, R	Reason for exclusion
Length of steep-sided gullies relative to area of catchment (dissection)	P	This is now incorporated in the present selected indicator, as a component of the gullying index which combines this attribute with headward erosion — an attribute necessary to distinguish currently active from historical gully activity.
Change in suspended sediment yield from outfalls of major tributaries, by catchment	P	The very high variability of suspended sediment loads in many Australian rivers may make this proposed indicator impossible to implement in most catchments, and for this reason it is rejected both here and by the Inland Waters Indicator Report. It was also proposed as an indicator of off-site impact for the National Collaborative Project on Indicators of Sustainable Agriculture, but was rejected because of the impracticality of interpretation of the data.
Wind scars in crops by AER	P	This proposed indicator has been rejected as being of low value to all but local scales, although the supplemental information assists detection of accelerated wind erosion in some areas of higher rainfall approaching the cut-off zones. Distinctive wind scars are found in young, emergent crops, particularly in mallee regions, that are detectable from aerial photography and remote sensing to a resolution of 1 m^2.
Sediment plumes in estuaries after exceptional rain events by coastal catchment	P	Very striking evidence of current erosion can be obtained from remote sensing images of such sediment plumes (R Smith, DOLA, archived sequences for the Murchison R, WA). However, to be of more than anecdotal value these data must be linked to an assessment of bare soil in the catchment and to contemporaneous rainfall data. This indicator is better treated at State or regional level, after consideration for the Estuaries and the Sea Indicator Report.
High P:N ratios in non-flowing and low-flow surface waters	C	Advice from nutrient-balance chemists and hydrologists was that the data for such an indicator only exists in well monitored catchments that have long-term research activities associated with them, and the indicator is not capable of routine application for national purposes.
Presence [absence] of key f unction soil microbial groups per IBRA	C	Not capable of routine, operational use, as this is still at an early research stage, with many uncertainties relating to selection of key groups for different types of environment.
Proportion of all rural research on establishment of perennial vegetation	R	Trial estimates for this indicator suggested that there are too many alternative methods of calculation and interpretation for it to be a robust and unambiguous indicator.
Level of compliance with Radiation Safety Council standards	R	Not a useful indicator for Australia, where use of radioactive substances is confined to small-scale, research or monitoring devices rather than power generation, given the condition indicator for radiation related to mining and storage of irradiated substances already in the report.
Measures to protect large intact areas from development by State, Territory , LGA	R	This indicator has been incorporated into the Biodiversity Indicator Report under responses to the fragmentation and clearing of native vegetation.
Percent forested area with exotic species dominant by forest type	C	Considered to be sufficiently well covered by Indicator 4.3, “Percent of total land area carrying different proportions of exotic families, estimated for each IBRA region”.
Spatial variation in P, N, Ca and heavy metals not consistent with soil type distribution.	C	Considered impracticable to derive from existing data sources, and taken up in the indicators relating to salt, nutrient budgets and heavy metal contamination.
Numbers of dams, including farm dams, and those on and off watercourses	P/C	Of greater significance at regional and local scales (rather than national), and only applies in areas of most intensive land management.

Appendix 2: Pressures, Conditions & Responses, and Equivalent Indicators

Table 10

Indicators of Pressure on Ecosystem Functions (Land)

Indicators of pressure have units of area or length per time per time (i.e. they express rate over time) or describe a practice that has a positive or negative impact

Anthropogenic Pressures	Indicators of Pressure
1. Accelerated erosion and loss of surface soil	[key indicators in bold type; italicised indicators dealt with in other reports]
- complete removal of all vegetation	**- exposed soil surface as % catchments, and x land use**
- clean cultivations with no stubble retention	- % cultivated land with exposed soils x catchment, AER
- clear felling in forests	- % clearfelled forests x catchments and landcover regions
- open cast mining	- total minesite bareground relative to rain erosivity x catchment
- unsealed roads, and earthworks	**- total area of unsealed roads + earthworks x catchment**
- overgrazing from total grazing pressure	**- total grazing pressure x land use and AER**
	- domestic vertebrate grazing pressure x land use & AER
	- feral and native vertebrate grazing estimates
- permanent sealing of land surfaces	- % catchment impervious to rain
2. Physical changes to natural habitats (vegetation cover and type, and hydrology)	
- changes to land values	- changes in land use by catchments, by AER, landcover regions
- permanent destruction of habitats	*- % land cleared by IBRA region, partitioned for land use*
- fragmentation of vegetation communities	*- % and rate of fragmentation of native communities by IBRA regions*
- urban expansion versus in-fill	*- % permanent loss of habitats beneath structures x IBRA region*
- construction of roads, railways, canals	*- rate of fragmentation by road construction (include mining) x IBRA region*
- tree thinning (deliberate and unintentional)	- rate and volume of logging by forest type
- deliberate and accidental bush fires	*- bushfire frequency x catchment, and landcover regions*
- changes in land tenures and conditions of title	- % land clearance for agriculture by AER and IBRA region
3. Hydrological disturbances	
- vegetation change towards lower transpiration	- ratio of area under perennials:annuals per total, by catchment
- low water utilisation by plants in agriculture	- % rainfall leaving catchment as runoff, stormwater
- groundwater pumping	- number of stock bores:numbers capped per artesian basin
- inefficient irrigation methods	*- rainfall efficiency/hectare + Ml irrigation water/crop grown*
- underpricing of water	*- price of irrigation water subsidised relative to real costs of delivery*
- old irrigation technologies	*- ratio of microjet +dripper irrigation to other methods per district*
- drainage and loss of wetlands	*- number of drainage approvals per catchment*
- water diversion & regulation	*- % catchment surface waters regulated (km/km) — or % total volume*
Italicised items for Inland Waters coordinator	
4. Introduction of novel biota into habitats and communities	
- deliberate, legal introductions for agriculture, horticulture	**- rate of extension of all exotic species into each IBRA**
- deliberate introductions for plantation forestry	*- % forested area with exotic species predominating*
- inadvertent and illegal introductions (including pests, weeds etc.)	- number of reports of new weeds, pests, diseases per AER, IBRA region — impact of
- agriculture on conservation lands by AER	
- migration of population between geographic regions	- number of passenger + cargo entries/port/IBRA region
- domestic escapes, feral adaptations	*see Biodiversity*
- local government and domestic gardening introductions	*see Biodiversity*
italicised items for Biodiversity coordinator	
5. Nutrient and salt cycling (may be difficult to discriminate climatic variability)	
- cultivation, harvesting & removal of plants + animals	**- total nutrient balance of N, P, K, Ca, S /year/AER and catchment**
- adding soil amendments to managed lands	- sources of P derived from land activities by catchment and AER
- mobilising salts through hydrological disturbance	- calculated: observed rate of salt encroachment by catchment
- local concentration of processing effluents	- off-site changes in soil and water pH, metal-rich colloids in water
6. Soil and land pollution(?)	
- storage and concentration of radioactive materials	- total contaminant load on land area by catchment
- unprocessed, open metal, plastic, PAH waste tipping	- number and condition of high radiation risk stores
- repeated and high rates of use of agri chemicals	- number of open tips, orphan industrial sites, landfill sites x catchment
- entrainment of nutrients, OCs in eroded sediments	- rate of onset of pesticide resistance in target species
- nil, low-grade treatment of effluents	- vol- pesticides sold per land use, by AER (surrogate for areas treated]

Table 11

Indicators of Condition for Ecosystem Functions (Land)

Indicators of condition have units of area or length per time, or describe presence or absence of environmentally required function

State or Condition	Indicators of Condition
1. Accelerated erosion and loss of surface soil	
- presence of features of accelerated erosion	- gullying index per catchment [rapid headward gully extension]
- dust storms	- change in dust storm : high wind events
- loss of surface soil and A horizon	- change in surface albedo, reflectance
- loss of organic matter + litter	- change in sediment yield per catchment
- high turbidity of inland and estuarine waters	- [estuarine sediment plumes]
- exposed soil surfaces	- [wind scars in crops]
	- lack of A horizon; no surface soil (paired sites)
2. Physical changes to natural habitats	
- reduction in habitat number/extent by built structures	- *number of IBRA regions affected by habitat alteration & loss*
- shrinking patch size & function through urbanisation	- proportion of forest:woods; shrubs:grasses by landcover class, IBRA region
- vegetation structural changes	- extent of forest and woodland thinned compared with reference sites by region
- fragmentation of natural communities	- *vegetation condition index (NDVI-based) by forest type*
- land clearance for change in land use	- *rangeland condition index by AER, landcover region (NRMS index)*
	- *vegetation age structure, x landcover region*
	- area approved relative to disallowed for clearing in each IBRA region, catchment
3. Hydrological disturbances (some indicators for Inland Waters coordinator)	
- vegetation changes reducing transpiration	- % land affected by dryland salinity by catchment, and AER
- ground-water pumping	
- vegetation-related rainfall incidence?	- change in water utilisation with landcover reduction or increase
- sealed land surfaces	- % catchment capable of infiltrating water, by catchment and AER
- *drainage of, and loss of, wetlands*	- change in water utilisation with landcover reduction or increase- *change in area of wetlands x catchment*
- *diversions, regulations of river flow*	- *change in area of wetlands x catchment- km regulated : unregulated rivers x catchment (1/ wild river index)*
- *excessive application of irrigation water*	- *km regulated : unregulated rivers x catchment (1/ wild river index)- rise in water table in irrigation areas*
(Italicised items for Inland Water coordinator)	- *rise in water table in irrigation areas*
4. Introduction of novel biota (some indicators in conjunction with Biodiversity coordinator)	
- widespread presence of domesticated species	- % land carrying high, medium, low proportions of exotic biota relative to total biomass per IBRA region
- migration of people between biogeographic regions	- number of quarantine infringements per AER, biogeographic region
- inadvertent, illegal introductions	- weed infestation index: rate of spread, habitats affected
- *change in indigenous biota from introductions*	- *accelerated rate of extinctions, rarity, from habitat pressure/disease etc.*
5. Nutrient and salt cycling	
- removal of harvested products	**- net primary productivity change x AER, catchment and IBRA region**
- additions of fertilisers etc. to farmed lands	**- total nutrient balance for N, P, K [Ca, S] by AER, catchment and IBRA**
- *change in C, P and N levels in surface and ground waters x catchment*	Relative rate of land-carbon loss to sequestration per AER and IBRA
- local concentration by processing effluents	- spatial variations in P, N, C, Na, metals, not consistent with soil type
- salts mobilised by hydrological disturbance	*see under Hydrological disturbances*
6. Soil and land pollution	
- storage and concentration of radioactive materials	**- Total contaminant load on land area per catchment**
- unprocessed open waste tipping	- radiation levels in soils surrounding high radiation sites
- petrochemical activities (manufacture, storage)	- pesticide usage and soil contamination by catchment
- repeated, high application of agri-chemicals	- rate of heavy metal occurrences in harvested products (NRS + MBS)
- entrainment of nutrients, organics, in eroded sediments	- presence [absence] of key functional soil microbial groups per AER,IBRA region
- nil, low-grade effluent treatment	- high P: N ratios in low-flow surface waters

Table 12

Indicators of Response for Ecosystem Functions (Land)

Indicators of response have units of area or length per time per time (i.e. rate over time) or describe presence or absence of a practice with a positive or negative impact

Societal Responses	Indicators of Appropriate Response
	[key indicators in bold type, those in italics dealt with by other Reports]
General Response Indicator	
1. Accelerated erosion	
- conservative stocking rates	**- % land managers using agreed Best Practice by land use and tenure**
- destocking in droughts	**- % pastoral leases@/< recommended stock rate by AER, landcover regions**
- repeal of drought assistance	- area of degraded pastoral land reverting to less damaging land uses
- reduced tillage and trash retention	- % destocking when feed reaches advised threshold by AER, landcover regions
- controlled felling	**- implementation of new drought policies by State/Territory**
- minesite rehabilitation	- % crop area in reduced-till + stubble by catchment
	- % forest areas cut to environmental guidelines, by title [- ratio of actual rehabilitation rates to mining company reports]
- research to prevent accelerated erosion	
- use of sustainable practices	- length of river banks and verges protected by vegetation by LGA
2. Physical changes to natural habitats	
- land zoning consistent with suitability	- no. overall policies; land capability mapping and planning in rural areas?
- legislation to prohibit clearing	-measures to protect large intact native areas from development, by State, LGA
	*- number of infringements in areas covered by law, by IBRA region**
- measures to control deliberate fires?	- fire control index by State and Territory
- measures controlling habitat fragmentation	urban expansion by area
- preservation of large intact areas	- existence of legislation to protect large intact areas from development by State etc.
- conservative logging cycles	- harvested and destroyed forest mass less than net forest growth rates by regions
3. Hydrological imbalances	
- research/practice in restoring perennial vegetation	- index of measures to increase perennial veg. cover, by area of catchment, AER
- measures to promote planting of perennials	- R and D expenditure on perennial vegetation rehabilitation
- effectiveness of environmental measures	- rate of removal of subsidies on water prices, new dams, irrigation-infrastructure by catchment
- bore capping of unused bores	- number of bores capped/aquifer (or +ve change in aquifer pressure?)
- removal of obsolete river structures	*- number of obsolete weirs, locks etc. removed / major catchment*
- measures to ensure environmental flows	*- % river length [not] covered by arrangements to ensure environmental flow volumes*
- conservation of existing wetlands	*- conservation plans for existing wetlands*
italicised items for Inland-Waters and Biodiversity coordinators	
4. Introduction of novel biota into habitats and communities	
- protection of native biota in agricultural areas	**- conservation 'index' per AER and IBRA region with agricultural land use**
- govt. services to control pests, diseases	- % expenditure on plant and animal pest control, and R & D, by State, Cwlth, and risk category
- adequacy of quarantine services	- use/absence of multiple strategies, risk assessment, port surveillance, penalties
5. Nutrient and salt cycling	
- action to manage nutrient balances	**- % forestry, farming system with stable nutrient balance, by AER; catchment tradable carbon sequestration rights per AER and IBRA**
- monitoring farms for nutrient balance	- number of farmers using soil and plant tissue testing
- measures to promote perennial vegetation	*see under issue 3*
- nutrient/ salt recycling in all systems	- % intensive rural industries with effluent managementt systems/recycling; % urban settlements with or without tertiary recycling systems
6. Soil and land pollution	
- improved rehabilitation for PAHs and highly toxic sites	**- percent sites on National Contaminants Inventory remediated by catchment and LGA**
- improved storage of radioactive waste	- Radiation Safety Council standards applied
- phasing out of open waste and landfill	- rate of change-over from open tip by catchment, State and LGA
- reporting of all pesticide applications	- national registry of all pesticide applications?
- control measures for soil colloid pollution	- ratio government support to land conservation measures in priority catchments: all catchments
- compliance for full effluent treatment	- % sewage works with full effluent treatments

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List of Acronyms

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACLEP	Australian Collaborative Land Evaluation Program
ACRES	Australian Centre for Remote Sensing
AER	Agro-ecological region
AGNPS	Agricultural non-point-source pollution model
AGSO	Australian Geological Survey Organisation
ALGA	Australian Local Government Association
ANCA	Australian Nature Conservation Authority (now a component of Environment Australia)
ANSTO	Australian Nuclear Science and Technology Organisation
ANU	Australian National University
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agricultural and Resource Management Council of Australia and New Zealand
AUSLIG	Australian Surveying and Land Information Group
AVHRR	Advanced very high resolution radiometry
BoM	Bureau of Meteorology
BRS	Bureau of Resource Sciences
CFCs	Chlorofluorocarbons
CRA	Comprehensive Regional Assessment (relating to RFA)
CRC	Cooperative Research Centre
CRES	Centre for Resource and Environment Studies
CSBP	A fertiliser company, located in Perth, Western Australia
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEST	Department of the Environment, Sport and Territories (now the Department of the Environment)
DIST	Department of Industry, Science and Tourism
DPIE	Department of Primary Industries and Energy
DOLA	Department of Land Administration (Western Australia)
DSE	Dry Sheep Equivalent
DSS	Department of Social Security
EA	Environment Australia
EPA	Environment Protection Authority (various States)
ERIN	Environment Resources Information Network (Environment Australia)
EU	European Union
EVAO	Estimated Value of Agricultural Output
ELZ	Extensive landuse zone
GIS	Geographic information system
IBRA	Interim Biogeographic Regions of Australia
ILZ	Intensive Landuse Zone
IMCRA	Interim Marine and Coastal Regionalisation for Australia

IPM	Integrated Pest Management
LGA	Local Government Area
LWRRDC	Land and Water Resources Research and Development Corporation
MDBC	Murray–Darling Basin Commission
MDD	Major Drainage Division
NAQS	Northern Australia Quarantine Strategy
NCPISA	National Collaborative Project on Indicators of Sustainable Agriculture
NDVI	Normalised Difference Vegetation Index
NFI	National Forest Inventory
NGGI	National Greenhouse Gas Inventory
NHMRC	National Health and Medical Research Council
NOAA-AVHRR	National Oceanic and Atmospheric Administration – Advanced Very High Resolution Radiometer
NPI	National Pollutant Inventory
NRIC	National Resources Information Centre
NSCP–NLP	National Soil Conservation Program–National Landcare Program.
PAH	Poly-aromatic hydrocarbon
PSR	Pressure–State–Response
QDPI/DNR	Queensland Department of Primary Industries/Department of Natural Resources
RFA	Regional Forest Agreement
SARDI	South Australian Research and Development Institute
SCARM	Standing Committee on Agriculture and Resource Management
SLA	Statistical Local Area (equivalent of Local Government Area)
SLWRMC	Sustainable Land and Water Resources Management Committee (under SCARM)
UNCED	United Nations Conference on the Environment and Development

List of Environmental Indicator Reports

Environmental indicator reports for national state of the environment reporting are available in seven themes. Bibliographic details are as follows:

Human Settlements

Newton P., J. Flood, M. Berry, K. Bhatia, S. Brown, A. Cabelli, J. Gomboso & T. Richardson (in prep.) *Environmental indicators for national state of the environment reporting – Human Settlements,* Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra.

Biodiversity

Saunders D., C. Margules, & B. Hill (1998) *Environmental indicators for national state of the environment reporting – Biodiversity,* Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra.

The Atmosphere

Manton M. & D. Jasper (in prep.) *Environmental indicators for national state of the environment reporting – Atmosphere,* Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra.

The Land

Hamblin A. (1998) *Environmental indicators for national state of the environment reporting – The Land,* Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra.

Inland Waters

Fairweather P. & G. Napier (1998) *Environmental indicators for national state of the environment reporting – Inland Waters,* Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra.

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Natural and Cultural Heritage

Pearson M., D. Johnston, J. Lennon, I. McBryde, D. Marshall, D. Nash, & B. Wellington (in prep.) *Environmental indicators for national state of the environment reporting – Natural and Cultural Heritage,* Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra.

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http://www.erin.gov.au/environment/epcg/soe.html